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ENVIRONMENTAL ANTHROPOLOGY AS ONE OF THE SPATIAL SCIENCES

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The growth of anthropological engagement with the importance of 'place' has roots in archeological approaches, and the use of aerial photography by some cultural ecologists. Spatial approaches exploded since the 1990s as more anthropologists saw advantages to using Geographic Information Systems (GIS) and satellite remote sensing data and spatial analysis in their environmental research. This increased use of spatial analysis has also led the field to be more interdisciplinary, more team-based in its field research, and more integrative than in the past. These are directions that an engaged environmental anthropology must take if it hopes to be a part of addressing the challenges of climate change and environmental change. All along anthropology has borrowed from other disciplines to achieve this interdisciplinarity in spatial approaches, borrowing from ecology, geography and other disciplines.

One of the key elements in the practice of anthropology has always been its attention to the ethnographic detail present in a village or community. More than simply a favored form of doing research, this became the only way we expected anthropological research to be carried out. This preference fitted well with a desire to provide a holistic picture of human society, and it helped ecologically-oriented anthropologists measure the relevant variables with some degree of completeness. This preference has become increasingly questionable as we have become more aware that the single village fails to adequately represent the range of variation present within even a limited region. Localized studies provide insights into family structure, subsistence strategies, labor inputs, health and nutritional status, flow of energy, socialization, and cultural institutions. Studies at this level, however, cannot address issues of origin concerns with the long-term and/or larger scale impact of environmental damage done by local communities (whether they be industrial or non-industrial societies). These issues require a different type of research method emphasizing historical, geographic, economic, and political change over time and space (Moran 1990: 286; Moran and Ostrom 2005). This increased aerial coverage also means that it is difficult to carry out such studies without resorting to some new methods that allow greater spatial coverage with an economy of effort.

Studies based on a single village should not be expected to represent the range present in any population and the construction of theory is set back by generalizing from single-site data. While some anthropologists have expanded to include regional analysis, many still are trained in single village approaches. Even the most isolated human population and its immediate environment maintains a fluid set of relationships with other communities–opening it up to demographic, economic, and cultural exchange that over time changes the constitution of those same communities. Ellen demonstrated how this works itself out in the Moluccas (1990). Earlier, Rappaport (1968: 226) had commented how, in retrospect, he had found the Maring local populations to be ephemeral through time and that the regional population would have been a more appropriate unit of study. A growing number of scholars have begun to consider local case studies in a regional context (Foster and Aber 2004; Turner 2005; Moran and Ostrom 2005), and to do so they have turned to spatial technologies such as GIS and remote sensing.

Regional Analysis and the Human Dimensions Agenda

This trend toward regional analysis gained further focus with the development of what has come to be known as human dimensions research (cf. NRC 1992, 1994, 1998; Moran and Ostrom 2005). What was new in this approach was a concern for the cumulative impact of human action. Research in this new multidisciplinary field concerns human activities that alter the earth' s environment, the driving forces or causes of these activities, the consequences of environmental change for human societies, and human responses to global change.

change events (for example, sea level rise, El Nino forecasts). It has also focused on the impacts of climate change; impacts of land use and land cover change on biodiversity, and on issues such as urban sustainability and globally significant resources such as water and energy (NRC 1992, 1994, 1998, 1999a,b; Tillman 1999). The NRC Committee on Human Dimensions of Global Change led the way in this area, and provided early syntheses of work done by the scholarly community.

Human dimensions research has already made a significant contribution to global change research by convincing the physical scientists (Lambin and Geist 2006) that research on global issues must address regionally-scaled processes. What is most evident to environmental anthropologists (cf. Moran 2006, 2007, 2010; Brondizio 2008; Brondizio and Moran 2008; Tucker 2008) is that human communities vary greatly in how they use resources. Less industrialized countries show even more variability in resource use. Tropical deforestation may be driven by population growth in Indonesia, but in Brazil it is more a product of tax breaks and subsidies given to cattle ranchers.

These environmental changes (i.e. deforestation, a global water crisis, pollution of air and water, erosion of coastal areas, sea level rise) will only continue in the twenty-first century. Major climate change cannot be safely relegated to the future (for example, carbon dioxide in the atmosphere had doubled already by 2003 from its 400,000 year geologic record as found in the Vostok ice core (Steffen et al. 2004)). The general scientific consensus is that climate change is here, it is real, and we are experiencing its impact. The demands of an additional 3–5 billion people by 2050 will alter land cover, water availability and quality, and social systems beyond what we can imagine. Environmental anthropology, environmental geography, human ecology, and environmental social science have a lot to contribute to addressing these challenges (cf. Moran 2010 for a discussion of the emerging metadiscipline of environmental social science). This will require new technologies and new ways of conceptualizing communities and how they interact with the environment.

The attention that the physical sciences' research community anthropologists and other environmental social scientists (Peck 1990; Vitousek et al. 1997; Moran 2010). Solutions to contemporary environmental problems will require the integration of experimental and theoretical approaches at a variety of levels of analysis, from local to global (Levin 1998). For participation in the contemporary debates over human impact on global environments, ecosystem models and ecosystem theory are fundamental (cf. Moran 1990 for a discussion of ecosystem approaches). This does not mean abiding by notions of equilibrium, fixation on calories, energy flow models, and functionalism (cf. Moran 1990, chapter 1, for a full discussion). Rather, it means understanding the nature of complex systems that link the atmosphere to the geosphere and to the living components of our planet (the biosphere). These systems are tied by complex cycles of matter, energy, and information. An environmental anthropology lacking the ecosystem approach would be largely irrelevant to the debates over the processes of global environmental change–possibly the most important research agenda for the twenty- first century (Lubchenco 1998).

The Challenge Before Us: Space, Time, and Scale

Contemporary environmental anthropology builds on the past experience of scholars who studied human interaction with the environment, but it must go beyond those approaches. Human-environment research for the twenty- first century must add refined approaches that permit analysis of global environmental changes and their underlying local and regional dynamics (Moran and Ostrom 2005). This poses a major challenge to research methods, as all researchers must employ generally agreedon ways of selecting sample communities or sites and collecting data across highly variable sites, despite significant differences in environment, culture, economy, and history (Moran and Brondizio 2001; Moran and Ostrom 2005).

No single approach will be adequate to the complex tasks ahead. Past approaches that emphasized equilibrium and predictability and were necessary to test hypotheses, do not serve this research agenda well because they hide the dynamic processes of ecosystems. Dynamic, stochastic ecosystem anthropologists need to use such approaches to engage, for example, ecosystem restoration (Pietsch and Hasenauer 2002; Mitsch and Day 2004), biodiversity (Tillman 1999; Nagendra 2001; Wätzold et al. 2006), agroecology (Vandermeer 2003; Wojtkowski 2004), and deforestation (Skole and Tucker 1993; Kaimowitz and Angelsenn 1998; Lambin and Geist 2006).

A tool ecological anthropologists and other human-environment scientists will need to use is geographic information systems (GIS) and the techniques of satellite remote sensing. Remote sensing from satellite platforms such as the National Oceanographic and Atmospheric Administration (NOAA)' s AVHRR sensor, the National Aeronautics and Space Administration (NASA)' s Landsat thematic mapper (TM) sensor, and the French SPOT satellite provide information of considerable environmental richness for local, regional, and global analysis (Conant 1978, 1990; NRC 1998; Moran and Brondizio 1998; Brondizio 2008). For analyzing global processes of large continental areas such as the entire Amazon basin, NOAA' s AVHRR is the most appropriate satellite sensor. Its resolution is coarser, but it offers daily coverage. More recently, MODIS, a midrange resolution satellite with 250 meter spatial resolution that provides daily coverage, has been used and connected to satellites capable of finer resolution (Hansen et al. 2002 a,b; Wessels et al. 2004; Anderson et al. 2005; Morton et al. 2005). Although designed primarily for meteorology, it has been profitably employed to monitor vegetation patterns over very large areas. Because of its coarse scale, social scientists to date have made little use of this data. Engagement with the use of these tools requires retooling and study on the part of social scientists just as acquiring a new set of tools (such as demographic ones) would require us to do. While one is likely not to be a stand alone specialist, one can learn enough to effectively think and participate alongside physical scientists in this work (NRC 1998 for an example of how social scientists engaged with remote sensing in the 1990s). Funding has been available at the National Science Foundation, NASA, NOAA, and NIH since the mid-1990s to social science.

Available since 1972, data from Landsat' s multispectral scanner (MSS) is relatively inexpensive and has been used by a number of anthropologists. The pioneering work of anthropologists Francis Conant (1978) and Priscilla Reining (1973) depended on this data. Use of MSS data is still valuable for studying relatively dichotomous phenomena such as forest/non-forest cover and establishing a historical account of land cover change in a particular region. Before 1972, remotely sensed data came from aerial photographs (Vogt 1974).

A significant advance took place in 1984 with the launch of the Landsat thematic mapper (TM) sensor that improved the spatial resolution from the 80 meters of MSS to 30 meters. It also included three visible spectrum channels and four infrared spectrum channels. This satellite has allowed anthropologists to make detailed studies of land cover changes in some of the most difficult landscapes known: the Amazon basin and the Ituriforest of central Africa (Wilkie 1994; Moran et al. 1994, 2002; Brondizio 1996, 2008; Moran and Brondizio 2001). Discriminating between age classes of secondary growth vegetation was achieved for the first time using satellite data (Moran et al. 1994, 1996), as well as discrimination between subtle palm-based agroforestry management and flooded forest in the Amazon estuary (Brondizio et al. 1994, 1996), erosion in Madagascar (Sussman et al. 1994), and intensification in indigenous systems (Guyer and Lambin 1993; Behrens et al. 1994).

Appreciation for scaling issues has increased as the challenge of integrating data and models from different disciplines and different temporal and spatial scales becomes necessary with the growth of global environmental change studies (Wessman 1992: 175; Walsh et al.1999). Bioecological data, coming as it often does from the study of individual organisms, must be connected to regional and global scales. Complex spatial variations and nonlinearities across landscapes occur which challenge facile extrapolations from the local scale narrow disciplinary approaches and require new strategies for acquiring and interpreting data (Wessman 1992: 175; Walsh et al. 1999).

The precision of regional analysis depends on the quality of the sampling at the local level. Detailed local-level 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 land use history, vegetation structure, and composition. The long-standing anthropological bias for understanding local-level processes, when combined with the use of analytical tools capable of scaling up and down, helps advance land use/land cover change research and articulation between differently scaled processes.

In order to advance the current state of knowledge, there is a need to engage all of the social sciences in multidisciplinary research, jointly with each other and with the biophysical sciences. In this enterprise, environmental anthropology has much to offer. Anthropologists and geographers bring two main contributions to the analysis of global change. First, both are committed to understanding local differences. When looking at a satellite image, for instance, they search for land use patterns associated with socioeconomic and cultural processes coming from local populations. Consequently they strive to find the driving forces behind land use differences and come up with land use classifications that are meaningful in socioeconomic and cultural terms.

A second important contribution is related to data collection and methods. Anthropologists, sociologists, and human geographers using satellite images want to reveal the living human reality behind land cover classes. Such a perspective requires methods that link local environmental differences to human behavior and geography (Moran and Brondizio 1998, 2001; Rindfuss et al. 2003). Environmental social scientists take pride in their fieldwork, and they can harness this interest to make important contributions to advancing the state of spatially-

The Use of Remote Sensing and GIS

It is hard to imagine trying to address global environmental change research challenges without the availability of earth-orbiting satellites capable of providing time-series data on features such as soils, vegetation, moisture, urban sprawl, and water-covered areas (Campbell 1987; NRC 1998; 2005; Lillesand et al. 2004; McCoy 2005; Jensen 2005, 2007), or studying impacts of climatic variability on populations (Gutmann 2000; Galvin et al. 2001; Moran et al. 2006). Environmental social scientists have enjoyed increasing opportunities since the launch of most recently a new generation of commercial satellites such as IKONOS with 1–5 meter resolution (see Figure 4.1 for a comparison of other satellites and resolutions available) (Batistella et al. 2004).

The use of GIS to overlay data layers in spatially-explicit ways added to this powerful set of techniques (Campbell and Sayer 2003; Goodchild 2003; Goodchild and Janelle 2004; Aronoff 2005; Okabe 2006; Steinberg and Steinberg 2006). GIS is an essential tool in the environmental analysis tool kit, and is also widely used by environmental NGOs, urban planners, and scientists in the natural and social sciences (Evans et al. 2005a; Hesse-Biber and Leavy 2006; Greene and Pick 2006).

FIGURE 4.1 Comparison of spatial, spectral and temporal resolution of main sensors used in environmental applications.

Source: Adapted from Batistella et al. 2004; updates available at www.sat.cnpm.embrapa.br.

Remote sensing techniques have elicited interest among environmental anthropologists. For example, Conklin (1980) used aerial photography in his Ethnographic Atlas of Ifugao. He integrated ethnographic and ecological data to show land use zones from the perspective of the local population (compare the review of aerial photo usage in anthropology in Lyons et al. 1972; Vogt 1974). The use of satellite remote sensing in anthropology started in the 1970s, with Reining (1973) studying Landsat' s MSS images to locate individual Malivillages in Africa and Conant (1978) examining Pokot population distribution. After spatial resolution was improved in 1984 with the Landsat TM sensor, more researchers began using this tool (see Conant promising topics addressed by anthropologists using remote sensing and GIS tools (Behrens 1990). In Nigeria, Guyer and Lambin (1993) used remote sensing combined with ethnographic research to study agricultural intensification, demonstrating the potential of remote sensing to address site-specific ethnographic issues within a larger land use perspective. A special issue of Human Ecology, September 1994, was dedicated to regional analysis and land use in anthropology. There was substantial agreement among the articles about the importance of local-level research to inform land use analysis at the regional scale. This conclusion was reinforced in an issue of Cultural Survival Quarterly (1995) dedicated to showing the connection between local knowledge and remote sensing, GIS, and mapping tools. The growing use of remote sensing in the social sciences is addressed in People and Pixels: Linking Remote Sensing and Social Science (NRC 1998), including the work of environmental anthropologists (Moran and Brondizio 1998; Sever 1998).

The use of spatial data in analysis presents a number of challenges. Scale persists as a problem, even at the basic level of terminology (Green et al. 2005b). In cartography the term 'large scale' refers to detailed resolution, while in anthropology 'large scale' refers to a large study area and loss of ethnographic detail. Another basic problem is the interplay between absolute and relative scales, which can result in confusion in modeling ecological processes. This challenge is being addressed by landscape ecology. Many scholars are using landscape ecology methods to better understand land use dynamics, and spectral analysis is being refined to work at the local level with more detailed requirements. In order to continue solving the challenges posed by multiscalar research on global change, social scientists must develop research methods that are explicitly multiscale and capable of nesting data and sampling strategy in such a way that scaling up or down is feasible and integral to the research strategy (see part 3 in Moran and Ostrom 2005: 127–214, for a discussion of methods user-friendly introduction to the handling of spatially-explicit data.

Methods for Multilevel Analysis

Multilevel research can start at any scale of analysis; hence, sampling at one level may need to be aggregated to a higher level or disaggregated to lower levels.[1] This requires paying attention to levels of analysis without subordinating scales. Land use/cover analysis provides us with a setting for the study of levels of analysis that connects human behavior in relation to economic forces and management strategies with ecological aspects of land cover.

We can conceptualize multilevel analysis of land use/cover change as built on a structure of four integrated levels of research: landscape/regional level; vegetation class level; farm/household level; and soil level (Figure 4.2). The conceptual model relies on a nested sampling procedure that produces data that can be scaled up and down independently or in an integrated fashion. The integration of multitemporal, high-resolution satellite data with local data on economy, management, land use history, and site-specific vegetation/soil inventories aims to make it possible to understand ecological and social dimensions of land use at the local scale, and link them to regional and global scales of land use.

Household/Farm or Local Level of Analysis

Data collection at the farm/household level can include a variety of internal and external aspects of this unit of analysis (Netting et al. 1995; Moran 1995). It is important to collect local data so that it can be aggregated with that of larger populations in which households are nested. For instance, demographic data on household composition (including sex and age) can be aggregated to the population level to construct a demographic profile of the population, but only if the data is collected in such a way that standard intervals of five years are used (Moran 1995). Another important set of data that is collected at this level and can be aggregated at higher levels is related to subsistence economy. It is fundamental for the analysis of land use to understand resource use, economic strategies, market relationships, labor arrangements, and time allocation in productive and nonproductive activities. At this level, it is important to cover the basic dimensions of

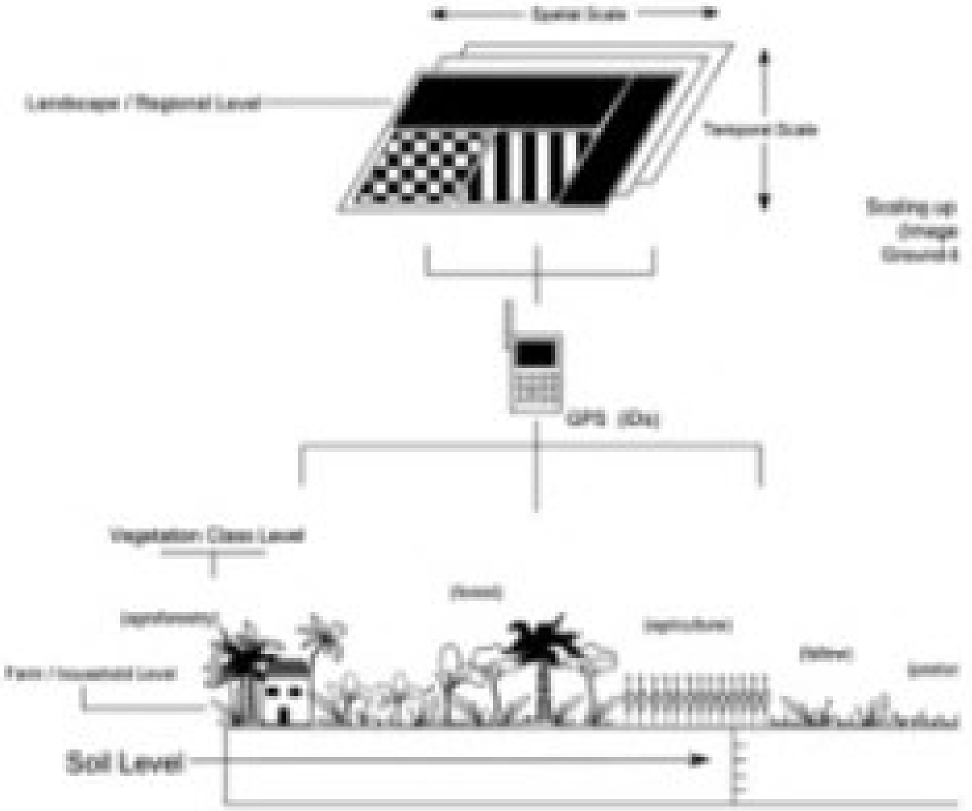

FIGURE 4.2 Multiscale analysis of land use and land cover change, showing examples of data collected at each scale and how to nest the data.

Source: Adapted from E.S. Brondizio, 1994.

Current concern with global change means that data collection at the local level must be capable of aggregation to higher levels of analysis, both in geographical and database formats. Georeferencing the household, farm boundaries, and agriculture and fallow fields (i.e. providing precise coordinates) may be achieved through the use of global positioning system (GPS) devices. These are small units that permit locating any point on the planet within a few meters. The level of precision will vary depending on a number of factors, such as the quality of the GPS receiver.

Vegetation mapping has implications for understanding the impact of land use practices on land cover. Basic vegetation parameters need to be included so they can inform mapping at the landscape level. In general, vegetation structure, including height, ground cover, basal area, density of individuals, DBH (diameter at breast height), and floristic composition are important data to be collected. These data inform the interpretation of satellite digital data, provide clues to the vegetation cover. Remote sensing has considerable potential in vegetation analysis because it enables wide-area, nondestructive, real-time data acquisition (Inoue 2003; Loris and Damiano 2006). The applications are also important in estimating aboveground carbon stocks, relevant to effective reports on Kyoto Protocol requirements (Patenaude et al. 2005) to reduce human-induced emissions of carbon dioxide by at least 5 percent below levels of 1990 by 2012 (most EU countries have failed to meet their targets, and some like the USA did not even try to set targets). To do so, countries must estimate carbon stocks in 1990 and any changes since that date, whether through afforestation, reforestation, or deforestation (Patenaude et al. 2005). The applications to monitoring and predicting severe drought also have grown in sophistication (Boken et al. 2005).

In terms of satellite data interpretation, the definition of structural parameters to differentiate vegetation types and environmental characteristics, such as temperature and humidity, is particularly important. Structural differences provide information that can be linked to the image' s spectral data. Floristic composition, although important, is less directly useful in interpreting spectral responses, but it may have to be considered depending on research questions. Environmental factors, such as soil humidity, soil color, and topographic characteristics, also are associated with spectral responses of vegetation cover. For example, at the farm level, vegetation structure is the main parameter used to evaluate the impact of human management practices, though floristic composition can be relevant. Some plant species are excellent indicators of soil type which are, in turn, associated with given management practices. Farmers commonly use the presence of given species to site crops. For instance, the presence of Imperata brasiliensis may be a sign of low soil pH in parts of the Amazon estuary (Brondizio et al. 1994). This kind of ethnoecological knowledge is site spe-cific, and such local knowledge does not extrapolate well to landscape, regional, or global analysis. To incorporate this data it is essential that the data be precisely goes to higher levels of aggregation in analysis.

To determine representative sampling sites of a study area' s land cover, four types of information need to be aggregated: vegetation classification, ethnoecological information of resource use, composite satellite images, and classified image/land use/cover maps of the area. Based on the analysis of these data, one can decide how sampling can best be distributed in the area to inform both the image classification (land use/cover map) and the structural- floristic variability of vegetation classes. In selecting a site to be a representative sample of a vegetation type or class, one needs to consider the size of the area and its spatial location on the image. The spatial distribution of the vegetation class must also be taken into account to avoid clustering of the samples and biased information about the vegetation structure and floristic composition. With the use of a GPS device, geographical coordinates of the sampled area are obtained as part of the inventory. If possible, the area should be located on a hard copy of the georeferenced image at the site, to avoid confusion and ensure precision of the GPS information. However, it is in the laboratory, using more precise methods of georeferencing, that the site will be definitively incorporated into the image file. A nested data set on land use history and vegetation inventory can be related through GPS-derived coordinates to a multitemporal image, allowing complex analysis of land use trajectories and re-growth history at site, local, and landscape levels.

Information on land use history is important not only in defining sampling areas of anthropogenic vegetation (for example, fallow and managed forest), but also in verifying that natural vegetation has not been affected or used in the past. For instance, it is important to know whether a savanna has been burned, and if so, with what fre-quency; or if a particular forest plot has been logged, which species were taken and when the clearing event took place. Land use and management history are more detailed in areas directly subjected to management (for example, agroforestry), since management and technology areas, estimates and actual measurements of production are critical for analyzing the importance of the activity on a broader land use and economic context. More importance should be given to the spatial arrangements of planted species and their life cycles as part of the inventory. This area has been neglected in past environmental anthropology research and needs to be addressed by working closely with spatially oriented scientists such as environmental geographers and ecologists.

Vegetation re-growth and agricultural production analyses are limited in their usefulness without information about soil characteristics. Soil analysis should always be associated with vegetation cover analysis; soils should be collected at inventoried vegetation, agroforestry, and crop sites of known land use history and management and georeferenced to the image through a GPS device (Moran et al. 2002). Ethnoecological interviews can elucidate many soil characteristics. Taxonomic classification of soil types based on color, granulometry, and fertility help identify the major soil types and their distribution with relative reliability. Folk classification can then be cross-checked and compared with systematic soil analyses. Soil analyses should include both chemical (pH, P, K, Ca, etc.) and textural (sand, clay, silt) analyses and permit the aggregation of data to regional levels (Nicholaides and Moran 1995).

Landscape and Regional Level of Analysis

The landscape/regional level provides a more aggregated picture of management practices and driving forces shaping a particular land use/cover at sub-regional scale. At this level, long-term environmental problems can be more easily identified and predicted than at farm or household scales (Booth 1989; Skole and Tucker 1993; Brondizio and Moran 2008). This level integrates information from vegetation class, soil, and farm/household levels (Adams and Gillespie 2006). However, landscape level data also informs important characteristics of local-level phenomena that are not measurable at the site-specific scale. For instance, information about the heterogeneity and patchiness of the vegetation is an important parameter to include in site-specific secondary succession analysis, but it can only be observed at the understanding the ecological and socioeconomic nature of the features of interest in land use/cover analysis, (2) identifying the extent and frequency of features of interest that can inform the appropriate spatial and temporal scales of analysis, (3) progressively increasing sampling, depending on the emergence of important variables, a process that landscape ecologists call using an adaptive approach (Turner et al. 1989) and that bears some resemblance to what Vayda calls 'progressive contextualization' (1983), and (4) considering the empirical methods needed for checking map accuracy, change detection, and projections and/or predictions, especially when associated with land use planning.

Satellite data are the most important for analysis at the landscape/regional level. However, it is always associated with other sources, such as radar images, aerial photography, and thematic and topographic maps. Anthropologists in the past left this kind of work to others, but today a growing number of anthropologists are developing these skills and making useful contributions to the analysis of satellite images (Behrens 1994, 1990; Moran et al. 1994, 2002; Brondizio et al. 1994, 1996, 2002; Moran and Brondizio 1998, 2001; Nyerges and Green 2000; Tucker and Southworth 2005). The digital analysis of satellite images may be divided in four parts: preprocessing, spectral analysis, classification, and post-processing. During preprocessing one needs to define an image subset, georeference it to available maps and coordinate systems, and register it to other images available if multi-temporal analysis is desired. The georeferencing accuracy depends on the quality of the maps, availability of georeferenced coordinates collected during fieldwork, and the statistical procedure used during georeferencing (Jensen 1996). A georeferenced image has a grid of geographical coordinates and is crucial for relating landscape data to site-specific data. When multitemporal analysis is desired, images from different dates need to be registered pixel to pixel, creating a composite image that provides a temporal change dimension at the pixel level, thus images that are five years apart), one can quantify the change during regrowth of secondary vegetation or a shift in crops grown in that five-year period with considerable accuracy, including statistics for the change in area for each vegetation type or class.

Digital analysis provides the flexibility to use a variety of scales to analyze parameters and to define sampling procedures, depending on the land use/cover pattern and extent of the study area. In general, one can work at the landscape or regional scale (for example, the whole Landsat or SPOT image, 185 by 185 kilometer areas for Landsat images) while staying in close association with local scale processes (for example, image subsets of a watershed) to help the selection of sampling areas that will inform the image about specific spectral and spatial characteristics of land use/cover classes. By taking a hybrid approach during image classification and processing, one can integrate unsupervised and supervised classification procedures. A hybrid approach allows one to develop an analysis of spectral patterns present in the image, in conjunction with ground information, and to arrive at spectral signature patterns which account for detailed differentiation of land use/cover features. In this fashion, a conceptual spectral model can be developed in which the features of interest can be incorporated. The model considers the reflection and absorption characteristics of the physical components that comprise each feature. For instance, in a Landsat TM image, the model attempts to account for chlorophyll absorption in the visible bands of the spectrum, for mesophyll reflectance in the near-infrared band, and for both plant and soil water absorption in the mid-infrared bands (Mausel et al. 1993; Brondizio et al. 1996). The integration of those spectral features with field data on vegetation height, basal area, density, and dominance of species can be used to differentiate stages of secondary regrowth (Moran et al. 1994). The analysis of spectral statistics derived from unsupervised clustering and from areas of known features and land use history allows the development of representative statistics for supervised classification of land

Classification accuracy analysis requires close association with fieldwork. Accuracy may decrease as spatial variability increases. Thus ground-truth sampling needs to increase in the same proportion. In this case, the use of a GPS device is necessary to provide reliable ground-truth information, whereas in areas with low spatial heterogeneity visual spot-checking may be enough. Accuracy check of a time series of satellite images for an area requires the analysis of vegetation characteristics and interviews about the history of a specific site with local people, so it is possible to accurately relate past events with present aspects of land cover (Mausel et al. 1993; Brondizio 2005, 2008).

Integration of data at these scales is an interactive process during laboratory analysis of images and field data, and during fieldwork (Meyer and Turner 1994; Moran and Brondizio 1998). Advanced data integration and analysis is achieved using GIS procedures that integrate layers of spatial information with georeferenced databases of socioeconomic and ecological information. Georeferencing of the database to maps and images must be a consideration from the very beginning of the research so that appropriate integration and site-specific identification are compatible. Data on household/farm and vegetation/soil inventory need to be associated with specific identification numbers that georeference it to images and maps so that integrated associations can be derived. For instance, the boundaries of a farm property may compose a land tenure layer that overlaps with a land use/cover map. These two layers may be overlapped with another layer that contains the spatial distribution of households. Each household has a specific identification that relates it to a database with socioeconomic, demographic, and other information. In another layer, all the sites used for vegetation and soil inventory can be associated with a database containing information on floristic composition, structural characteristics, and soil fertility, which will also relate to land use history.

Global Level of Analysis

integrated assessment modeling, GCMs (global circulation models), and other approaches at a biosphere level of analysis. Some of these have even managed to focus on the human impacts on the earth system (compare Weyant et al. 1996). GCMs were developed first and lacked a human dimension. They were largely concerned with climate and atmospheric processes, using a very aggregated scale of analysis that made even large-scale units, such as national boundaries, not always relevant to understanding differ-ences, say, in rates of energy consumption. However, a new generation of models has emerged in the past few years that have relevance for environmental anthropologists. These are a vast improvement from the pioneering work of the Club of Rome models that appeared in the early 1970s in Limits to Growth (Meadows et al. 1972). Despite the many problems with this early effort, it introduced important concepts like feedback, overshoot, and resource limits to everyday discourse and scientific debate. The next attempt came from the International Institute of Applied Systems Analysis (IIASA) in Austria, with its Finite World model examining global energy flows (Häfele 1980). This attempt was broadly criticized in the scientific community and little happened until the first Intergovernmental Panel on Climate Change (IPCC) published its initial assessment in 1990. New generation models benefited from the progress made by GCMs, growing evidence of the global nature of environmental problems, and the democratization of computer technology through its wide availability (Alcamo et al. 1998: 262). The next step was clear: both social and physical aspects of the world system had to be coupled in so-called integrated assessment models. Most global modeling groups today acknowledge that progress on the accuracy and predictability of modeling efforts at this scale will require a simultaneous effort to link them to regionally scaled models that can improve the quality of the spatial resolution, and the role of human drivers in global change.

One of the more sophisticated models to date is known as IMAGE 2 (Alcamo et al. 1998). It was the first global integrated model with geographic resolution, an important feature that permits improved representation of global dynamic processes, including feedback and rapid, efficient testing against new data. It is composed of two fully linked systems of models: a socioeconomic system model, and an earth system model. The socioeconomic model is elaborated for twenty-four regions of the world, whereas the earth system (or ecosystem/atmospheric) model is spatially explicit on a 0.5 degree grid scale. The terrestrial environmental model simulates