ACT Publication No. 04-06

The Challenge of Scalability

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Reprinted from:
The Archaeology of Global Change: The Impact of Humans on Their Environment. C. L. Redman, S.R. James, P.R. Fish and J.D. Rogers (eds) 2004. Smithsonian Books. Pp. 278-284.

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The Archaeology of Global Change

The Impact of Humans on Their Environment

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The Challenge of Scalability

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The contributions to this volume provide ample evidenc that archaeological ecological studies can shed light on th human dimensions of global environmental change. The stress, in particular, that such studies need to pay very clos attention to scale and need to show how their research ap plies to the contemporary dilemmas faced by human socie ties. Our species is clearly practicing unsustainable behav iors that ensure future collapses of the kind seen in th record of the past provided by archaeology. One very bi difference, of course, is that the collapse this time could b a "global" event rather than simply the demise of a singl civilization, region, or city-state. The interconnectedness o today's economies, their common dependence on fossi fuels, their growing indebtedness, and the disconnect be tween macroeconomic processes and microeconomic be havior all suggest a planetary-scale crisis—at least for thos societies bent on these behaviors. Fortunately, there is evi dence, too, that human communities with a contrarian o traditional view have always existed. Theirs is a culturally resistant view, as it were, that provides alternatives—and possible deliverance should the dominant paradigm of growth and development fail to deliver on its promises. Archaeologists' integration of climatic evidence, sociocultural change, and assessment of causes and consequences of past processes offers a healthy antidote to our contemporary myopias.

In the pages that follow, I point out why all students of global change must devote greater attention to issues of scale and to the scalability of their findings if they are to avoid the pitfalls of a global approach. As is widely recognized, research questions and research methods are often scale-specific, as can be demonstrated for work in the Amazon region (Moran 1984, 1990). Many debates on Amazonian cultural ecology, for example, have arisen because studies have shifted between different levels and scales of analysis, without explicit recognition of the shift. Issues of scaling—of integrating data of different temporal and spatial scales from different disciplines— will require even more attention as studies of global environmental change increase (Wessman 1992:175). Bioecological data, in particular, coming as they often do from the study of individual organisms, must ultimately be connected to regional and global scales. This procedure is, unfortunately, not a simple task. Complex spatial variations and nonlinearities across landscapes make it difficult to extrapolate from local scale to more inclusive scales and hence call for new strategies for acquiring and in-

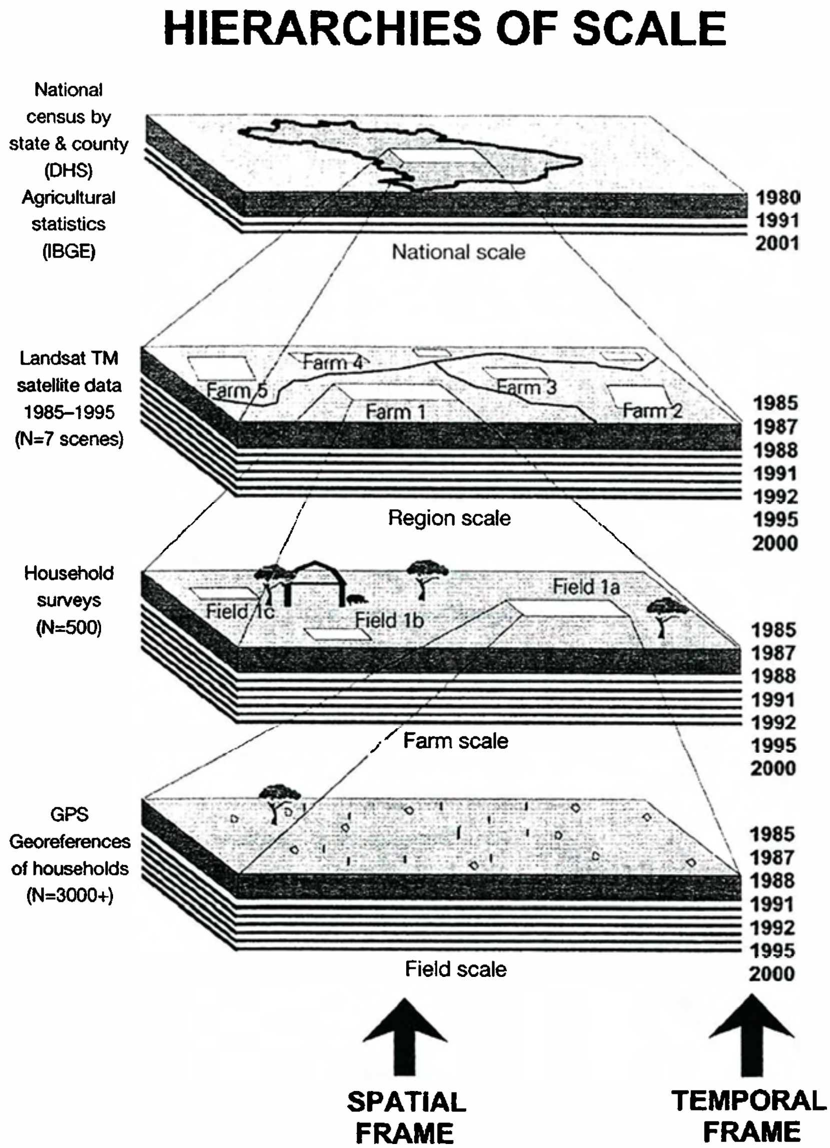

Figure 16.1. Hierarchies of scale. Nesting spatially explicit data in a GIS permits gross-scale analysis and enhances understanding of sampling limitations at a variety of scales.

terpreting data that can overcome narrow disciplinary approaches (Wessman 1992:175). Figure 16.1 illustrates hierarchies of scale linking field, household, regional, and national data compiled in our Amazonian studies.

This and other research procedures implemented in ongoing studies on the dynamics of secondary growth in eastern Amazonia show the range of approaches that may be used, as well as the successes and failures thus far in articulating our findings across scales. The role of research tools such as remote sensing, GIS, land-use histories, and vegetation stand structure is of particular interest here because such tools permit fine-grained analysis and make it possible to zoom to local scales such as a forest gap or a small deforested area while also studying regions of many thousands of square kilometers. The preciseness of regional analysis depends on the quality of the sampling or ground truthing at a local level, but such sampling is far from common in traditional remote sensing. Much of what goes for "ground truthing" is visual observation of classes such as dense forest, or cropland, without detailed examination of biomass, basal area, or species composition. The long-standing anthropological bias toward local-level processes, when combined with the use of analytical tools capable of scaling up and down, constitutes a very important step in advancing the research on land-use/land-cover change and in resolving issues surrounding differently scaled processes.

Traditional Approaches

While spatially homogeneous systems present few problems of scaling, the more common spatial heterogeneity of ecosystems constrains our capacity to take information from one scale to another. To achieve coherent and scalable results, one should use both bottom-up and top-down approaches concurrently (Wessman 1992:178).

Remote sensing, from platforms such as Landsat 4 & 5, and SPOT, provides information of considerable ecological richness for local and regional analysis. It is less suitable for compiling data at continental scales because of the effects of cloud cover, differences in sun angle, and the large number of scenes required to mosaic a continental-size area. Landsat and SPOT information can be used in two formats: either as multiband digital data or as a single or multiband photographic product. For analysis of very large regions such as the Brazilian Amazon, which requires more than 200 Landsat scenes (each scene being 185 by 185 kilometers), it has been common to rely on single-band Landsat photographic products (Skole and Tucker 1993) or on AVHRR meteorological satellites operated by the National Oceanic and Atmospheric Administration (NOAA).

Over the past 15 years, a number of scientists have used these data to assess the extent of deforestation. Earlier work, continuing into the present, relied on coarser data such as provided by NOAA's AVHRR with a spatial resolution of 1.1 kilometers in the visible, near infrared, and thermal infrared. Although designed for meteorological studies, it has been used to monitor vegetation patterns over very broad spatial areas. Specialists recognize that the spectral bands are not ideally positioned for vegetative analysis (since they are not focused on the spectral regions of maximum interest) (Campbell 1987:390; Tucker et al. 1984). Such analysis can be used to monitor how many fires in a given day have been set in the Amazon Basin (the most dramatic data being for 1987, when on a given day 8,000 fires were recorded [Booth 1989]). It cannot monitor changes in types of vegetation cover but only distinguish between dense forest and its absence. Several efforts to use AVHRR and the more refined scale of Landsat MSS (at 80 meters spatial resolution) to observe secondary growth following deforestation met with no success (Woodwell et al. 1986; Woodwell et al. 1987). AVHRR data cannot be used to study specific sites but only to provide overviews of general ecological conditions (e.g., drought, using a "greenness" index, or NDVI) and identify regions where more detailed study with high resolution data may be required.

Thus there has been a steady migration from usi AVHRR to count the number of points of deforestation considering other processes, such as what happens to tho landscapes after they have been burned. Because the enti basin is the focus of attention, a number of specialists ha relied on single-band Thematic Mapper photographic pro ucts (e.g., Skole and Tucker 1993) that allow one to asse the total area deforested, and even the potential area affect biologically by deforestation, by taking into account ed effects and fragmentation of forest. Using GIS technique researchers constructed a computerized map of defore tation and forest fragmentation from images at a scale 1:500,000. Areas of deforestation were digitized into the G and the forest fragments and edge effects that resulted fro the spatial pattern of forest conversion were determin (Skole and Tucker 1993:1905).

The use of the single-band Thematic Mapper (TM) da and GIS made it possible to classify Amazonian vegetatic into very general categories that could then be compare with information from other studies. The GIS provided tool for managing large amounts of spatial data and f merging and geocoding information from the more tha 200 scenes used (Skole and Tucker 1993:1906). Data for 19 were compared with single-channel MSS data for 1978 usir approximately 50 scenes to arrive at changes in forest cove The authors consider the use of single-band (i.e., band mid-infrared or 1.55 to 1 μm) black-and-white photograph products sufficient to determine deforestation.

Their results agree broadly with earlier assessments usin AVHRR—which show that deforestation was concentrate in a crescent along the southern and eastern fringe of th Amazon and along major roads and rivers going to the ir terior. However, most recent analyses using single-band T analysis suggest that deforestation estimates based o coarse-resolution satellites such as AVHRR have overest mated deforestation by about 50 percent (Skole and Tucke 1993:1909). According to observations of field scientist there are large areas of regrowth throughout the basi (Moran et al. 1994; Tucker et al. 1998). Scientists and polic makers have been concerned about deforestation in th Amazon in part because tropical deforestation releases va quantities of carbon dioxide into the atmosphere. Shoul the regrowth be widespread, however, it means that substantial carbon is being sequestered, and this has considerable significance for carbon estimates.

Current Research on Amazonian Deforestation

The work by David Skole and Compton Tucker (1993) provides a backdrop for the finer-grained analysis that our research team has been carrying on for the past 12 years with support from the National Science Foundation, the Midwestern Center of the National Institute for Global Environmental Change, the National Aeronautics and Space Administration, and the National Institute of Child Health and Human Development's Population Program. Our work was designed to link up with past work using coarser scales (but having continent-wide coverage) and to focus on the possible role of successional processes in counteracting the emission rates of carbon. Until regrowth was reported (Skole and Tucker 1993:1909), most satellite-based research in Amazonia had overlooked the generality of regrowth processes and their variability spatially and temporally. Since then there has been a virtual explosion of interest in secondary succession (e.g., Brondizio et al. 1994, 1996; Moran et al. 1994; Tucker et al. 1998).

Global circulation models (GCMs) often assume the complete removal of tropical forest and its replacement with pasture, a scenario that is possible but unlikely (cf. Lean and Warrilow 1989; Shukla et al. 1990). Ann Henderson-Sellers (1987) has advocated a more regional and less global approach to predicting the climatic impacts of forest removal. Indeed, the concurrent pursuit of global, regional, and local research needs to be not only attempted but given priority, despite its challenges.

According to R. P. Detwiler and Charles Hall (1988:43), rates of land-use change need to be specified if carbon release estimates are ever to be accurate. To this end, our work began with the development of a preliminary classification of types of vegetation in two study areas: one in the estuary, the other in an interfluvial moist forest region of eastern Amazonia. We used Landsat TM digital data because it had seven bands from the visible to the thermal infrared (0.45 to 12.5 microns) and adequate spatial resolution to permit analysis down to 1-hectare fields. We felt that the better spatial resolution, and broader spectral capabilities of TM digital data, would permit us to make a distinct contribution to the existing literature on deforestation, and we hoped it would allow sufficient discrimination to monitor secondary growth. We started working with three dates for each of the two areas, representing the dry season when cloud cover is considerably less. We concentrated on a three-week period so as to reduce variability due to seasonality. Since that early effort, we have expanded our image data set to one consisting of 10 dates over a 30-year period at 3-year intervals that permit refined discrimination in land-cover change.

Work began from the top down, that is, by taking six of the seven channels of digital data and letting the computer work on spectral differentiation, supplemented with previous knowledge from the two study areas. Rather than working initially with whole scenes, subareas of 500 by 500 pixels were used to develop familiarity with spectral patterns using sample areas representing different kinds of processes, from untouched mature forest far from settled areas to areas highly affected by cattle ranching, roads, and urban development. These subareas were subjected to unsupervised classification procedures (cluster analysis) and to multispectral image interpretation. Gradually, bands 2, 3, 4, and 5 proved capable of making the best discriminations and clustering resulted in up to 50 classes. Through analysis of the spectral statistics, we were able to reduce this number to approximately 18 classes, which were taken as the basis for field studies and ground truthing.

In the field, we implemented a procedure designed to ensure that sampling bias was not unwittingly introduced. Twenty large sample areas were marked on the scene, spread over the entire region, so that all parts of the image were represented. In each area, precise locations of pixels were obtained using a GPS and coordinates obtained. Field observations were then made of classes obtained through unsupervised classification, with particular attention to forest and secondary successional age classes. Farmers throughout the area were also interviewed in order to obtain land-use histories. These histories provided a sample of differently aged classes of secondary growth that would become the focus of further field sampling. In 1992, working with a crew of six collaborators, we sampled 22 plots at one site and 27 at the estuary site. Additional samples were obtained during fieldwork in 1993. At each sampled area, we took soil profile samples to a depth of 1 meter, counted and named plant species, estimated percentage of vegetative cover, and recorded stem height and total height of all plants over 10 centimeters in diameter at breast height or over 2 meters tall.

These detailed data were then incorporated into a database program for later inclusion in a GIS. A georeferenced base map was created using ARCINFO, which included the GPS coordinates collected in the field. The base map has exactly the same size and coordinate system of the image with which it is overlaid for analysis. The total number of waypoints were separated into three groups: households, vegetation samples, and other observations. A base map was drawn for each group. Second, the information related to each coordinate point in the base map was organized into a relational database structure. The key step was to ensure that information in the database had the same ID number as the respective coordinate. The side-by-side visualization of the database and map display make it possible to interrelate ground information with land-use classes and to check if the classification is accurate. Third, the waypoint map was converted to ERDAS (i.e., to a raster format) to be overlaid in a six-channel TM Landsat image. The TM thermal channel (i.e., 6) was not used in this study because its resolution was coarser (i.e., 120 meters rather than 30 meters) and it lacked the power to distinguish between vegetation classes. One extra channel was created on the image to be used for the waypoint base map, since it has the same coordinates.

As a result of the detailed field observations supporting the spectral analysis, supervised classification of land-cover classes was obtained for both sites, and signatures obtained for 9 land-cover classes at the Transamazon colonization site and 15 at the estuary site. The results from the analysis of the interfluvial site (Moran et al. 1994) and those from the estuarine site (Brondizio et al. 1994, 1996) have for the first time made it possible to obtain precise signature patterns for tracking secondary successional regrowth of 0–5 years, 6–10 years, and 11–15 years. Overall classification accuracy exceeds 92.2 percent at the interfluvial site (Mausel et al. 1993).

The basic function of spectral modeling is to detect the sensitivity of visible bands to chlorophyll absorption, of the near infrared to mesophyll reflectance, and of the mid-infrared to water and moisture absorption. For example, an unmanaged flooded forest has a more irregular and higher canopy and a denser understory, and hence more stratification, which creates shadowing that depresses the near-infrared and mid-infrared spectral values, in particular. This makes it possible to distinguish between managed and u managed flooded forest (Brondizio et al. 1994). Thus, a sh in importance value for açaí palm (*Euterpe oleracea*) from 0 in an unmanaged area to an average 0.6 in a managed ar translated to a spectral shift from 71 to 77 in band 4 averag digital values (whereas differences in digital values we nonsignificant in bands 5, 3, or 2).

Managed flooded forest is a class that gradually becom spectrally distinct as the importance value of the manage species increases. In this case, açaí palm occurring at nat rally high densities in the flooded forest is further incr mented through selective clearing around it so that mor plants can occupy the same territory. There is a distinct shi in species diversity with increasing density of açaí, but con siderable species diversity remains nonetheless.

These detailed field data, and the additional data col lected in the past six years at four new sites, have made i possible not only to assess shifts in land cover and land us in six regions of approximately 6,000 square kilometer each, but also to link individual households to communit and regionally scaled processes (Moran and Brondizio 1998) One thing missing from our studies to date is the deep ret rospective perspective such as environmental archaeolog offers. The chapters in this collection attest to the value o archaeology in the study of global change processes.

Conclusions

The time is clearly ripe for more emphasis on linking ground observations to regional and global scales in order to take full advantage of the detailed data available at different scales (Wessman 1992:180). Although some research of this type is already under way, it has paid scant attention to the human dimensions of ecological processes. In the past, it was difficult to extrapolate the results of ecosystem research to regional and global scale. Few instruments were available to measure large-scale spatial heterogeneity and long-term patterns of successional dynamics.

Remote sensing linked to ground-based successional studies provides the most promising tool for understanding ecosystem structure, function, and change (Liverman et al. 1998). The capacity to detect long-term change in ecosystems can be enhanced through the analysis of image texture combined with spatial statistics, which in turn make it possible to assess stand structure from satellite data (Wessman

1992:189). The potential application of such analyses can be seen in a recent study of a northeastern boreal forest, where a 10-year time-series Landsat data set based on species composition and age structure was used to track changes in its succession state. Once the images were rectified for changes in atmospheric conditions between years, it was possible to infer the dynamics taking place in space.

Similar procedures, with the added advantage of higher resolution TM data, have been implemented in our Amazonian research, where we have been able to assess successional processes and their linkage to differences in soil fertility, land-use history, and size of areas cleared (Brondizio et al. 2000; Moran et al. 2000). We have now studied seven distinct landscapes in the Amazon region, representing a range of systems of land use, different lengths of human settlement, different technologies, and even different ethnicities. The methods used have been consistent across all sites, so that comparison between them now permits robust findings about the driving forces of deforestation at different scales of analysis.

Recently, for example, we found that differences in soil texture and chemical composition explain more of the variance in rates of forest regrowth between landscapes (interregional comparisons), while land-use differences explain more of the differences between sampled plots within a location (Moran et al. 2000). Indeed, one of the key reasons that attention to scale is fundamental is that while levels are interconnected, the main forces behind environmental change may vary from the local to regional to global scale (Moran et al. 2003). The exciting challenge for the global change research community is to tease these apart while maintaining the integrity of a truly multitier systemic analysis.

Acknowledgments

This chapter would not have been possible without the collaboration of many team members from a variety of disciplines, among them: Eduardo Brondizio, Paul Mausel, You Wu, Mario Dantas, Lucival Rodrigues Marinho, Jair da Costa Freitas, and Amy Gras. I am also grateful for funding from the National Science Foundation (through grants 9100526, 9310049, 9521918, and 9896014), the National Institute of Child Health and Human Development (through grant 9701386A), and the National Aeronautics and Space Administration (through grant NCC5-334). Their generous support made it possible to conduct a series of studies in Amazonia that provide the basis for many of the thoughts shared herein. An earlier version of this chapter was presented at the annual meeting of the American Anthropological Association in 1993.

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