Locating Amazonian Dark Earths: Creating an interactive GIS of known locations

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Locating Amazonian Dark Earths: 
Creating an interactive GIS of known locations

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Abstract
Amazonian Dark Earths are anthropogenic organic-rich highly fertile soils found in relatively small patches throughout the Amazon Basin. These soils are gaining considerable attention given the relative lower fertility of the majority of Amazonian soils in which they are embedded because of their improved agricultural potential and also because of their links to Amazonian pre-colonial history. Because of their small individual extent and local nature, documenting where these soils are located in the Amazon is a challenging task. Few comprehensive maps exist, and some locations are only approximate. In this article we present an interactive GIS in which we have tried to consolidate all known locations of ADEs to date, and to note for each location a level of accuracy and specificity of both the soil and its location. This is necessary as many older sources of locations are historical and give only an approximation of where they are. For more recent ADE citations, the geo-referenced location is given when available. The source citation is given for each location on the map, making this interactive GIS at once also a bibliography of Amazonian Dark Earth locations. We also discuss the selection of the cited locations, the creation of the GIS, and reflect on the potential uses of the resource. We acknowledge that the GIS is a work in progress, and we anticipate keeping it updated as more materials are published and otherwise made available.

Keywords: Amazonian dark earths, terra preta, black earth soils, GIS, Amazon

Resumo
Terras pretas são solos antropogênicos, ricos em matéria orgânica, bastante férteis, que ocorrem em pequenas manchas por toda bacia amazônica. Esses solos têm chamado atenção porque, em geral, os solos amazônicos são de relativa baixa fertilidade e por suas ligações com a história pré-colonial da amazônia. Por ocorrerem em pequenas manchas isoladas, a documentação desses solos tem se constituído um desafio. Existem poucos mapeamentos desses solos e a localizações dos mesmos são, muitas vezes, aproximadas. Apresentamos nesse artigo um SIG interativo no qual consolidamos todas as ocorrências documentadas de TPs e para cada registro, indicamos o nível de acurácia e especificidade

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tanto do solo como de sua localização. Isso é importante pois muitas fontes de informa-
ção sobre a localização desses solos são antigas e dão apenas uma indicação aproximada
de onde realmente estão. Para citações mais recentes de TPs, a localização georeferencia-
da é dada, quando disponível. A fonte da informação de cada registro é citada, tornando
esse SIG interativo uma bibliografia geográfica de TPs. Também discutimos o processo
de seleção das localidades citadas, a criação do SIG e refletimos sobre potenciais usos
dessas informações. Reconhecemos que esse SIG é um trabalho em andamento e an-
tecipamos incorporar mais registros à medida que novas informações são publicadas e
disponibilizadas.
Palavras chave: Terra Preta, Amazônia, SIG

Introduction

Amazonian Dark Earths (ADEs) are anthropogenic soils found mostly in
small patches throughout the Amazon basin. High in organic matter and often contain-
ing pottery sherds, these soils are evidence of long-term settlement in the past and are
the most compelling piece of evidence that scientists have in regard to revising Ama-
zonian prehistory. Over the last decade these soils have received much attention from
scientists from a variety of backgrounds, and there has been a significant increase in
research on them, much of it published in four edited volumes on the topic (Lehmann
et al. 2003; Glaser and Woods 2004; and Woods et al. 2009; Teixeira et al. 2009) as well as
numerous journal publications. Despite the surge in research on the topic, the locations
of the soils have not been well mapped, especially not at the regional basin level. Local
maps exist, especially of archaeological sites, but all of the known locations of ADEs
have not, to our knowledge, been compiled into one comprehensive map. To date the
best map of the locations of all the known ADEs is a map presented in Kern et al. (2003:
54) and Gerhard Bechtold's website (2008). As research on ADEs continues and the im-
lications of their existence considered, we feel that time has come for a comprehensive
“map” and we have developed it in the form of an interactive GIS.

What we present in this article is an interactive GIS of the majority of known
ADE locations to date. This GIS can be accessed via

http://www.geo.msu.edu/amazonia/dark_earths_gis.html
[username ‘adedata,’ password ‘Sombroek’].

It contains reference information about the source of each location and the
level of confidence of each of the locations. We first provide more background information about ADEs and then describe how the GIS was created. We realize that the GIS is far from complete, and see this as the start of an on-going project.

Amazonian Dark Earths

Amazonian Dark Earths, a continuum of soils that include Terra Preta do Indio
(black earth of the Indians) and Terra Mulata (brown earth), are highly fertile, organic-
rich soils found in patches throughout the Amazon basin (Woods and McCann 1999)
(Figure 1). These patches range in size from less than two to several hundred hectares,
with the majority (80%) about two hectares. Overall it is estimated that there are 6,000-
18,000 km² (or 0.1%-0. 3%) of ADEs in the Amazon basin (Sombroek et al. 2003: 130).
Researchers estimate that once all existing ADEs have been located, it is possible that the
regional extent might be as much as 10% (Mann 2000). The small individual extent of
these soils has contributed to the lack of mapping of them, despite local identification,
knowledge, and use of them. At best ADEs are described as inclusions in the dominant
soil categories for the basin, the Oxisols and Ultisols.
The persistence of the fertility of these soils is a consequence of their high organic matter content, which in turn is related to the existence of pyrogenic charcoal in the soil. This particular type of charcoal (also known as black-carbon or aromatic carbon) is highly recalcitrant and resists weathering in the high temperature and humidity regime typical of the Amazon region. Aromatic charcoal is formed during slow, cool burns, a process some scientists call “slash and char” (Steiner et al. 2004). The particular process of formation is not yet well understood and is being investigated by researchers in Brazil, Germany, the U.S.A. and elsewhere. Soils with this type of charcoal attract and retain nutrients better, hence there is more plant-available P, Ca, N, S in ADEs, and water is better retained as well (Falcão et al. 2009). There also appears to be an important, possibly unique, microbiological composition in soils with pyrogenic charcoal, which may also contribute to their persistent fertility (O’Neil et al. 2009; Tsai et al. 2009).

ADEs are presently used for various purposes, especially for intensive horticulture. What is not yet understood is the process (or processes – there is likely more than one pathway) of ADE formation in the past, and whether there might be a way of reproducing them (Lehmann 2009). How deliberate people were in making these soils is not clear, although their formation as a consequence of long-term sedentary occupancy and farming is accepted by some (Erickson 2003; Denevan 2004, 2006; WinklerPrins 2009). Some ADEs are old middens, discard and refuse piles, with broken pottery sherds embedded. Other ADEs, ones often referred to as *terra mulata* (brown earth), are the likely consequence of long-term farming with in-field burning as still seen today amongst the Kayapó (Hecht 2003; 2009), the Kuikuro (Heckenberger 2005; Schmidt and Heckenberger 2009) and in other native Amazonian agricultural practices (Denevan 2001; 2004).
The key is that ADE formation is the result of long-term occupancy, which is a feature of pre-colonial Amazonia. Many ADEs are documented to be about 2,000-2,500 years old (Erickson 2003) others may be older, others are definitely younger. The ADEs located thus far, as can be seen in our interactive ADE GIS (Figure 2), are located mostly on riverine bluffs – substantiating Denevan’s claim that native Amazonians lived on or near bluffs in the pre-colonial period (Denevan 1996). The existence of ADEs is contributing to the rewriting of the pre-colonial history of the region, by supporting long-term sedentary agriculture, which has long been deemed incompatible with the environment of the region (Meggers 1996 [1970]). Although there is much evidence to the contrary (Denevan 2001; Heckenberger et al. 2007; Junqueira et al. 2010), the persistent image of the region is that long-term sustainable farming is not possible. Failure of colonist farming along the Trans-Amazon highway does little to dispel this idea, although the failure of the colonists has more to do with structural issues than with the inherent quality of the soil or soil management (Perz et al. 2006). ADEs demonstrate that the past was different than previously thought, and may offer clues about how to farm the region sustainably in the future. If it is possible to create the form of charcoal that seems prevalent in ADEs, its potential use as a soil conditioner in tropical soils could revolutionize tropical agriculture.

Figure 2. Amazonian Dark Earth GIS as viewed in Google Earth.

Locating ADEs and Creating the GIS

There are several maps showing “all” locations of ADEs (e.g. Smith 1980; Lima et al. 2002; Kern 2003; Bechtold 2008; Herrera and Ali 2009), however, we feel that to date there is no comprehensive map of all known ADEs. From the literature emerge a wide range of locations with varying degrees of specificity (see section below on ‘con-
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Locating ADEs

Creating a Geographic Information System (GIS) of ADE locations is a form of meta-analysis meant to represent an existing body of published research in a spatial manner, with the goal of enabling new research directions. The process involves accumulating key ADE references from sources in the growing literature on ADEs which spans the disciplines of geography, soil science, archaeology, cultural and historical ecology, agronomy, and others. Much of the literature on ADEs is in English and Portuguese (Woods and Denevan 2008), and we have done our best to include all of which is available to us. There is an emerging body of ADE literature written in other languages, though it has not been included in the ADE GIS to date. It is our hope that this literature can be integrated into the spatial database of ADE locations in the future. Among the sources included are journal articles, book chapters, theses, and reports which include geographically explicit figures – maps, detailed descriptions of locations, and occasionally even geographic coordinates. Sources that provided geographically explicit locations were added to the GIS database, and our intent is to include more geographically explicit locations once those data is made available to us. In certain sources, ADEs were indicated broadly as general areas rather than point locations. In such cases – typically in the more historical accounts such as Smith (1879) or Oliveira (1926) – they were included as polygons in a separate GIS database not included here, but available from the authors directly. All of the sources on which the GIS is based are listed in the Appendix.

Process

For the vast majority of ADE locations precise geographic coordinates are not available (only one site in our database includes geographic coordinates collected in the field); researchers typically do not publish the latitude and longitude (or UTM) of each of their soil pits or archeological digs in journal articles as space is frequently at a premium. However, many ADE accounts do include a site map, or a regional map displaying ADE locations. Using these maps we painstakingly created a GIS database of point locations through a process of “heads-up” (i.e., on-screen) matching of points on large-scale maps from published ADE research to geographically orthorectified satellite imagery streamed from the Environmental Systems Research Standard Map Services. Because most currently known ADE sites are located near rivers, often on bluffs (Figure 2), most of these sites were relatively easily located because, in the majority of cases, published maps were of sufficient detail to match the published maps of ADE sites to features on the orthorectified satellite imagery. However, these sites represented in the GIS are typically less accurate than if geographic coordinates captured by Geographic Positioning Systems were available in all cases.

Though most ADE locations were not described as areas, when accounts of geographic areas with substantial inclusions of ADEs were described in the literature, we included them in the GIS as polygons. One example of an ADE polygon was described by Katzer (1944: 35): “They can be found to the west of Óbidos and along the Trombetas [River], above all along the margins of its numerous lakes.”

For each site, whether point location or polygon, we gathered other identifying information and other attributes from the literature. Figure 3 displays these attributes, which include the name of the community connected to the ADE, the quote/location in the reference where the site is described, a bibliographic reference for the site, a confidence level in the location and its ADE soil (described further below), a description of the confidence level for each site, whether GPS coordinates were available, size of the
area (when available), and the type of research which describes the site (e.g. whether it was an archaeological study, pedology, agronomy, ethnobotany, etc.). In the future, if the data are available, we will also include attributes for the age of the soil for each site, and a description of the process used to acquire ages, as well as any further information which may be useful to potential users of the GIS.

Figure 3. Example of database fields.

Sources

Our ADE GIS currently contains points and areas gathered from over 60 sources (listed in the Appendix), which outline the characteristics and locations of over 500 ADE sites. Just over half of the sources come from Brazilian journals or reports, with the remainder coming from edited volumes or journals published in Europe or North America.

We realize that far more sources detailing ADE sites in lowland South America exist, especially when the literature is expanded to include not only Portuguese and English, but also sources published in Spanish, French, German or other languages. Currently, the sources assembled in this map are drawn primarily from the geographical, ar-
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cheological and soil science literatures; other disciplines likely also have ADE references which will eventually be included in this GIS.

Figure 4. Examples of high (A), medium (B), and low (C) levels of confidence of ADE locations.
**Confidence Levels**

For each ADE site we include a confidence level: high (red), medium (yellow), or low (green), indicating our best estimation of how legitimate the site is as an ADE location. We also describe why this confidence level was assigned. The confidence level is based on the specificity of the description in the source, for example, whether soil analysis was conducted to classify an ADE as a legitimate ADE or whether it is a more general description of a “dark earth;” whether potsherds were discovered, etc. In other words, the level of confidence is more a measure of how certain we are that the ADE site is indeed an ADE, rather than the certainty associated with specific geographic location (which can only be most confident if a GPS location is given).

A high confidence site is one where the soil is well-described and, if possible using standard soil description survey processes, and according to that description is clearly an ADE soil (Figure 4A). Typical examples of such cases are pedologic and archaeological sites, the former because soil scientists have developed a way to classify ADEs (Kämpf *et al.* 2003), the latter because a vast majority of archeological sites in Amazonia include potsherds and because of that are clearly recognized as ADE, and *terra preta* in particular (*Ibid*). Medium confidence sites are those which include descriptions of ADEs or soils that sound very much like ADE soils, and are often associated with agronomic or some archaeological investigations, but are not as thoroughly documented as the descriptions with ‘high confidence’ (Figure 4B). Low confidence sites are typically those associated with historical accounts which often provide only cursory descriptions of soils, and frequently include vague or incomplete descriptions of site location (as is the case of Figure 4C).

We realize that assigning a level of confidence is subjective, and therefore our level of confidence in these sites is not fixed. For instance, one ADE site on Marajó Island at the mouth of the Amazon is listed in the ADE GIS as “medium” confidence due to the description of the site focusing on the large number of potsherds there, but no description of the soil. If we received a more explicit description of the site which included a description of the soil, and it turned out to be and explicitly confirmed ADE site, we would adjust the confidence level up (or down, if it evidence showed it was not). This GIS database is a work in progress, and it is our hope that it will remain so for a long time to come as more locations are documented and we obtain more information on sites already in the database. Therefore, no location in the database is permanently assigned to a confidence level or, for that matter, other attribute information. For instance, there are a large number of ADE sites on the right bank of the Negro river near Manaus where agronomists and archeologists have occasionally worked together. If a site was initially described as containing potsherds but not further described as being an ADE, and therefore being of “medium” confidence level at best, and then is revisited and thoroughly described so that it can officially be classified as an ADE, then the confidence level could be upgraded to “high.” Furthermore, if we are provided with geographic coordinates for these sites we will be much more confident in the accuracy of the location in the GIS database. We thus welcome any information that will make our GIS more accurate.

**Visualization and Scale**

Thus far we have described most ADE sites in the GIS database as being either “locations” or “areas.” In fact, as has been pointed out to us, all ADE sites are areas, often of multiple hectares. Therefore, it would seem most appropriate to display these sites as areas. Unfortunately, with a few exceptions, most ADE research sites have not had a thorough and geographically explicit site survey done. They are often mapped, when mapped at all, on a sub-regional or community scale which prohibits representa-
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Locating ADEs as an actual area in the GIS. In other words, as ADE sites are typically not represented as areas in the sources, and when they are it is often through amorphous descriptions of vast portions of the basin which have ADE “inclusions” and are far from specific (see endnote 4). Of course, if spatially explicit areas for sites were made available we would enthusiastically include them in the database.

Another reason for the use of point representation in the ADE GIS is because many ADE sites are only a few to a dozen hectares in size. When viewed at a small-scale over the entire basin (such as 1:4,000,000), these sites appear only as points scattered along the rivers which drain this vast region. Of course, in an ideal world such a GIS would include every ADE location as a perfectly geographically accurate area (this is our eventual goal, even if unattainable), but at this time, point representation is the only practical representation for most ADE locations currently in the database.

Another way of representing these sites would be to represent ADEs as lines along the bluffs of the rivers where many of them are located. While at regional scales this would be an excellent strategy, because size of the representation of a geographic phenomena is often assumed to reflect the size of the phenomena, this would imply the representation is proportional to the size of the ADE site itself (Robinson et al. 1995: 316-330; Monmonier 1996). At regional scales this may not be a serious problem, but at basin scales such a representation strategy would exaggerate the area covered by ADEs and at highly local scales it would under-represent the size of ADE deposits. Therefore, a further reason for representing ADE sites as points at present is to avoid false interpretation of ADE area size from the GIS; the GIS is currently one of the general location of ADE sites rather than a map of the specific sites. It is a GIS of the characteristics of ADE sites; this information is stored as site attributes, which can be queried at each site (Figures 4A, 4B, 4C).

Eventually, we hope that the ADE community can work together to define the area of ADE sites in a geographically explicit way, and therefore improve this representation to accurately represent not only the distribution of ADEs, but also the location and extent of them as well. Such a project is not without some concerns, including that making such information widely available could be detrimental to preserving archeological finds and may lead to land use intensification should previously unknown ADE sites become more widely known in certain locales. However, this latter concern is not likely to be a real issue since local land managers throughout Amazonia are already highly knowledgeable about the soil resources available to them, including the locations of ADEs, which they seek and use with enthusiasm (Hiraoka et al. 2003; Steiner 2009). We have protected our GIS with a password to forestall random access.

Possible uses for the GIS

We envision several uses for our GIS. As a teaching tool it can be used to help students visualize people-environment interactions in the Amazon Basin by linking human activities to environmental change in the past. The display of this widespread geographic data immediately emphasizes the extent to which people have been modifying the environments of Amazonia over the centuries, and can quite easily be used to teach about the modification of the Amazon’s forest and river environments by indigenous peoples. This GIS could quite easily be integrated into lectures or activities focusing on the indigenous populations of the Amazon, the debate surrounding the first human inhabitants of the Western Hemisphere, and even the social construction of nature (i.e., the GIS provides a picture that shows the geographic extent of the anthropogenic landscape of Amazonia). Because these data are made available in the form of Google Earth KML (Keyhole Markup Language) files, they can easily be integrated into the
widely familiar, easy to use, and free Google Earth software environment. Furthermore, KML files can also be viewed in online mapping applications available on a number of websites and the free WorldWind software environment developed and distributed by the National Aeronautics and Space Agency (NASA).

As a research tool the GIS and attached database will serve as a resource that integrates a diverse body of literature and creates a visual representation of that data. The GIS can be used to suggest what parts of the Amazon basin could be the focus for new ADE-focused exploratory research. As more data become available, and the GIS becomes more geographically accurate, this database could help uncover the environmental and social factors which may predispose certain areas to ADE formation.

Conclusions

ADEs are an Amazonian resource and are attracting more attention. Their existence is helping to rewrite the pre-colonial history of the region as well as offering ideas for future sustainable agriculture there as well as in other lowland tropical regions (Kern et al. 2009; Lehmann 2009). With this interactive GIS we hope to help investigators visualize where ADEs are and to help spur further investigation. It is important to see the pattern of where known ADE locations are, especially so that we can query the spaces where they are not. We hope this will be of value to students and scholars interested in ADEs and the historical ecology of the Amazon.

The creation of this GIS is just a first step in what will be an on-going process of database management. We anticipate an improvement in the accuracy of the material already included, as well as the addition of more sources. We welcome comments and contributions.

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Notes

1 Available at: http://www.esri.com/software/arcgis/arcgisonline/map_services.html, last accessed July 3, 2009.
2 It is likely that a larger area of ADEs will be found in interior locations in future surveys.
3 Original Portuguese text: “Se apresenta ao oeste de Óbidos e ao longo do Trombetas, sobretudo nos trechos marginais aos seus numerosos lagos...” Katzer 1944: 35 (our translation).
4 For the time being area polygons are not included in the figures in this paper or the downloadable GIS database because they generally replicate the point locations, but with far less geographic specificity.

References


**Appendix**

References for sources included in the ADE Interactive GIS Database.


dge regarding arcaeological black earths of Amazonia. In *Amazonian Dark Earths: Ex-
Verlag.


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An interesting BBC video on the ADEs is available here:  
http://sites.maxwell.syr.edu/clag/darkearths.htm