

Forthcoming In I. Vaccaro, E. A. Smith, and S. Aswani (eds.) *Environmental Anthropology: Methodologies and Research Design*. Cambridge, UK: Cambridge University Press.

Spatial-temporal methodologies in Environmental Anthropology: Geographic Information Systems, remote sensing, landscape changes and local knowledge.

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Introduction

Spatial tools such as remote sensing (RS) and geographic information systems (GIS) are increasingly used in a variety of research applications. The popularization of geospatial data and tools in the media and society has significantly changed the way we perceive, understand and manage our landscapes. A variety of social actors have become familiar with these technologies, whether they be an extractivist cooperative disputing borders in the Brazilian Amazon, a US resident checking his property in cadastral map, or a school teacher in India, using a satellite image to teach regional geography. Today, geospatial technologies are recognized as valuable assets of civil society and essential tools to address social and environmental problems (NAS 2002). The proliferation of satellite and public-domain spatial data, Global Positioning Systems (GPS), affordable computer hardware and software, and data processing and analytical techniques continue to expand the use of these technologies in anthropology generally, and environmental anthropology in particular. Such spatial information is frequently used in visualization (e.g., displays of aerial photography or satellite imagery for a study region) using Google Earth or other public domain software that allow quick online data access/display without requiring specialized training. More in-depth research and analyses entail the use of designated RS/GIS software programs (e.g., ERDAS Imagine, ArcGIS, Idrisi, Multispec, among many others), and the actual acquisition of the relevant GIS datasets (as opposed to merely accessing them for online displays and/or simple queries).

This chapter reviews uses and issues in the application of RS and GIS in anthropological research. We briefly review fundamental geospatial concepts and provide a concise history of RS and GIS applications in Anthropology. Next, we present the range of geospatial concerns in anthropological research design, highlighting research questions, units of analysis, data search and temporal sampling, and assessments of data processing needs and analysis. In order to illustrate these geospatial concerns, we focus in particular on land use/cover change research, and provide guidelines for data planning and research design. Finally, we present critical ethical and pragmatic issues in the (re)presentation of spatiotemporal data and maps, reflecting on the positive potential as well as perils of using these tools in anthropological research.

Fundamentals of remote sensing and GIS

RS, GIS and GPS are complementary suites of geospatial technologies and methods, collectively implicated in GIScience (Jensen 1996; Goodchild and Janelle 2004). RS involves the collection of surface reflectance data from a distance, such as in analog/digital aerial photography or satellite imagery recording information about the earth surface in gridded (raster) products. These data constitute the most significant sources of quantitative information about land cover

and land use changes in the tropics and elsewhere (Sader *et al.*, 1994). GIS, on the other hand, involve hardware, software, database systems and methods for the storage, representation, processing, integration and analysis of diverse spatial data and their attributes. Both spatial and nonspatial information may be recorded in raster data or vector features such as points, lines and polygons, referenced to a common cartographic system of spatial location. GIS enable the collation and processing of RS products for further representational or analytical tasks, such as modeling deforestation by linking data on forest (change) patterns with ancillary, spatially explicit socioeconomic variables. The following sections briefly review key elements of RS and GIS.

Remote sensing technologies enable the mapping of the earth's surface and subsurface features based on their differential reflectance of incident electromagnetic energy. A fundamental distinction among remote sensing technologies is based on the source of that energy: passive sensors record reflectance of incident solar radiation (i.e., the energy source is independent of the measurement device, exemplified by optical systems such as Landsat), while active sensors record the return of wavelengths generated by the sensor system (e.g., microwave RADAR or LiDAR). Since the military surveillance systems of World War II, sensors have improved to capture reflectance in a wider range of optical wavelengths with greater resolution, for progressively more information content. The level of detail (resolution) in digital imagery can be related to at least three aspects: spatial, spectral and radiometric. These resolutions trade off with each other, and with the overall areal extent covered by each image scene/snapshot. Spatial resolution refers to the size of individual pictorial elements (pixels), corresponding to rectangular portions of the earth surface being imaged. Higher spatial resolution systems such as IKONOS or Quickbird map earth surfaces in great detail, with sub-meter pixels. Spectral resolution refers to the precision with which sensors partition the electromagnetic spectrum (into "bands") to record reflectance. The human eye is sensitive to wavelengths in the visible range, or 300-750nm (blue to red wavelengths). NASA's Landsat Thematic Mapper sensor system captures the visible range in 3 ranges or reflectance bands (blue, green and red), and additionally records reflectance in four infrared bands (three mid/near infrared and one thermal), as opposed to up to 220 bands in hyperspectral remote sensing (NASA's EO-1 Hyperion sensor). Radiometric resolution refers to the levels of quantization (referred to as bit depth) with which the sensor captures spectral reflectance intensities in a pixel, typically ranging from 0 to 255 (8 bits). Additionally, temporal resolution refers to the revisit frequency of the sensor for a specific point on the earth. Landsat TM has a temporal resolution of 16 days, compared to the NOAA AVHRR satellite's twice-daily imaging frequency. Processing satellite imagery or digital aerial photographs of varying spatial, spectral and radiometric characteristics involves three essential steps: geometric correction (georeferencing), radiometric correction (noise removal) and various methods of information retrieval relevant to the chosen application or research question. Subsequent sections (V) will discuss some of these image processing techniques utilized in anthropological research on landscape characterization and change detection. Most RS applications, however, involve the analysis of RS-derived data with GIS tools.

Geographic information systems center on linked spatial and attribute (nonspatial) data, structured within a chosen model to represent real-world spatial objects and relations. Typically, GIS data models are of two basic types: raster and vector. Raster data represent a

space-filled, *field-based* view, in which the geographic world is made up of continuously varying data values in gridded layers covering a study region. Spatial and attribute data are embedded within the same data structure: the spatial grid is divided into square/rectangular units, typically of uniform dimensions, each cell recording qualitative or quantitative attributes of interest (e.g., land use codes, distance to nearest road network, degree of fire risk, etc.). Vector data, on the other hand, subscribe to a *feature-based* view of the world, recording precise boundaries and information about specific objects of interest, rather than all space within a study area. Three types of features typically used are points (e.g., houses), lines (e.g., roads) and polygons (e.g., land parcels). In a vector data model, spatial and attribute data are stored separately but linked through a common identifier, often within a relational database.

The development of modern GIS was application driven, and dates to the computerization of spatial data management tasks in the US Census and Canadian Land Inventory during the 1960s. GIS software offer tools for spatial and relational data entry and storage (including coordinate and attribute data capture or importation), representation (e.g., through various data models), transformation and management (e.g. projections, editing, reduction/summarization), and visualization (various output formats and symbolization, alternate/dynamic renderings of 2 or 3-dimensional products, often embedded with internet mapping). Most significantly, GIS techniques enable the integration of data from disparate sources, and the analysis of multiple spatial data layers. Analytical tools range from simple querying, distance and buffering tools, to map algebra and spatial statistics/interpolation, as well as complex network/topological/terrain analyses, multi-criteria evaluations and environmental modeling. Several of these techniques entail the integration of research/methodological approaches as well as diverse data sources such as ethnographies and field-derived surveys, cadastral information, digital elevation models, satellite or station derived climate data, land cover information, or utilities and infrastructure networks. These characteristics explain the increasing use of GIS in research and planning, as well as environmental and spatial decision-making. GIS are embedded, however, within a broader theoretical framework of *GIScience*, drawing from geospatial technologies (RS, GIS, GPS) as well as informed by information theory, mathematics and statistics, cartographic and cognitive sciences as well as linguistics. Thus, anthropological research (e.g., on spatial social relations and environmental perception/cognition) may draw from and contribute to both GIS applications, and GIScience more broadly.

A brief history of RS-GIS applications in Anthropology

In Anthropology as in other disciplines, the use of geospatial technologies expanded greatly since the 1970s, commensurate with the broad proliferation of GIS and RS, and with a trend towards interdisciplinarity in anthropological paradigms and methods (Conant 1978, 1984, 1994; Aldenderfer and Maschner 1992). Today, GIS and RS frequently contribute to methodological training in environmental anthropology, archeology, and social sciences in general, aiding in the study of local populations and socio-cultural phenomena (Behrens 1994, 1992; Fox et al 2003), the history of landscape (Nyerges and Green 2000; Guyer 2007), understanding and quantifying socio-environmental transformation (Galvin et al 2001; Brondizio 2008), preparation of field research (D'Antona et al 2008; DeCastro et al 2002), and practical applications relevant to local populations and policy (Cultural Survivor 1995; Smith et

al 2002). Conversely, anthropological concerns with local scales and richly detailed human-environment processes have also contributed to refining spatial categories and methods of analysis (John 1990; Liverman et al 1998; Moran 1998). For instance, researchers in anthropological and related fields have engaged in the development of participatory field techniques, image interpretation, validation of land cover classification products, discussion of ethical and confidentiality issues in spatial data use representation and use, and disseminating geospatial products to local communities and indigenous groups (D'Antona et al 2008; Brondizio et al 1994).

During the 1970s, anthropologists began to utilize newly available Landsat (Morain 1998) and radar data in addition to longer-used aerial photography (Reining 1979), expanding their applications in archeology (Lyons and Avery 1977; Server and Wiseman 1984; Gibbons 1991; Stone 1993; Heckenberger et al. 2003; Fisher and Feinman 2005). These data have helped locate and contextualize villages in remote areas, and provided a lens by which to understand subsistence activities, assess infrastructure and environmental resources, and track the mutual transformation of social groups and landscapes, assisting in planning fieldwork, testing hypothesis, and generalizing local findings. In some cases (e.g., Conklin 1980), geospatial methods allowed the presentation of long-term ethnographic data over regional landscapes. Interestingly, by offering new perspectives and modes of analysis, geospatial methods have driven a pluralization of anthropological questions, demands for more, not less fieldwork (Conant 1994), and interdisciplinary collaborations amidst the emerging research agenda on global environmental change (John 1990; Aldenderfer and Maschner 1992; Moran and Brondizio 2001). Likewise, it has provided important resources to grassroots social movements concerned with environmental degradation and land demarcation since the 1980s (Wilkie 1987, 1990; Cultural Survival 1995; Smith et al 2002).

GIS and RS methodologies to explicitly link distinct spatio-temporal scales have greatly benefitted human-environment studies in anthropology, geography and ecology. Across these disciplines, efforts to conceptualize boundaries and relations among human populations and their environment have focused on households, sociocultural/ethnic groups, communities, cultural areas, territories and territoriality, niches, ecosystems, landscapes, biomes, states and nation-states, among other units. An illustration of historical approaches to conceptualize units of analysis anthropology include Kroeber 1939; Steward 1955; Geertz 1963; Vayda and Rappaport 1968; Vayda and McCay 1975; Moran 1990; Fairhead and Leach 1995; Brondizio 2005; Walker and Peters 2007). Various traditions within environmental anthropology favor particular articulations of scales/units, such as individuals and cultural groups (symbolic ecology); localistic approaches (ethnobiology); socio-demographic units and their biophysical environment (ecological anthropology); local connections to national and global scales (political ecology); groups with shared/contrasting interests in common pool resources (institutional analysis), or local/regional landscapes or a nexus of these (historical ecology). This diverse legacy has been enriched by the spatial resolution and relational analyses offered by GIS/RS (Brondizio et al n.d.).

Assessing geospatial data needs in anthropological research

The specification of research questions and analytical units are the most fundamental tasks in planning anthropological research. Geospatial data and the articulation of spatial information

with non-spatial attributes afford particular opportunities and challenges in research design. This section outlines key considerations in the integration of GIS and RS with research foci in environmental anthropology, focusing on units of analysis, the formulation of spatio-temporal research questions, and pragmatic aspects of referencing data availability to research design. Finally, these considerations are linked to implications for data manipulation and analysis by focusing on a particularly relevant environmental anthropological research application: the detection and analysis of landscape change.

Analytical questions and units

The selection of units of analysis lies at the heart of understanding processes of socio-environmental change, including deforestation or urbanization, and the roles of different forces such as cultural diffusion, environmental constraints and political economy. This analytical choice is also the single most important step in preventing scalar mismatch between agents and outcomes of change, and the 'ecological fallacy' (ascribing relationships detected at one scale to a lower level of analysis). A common example of this problem is presuming correlations between population growth and deforestation in a given area, without considering population distribution patterns and the role of external agents. Along the same lines, the selection of units of analysis is important to avoid 'adaptation fallacies,' or assuming a perfect match between a given population and the local resources, perhaps ignoring alternative relationships, such as external subsidies or exported environmental costs.

Defining units of analysis requires negotiating boundaries which may be ephemeral, fuzzy, open, circumstantial, and/or seasonal, thus requiring a flexible and critical approach. With few pre-defined units in human-environment analysis, a central guiding principle is to consider the hierarchically nested scales relevant to research questions of interest. For a given region, these decisions should account for local forms of social organization, spatial distributions of environmental resources, human populations, infrastructure and land use systems. Thus, the researcher may identify questions, involving distinct political (e.g., states, municipalities, districts), institutional (government, private, communal areas), biophysical (e.g., watersheds, edaphic zones), socio-cultural (e.g., ethnic groups, clans), demographic (e.g., households, cohort groups), and contextual units (e.g., distinct distance buffers relative to village centers/markets/rivers/roads). The diversity of environmental, historical and economic factors that mitigate against easy generalizations in a given region (Tucker 2005) necessitate the integration of local detail and knowledge into remote sensing and GIS data.

Intraregional analysis accommodates such complexity, recognizing environmental and social variations within a region (Brondízio 2005; 2006; Lambin 2003). In this context, hierarchically nested units can be defined according to one's research questions and regional structures, such as farm lots within a settlement, settlements within a community, rural communities within a municipality or in relation to a conservation reserve, reserves within a region, and so forth. Biophysical units such as vegetation types or watersheds can also be nested in this context (Miller et al 2009). Intraregional analysis thus entails regional stratification according to spatio-temporal patterns of social settlement or ecological change, a process that can be very useful during image classification (described in following sections). Figure 1 illustrates a regional stratification according to historical occupation and spatial scale (Brondízio 2006). While histories are not units of analysis per se, the institutions, social groups,

and forms of resource use and ownership created through time can be. Thus, accounting for such variations may help to avoid unwarranted comparisons and to improve the level of detail in the analysis of landscape change, as well as offering image segmentation by social, historical, and environmental variation as opposed to classical remote sensing partitioning by pixel reflectance values.

Closely related to the selection of observational units in environmental anthropology is the task of defining a study region's precincts, and matching them to political, sociocultural, institutional and biophysical boundaries that typically do not co-align. These overlaps (or mismatches) are important not only to understand if, where, how, and when a given population uses different parts of a landscape, but whether resource management at one level (e.g., community) is appropriate to deal with problems resulting from another level (e.g., watershed) (Brondizio et al. 2009). An additional challenge lies in matching social and spatial/environmental boundaries with chosen units of observation (McCracken et al 1999; Fox et al 2003; Boucek and Moran 2004; Ostrom and Nagendra 2006). For instance, researchers investigating agricultural management in a given region need to consider whether prevailing relationships are one-to-one (e.g., each household in a study site cultivates a farm lot), one-to-many (e.g., each household farms several plots), or many-to-one (e.g., a given parcel managed by multiple households over time). RS derived data on land cover and/or change, when integrated with ancillary GIS data on agents of change and their connectivity to parts of the land, can reveal patterns and processes of management/social relations. GIS also aids in the creation/consideration of contextual (proxy) boundaries for areas lacking clear administrative/jurisdictional cartographies. For instance, if one wants to estimate land use change associated with a given village where no clear bounding coordinates are defined, researchers may generate buffer zones at different distances from a village center or utilize a common alternative, Thiessen polygons (Siren 2007; Siren and Brondizio 2009). Fundamentally important in such boundary definitions are considerations of their fluidity, contingency and contestation, as well as of who is defining them (e.g., whether customary boundaries are more meaningful than formal ones), and how they change through time (including between seasons). Geospatial tools allow such manipulation of analytical units, thus rather than constrained to given units, it allows comparison and testing of human-environmental relationships according to various spatial nexus and comparative frameworks.

Cross-referencing available data in preparing a research design

Preparing a research design integrating RS, GIS, and other methods from the toolkit of anthropologists require the definition of clear research questions, the searching of available data, estimation of field efforts, and understanding the limitations inherent to the resolution of different data sets (including not only spatial data, but surveys and ethnographic material). Figure 2 provides a practical guide to define, search, cross-reference, and evaluate the extent to which available RS and GIS data can be used to address one's needs. In preparing for this exercise one should identify (1) the research question of interest; (2) the time frame of interest and/or the sequence of relevant events affecting an area; (3) the seasonality of the area: how climate or land cover/use may change through the year; (4) the spatial dimensions of important social and environmental features and/or ideal data requirements. Once the above questions and data needs are outlined, potential sources of eligible RS/GIS data may be identified. Image

scenes for specific regions may be quickly located using global referencing systems (e.g., the World Reference System¹ [WRS I or II] to identify Landsat images) and/or locational (e.g., UTM or geographic) coordinates. Several search engines and public data archives (see VII - Sites of interest) allow one to locate geographic coordinates in relation to image footprints.

As the scope of research frequently includes temporal trends/processes, it is helpful to develop a temporal nesting of identified datasets by seasonal vs. inter-annual/longer time intervals (Figure 2, items 2-4). If seasonally referenced data are available, they enable discerning vegetative/land cover phenology and calendars of land-based/economic activities in a given area, and may suggest the need for proxy measurements/adjustments (e.g., considering bare soil in/as agricultural fields in an image captured outside the growing season). Longer-term datasets (e.g. image snapshots over years or decades), on the other hand, can reveal the impacts of historical events and period effects (e.g., major policy or economic changes, important conflicts, a major development project, changes in technology, or the occurrence of natural events such as droughts or floods, etc).

Data quality concerns are important when selecting among alternate short or long-term RS datasets that may match research needs. These include considerations of scene cloud cover, and patterns of geometric or radiometric corrections that are likely necessary. Quality and informational content is equally important in ancillary GIS data, and researchers need to assess the type and detail of thematic information about features of interest, as well as their cartographic aspects (e.g., projection system, scale and minimum mapping units, and metadata detailing types of corrections/transformations applied). These features will fundamentally influence data input as well as the quality of registration/overlay with other data layers. Plotting available data and information pertaining to an area over time as well as explicitly evaluating its quality helps the researcher adjudicate among available data or spatio-temporal sampling designs. It also helps to define fieldwork strategies might be needed to collect additional data or to validate and correct existing ones, and the costs associated with these choices: key issues in the progressive refinement of research questions and strategy. Figure 3 summarizes the major activities and concepts in data organization and manipulations common to anthropological applications.

Research application: detecting and understanding land change

A comprehensive discussion of data processing in RS and GIS, even within the field of anthropology, would be well outside the scope of a book chapter. In this section, we therefore highlight data processing and analytical considerations as exemplified in one common area of application of RS/GIS in environmental anthropology: the characterization of land cover and/or use, and depicting and understanding its change over time. Digital image processing in RS for land change analysis includes three main phases: pre-processing, land cover characterization with classification and/or continuous indices, and change detection, with field data collection at various phases throughout. GIS analysis may assist during the process of change detection, as well as enable a deeper investigation of the processes of historical change and/or future projections and scenarios.

Data Preprocessing

Digital image processing usually begins with the importing/conversion, display and examination of each image layer (band) and statistics. Depending on the specific research objectives, data source, and study region, the researcher makes choices at this stage regarding image mosaicking or sub-setting (to cover a study area in adequate spatial extent and/or detail), the use of spectral bands (i.e., whether all bands are necessary, and whether transformed bands are needed), and radiometric/atmospheric correction algorithms to improve signal-to-noise ratios before further analysis (Green et al. 2005). In some cases, such corrections are necessary to correct for atmospheric problems in different parts of the same image (Siren and Brondizio 2009). Advanced image processing software programs include pre-defined routines for radiometric enhancement, some of which are well-understood and commonly used to improve image quality (e.g., the Tasselled Cap transformation used to reduce atmospheric haze that especially affects lower wavelength bands), aiding in the preparation of clear image printouts for fieldwork, etc. Principal Components Analysis can dramatically reduce both random noise and systematic noise in imagery, and has been successfully applied to Landsat TM bands to enable high-resolution land classification in the tropics (Roy Chowdhury and Schneider 2004). As a rule of thumb, however, it is advisable not to undertake major radiometric transformations of the data if one is not experienced with their theoretical/empirical character (the nature of those changes and how they can affect the image).

One of the most important steps during pre-processing is geometric correction (used interchangeably with geo-correction and geo-referencing). Geometric correction involves spatial transformations to map (or reassign) pixels to a geographic (latitude/longitude) coordinate system or a standard map projection, such as the Universal Transverse Mercator (UTM) (Jensen 1996; Wilkie 1996). While images can be ordered with vendor-applied georeferencing, performing the corrections “in-house” enables greater control of positional accuracy and error distribution. Geometric correction is a necessary step to most applications in environmental anthropology and to anyone interested on assembling a GIS and cross-referencing any kind of spatially-explicit data. Similarly, it is necessary to prepare images for use during fieldwork, particularly if one wants to use a GPS in the field to locate a place on an image. The actual steps involved in geometric correction include the use of reference data (a pre-georeferenced map or image, in the absence of which field-derived GPS points may be substituted) alongside the target image to be transformed, and the selection of key locations/landmarks or Ground Control Points (GCPs) clearly visible in both reference and target images. The number (greater, the better) and spatial distribution (widely and evenly distributed, the better) of GCPs are important to minimize the magnitude of locational inaccuracy, captured as root mean square error (RMSE) after the coordinate transformation (Jensen 1996). A basic rule of thumb is to aim for a RMSE equal to or less than half the image pixel size, and use the lowest-order transformation function feasible (e.g. the nearest neighbor or affine transformation, for faster processing and least alteration of pixel attribute values). After geo-referencing, the transformed image may be overlaid with the reference maps check for the quality of their spatial matching.

Pre-processing may further entail band transformations, and/or the integration of of GIS techniques. For instance, a variety of algorithms allow the generation of indices of vegetation, soil, impervious surfaces and spatial texture. As mentioned earlier, principal component analysis can yield transformed bands that reduce image noise and data

redundancy/dimensionality. Quantitative measures derived from transformations of red and infrared bands, such as the normalized difference of vegetation index (NDVI), are useful indices of relative biomass in many regions. NDVI as well as spatial texture measures have been found to enhance the ability to distinguish between land cover classes when overlaid with dehazed bands prior to image classification (e.g., Roy Chowdhury and Schneider 2004; Lu et al 2004). Ancillary GIS data (e.g., digital elevation, soil or vegetation layers) may also be used as prior probability images in image classification (described in the next section), to improve land cover discrimination and classification accuracy (Pedroni 2003; McIver and Friedl 2002; Maselli et al. 1994).

Characterizing land cover and land use: Continuous and discrete approaches

Land cover can be described with quantitative or categorical data. Quantitative approaches derive indices of aspects of land cover features such as vegetation, bare soil, built-up or impervious surfaces and/or their moisture conditions can captured in image band transformations as described in the preceding section. Such measures include ratio or soil-line based indices, such as simple ratio (SR), NDVI and numerous variants, including the enhanced vegetation index (EVI), soil adjusted vegetation index (SAVI), modified soil adjusted vegetation index (MSAVI), soil adjusted total vegetation index (SATVI) etc. (Jordan 1969; Rouse et al. 1973; Rondeaux et al. 1996; Lawrence and Ripple 1998). These indices represent the physical condition of the landscape through continuously varying values across space.

Land cover classification, on the other hand, reduces continuously varying spectral reflectance (or vegetation index) values to fewer, discrete categories (nominal/qualitative data) that are meaningful to local social and/or ecological conditions. While it may seem desirable to always aim for the greatest number of detailed land cover classes, precision/accuracy tradeoffs mean that numerous classes of finely detailed cover categories are typically classified with lower per class accuracy, while fewer and (spectrally) broader cover classes have greater classification accuracy/reliability. It is important to aim for similar accuracy among classes, and a minimum accuracy of 85% is widely accepted. In case of low accuracy, one should consider aggregating a class one level up where a more general definition may improve accuracy.

Optimizing detail and accuracy is thus a particular challenge in image classification. Other considerations include: the system should be reproducible by another interpreter; classes should apply over extensive areas; aggregation of classes across levels should be possible; and, if necessary, classes should recognize temporal and seasonal dynamics (Anderson et al 1976; DiGregorio and Jansen 2000). A further challenge lies in the distinction between land use and cover. While environmental anthropologists may be interested in locating particular forms of land use (e.g., pastures) in a regional landscape, those uses need to be translated to biophysical land cover characteristics (e.g., herbaceous/grassy cover) for the purpose of land classification. This is important since different land uses (e.g., crops and pastures) may actually produce very similar land covers which may be or not spectrally distinguishable (e.g., coffee agroforestry vs secondary vegetation). The spectral signature of land cover features is defined by a combination of vegetation, moisture and soil conditions. The challenge we then face is to translate these conditions to land cover classes, and then relate them to relevant land use information.

Manual digitization (using digitizing tablets for analog products such as printed aerial photography, or on-screen digitization for digital photos/images) may be used to derive land cover maps without digital image classification. This method relies on the photo/satellite image interpreter's ability to discriminate features on a given image corresponding to distinct land cover classes. A number of spatial elements aid in the discrimination of land cover classes and/or features, including shape, size, pattern, and proximity/context of different features, as well as texture, tone, and shadows. Digital image classification, on the other hand, entails two main suites of techniques: supervised and unsupervised classification; hybrid classifications entail iterative combinations of the two.

Unsupervised classification allows the definition of classes without requiring knowledge of the image or study area, enabling the user to classify a large region into distinct categories of land cover in a time and cost-effective way at the beginning of research. The process identifies natural groupings of pixels in an image based on their location in multispectral feature space (their reflectance patterns in multiple bands). The number of clusters is defined by the user according to research questions. After classification, "...the analyst then attempts *a posteriori* to assign these natural or *spectral* classes to the *information* classes of interest" (Jensen 1996:231). Spectral classes may be difficult to interpret sometimes, with little resemblance to local reality. This assignment of unsupervised spectral classes to informational, "real world" classes entails ancillary knowledge of the area and GPS-assisted field visits. Nevertheless, many analysts prefer to use only unsupervised classification, often beginning with larger numbers of clusters, later aggregating similar spectral classes and using field-based information to identify the land cover categories they represent. Others prefer to use unsupervised classification only as the first step, then collecting field information to inform supervised or hybrid classification.

The first step in supervised classification is to develop a target classification scheme of land use/covers of regional interest. Such schemes are usually developed in an interactive process which involves the examination of land cover variability within an image, as well as thematic and field knowledge. Many researchers prefer to adopt hierarchically nested classification categories: the advantage of a hierarchical scheme is that detailed land cover classes may be aggregated to address questions about land use and cover change at different levels of analysis. For most studies, a classification scheme can be divided into three levels. The first level, suitable for regional analysis, divides the area into major land cover classes. A second level, more appropriate between the regional and local scales, divides the first level into more specific categories of land cover structure/composition and/or physiographic (e.g., topographic) characteristics of major landscape elements. The third and most detailed level aims at defining land cover classes for use in site-specific analysis, attentive to subtle differences in land cover classes relevant to ethnobotanical and land use questions. For instance, a general level I class of 'successional forest' can be divided into two structural/seral stages of secondary forests at level II, and three or even four in level III.

Based on target classes, "the analyst uses 'training samples' to define areas with pixels of known identity (through a combination of fieldwork, aerial photos, ancillary data, etc.) and use its 'statistics' to classify pixels of unknown identity" (Jensen 1996:231). The user defines areas of interest (AOIs) representing training sites (TS) for each target class, which can then be used by the selected classification algorithmⁱⁱ to classify pixels of unknown identity, and also to support accuracy assessmentⁱⁱⁱ. TS need to be collected for as many as samples as possible for

each of the proposed land use/cover classes, and be large relative to image resolution (e.g., minimally 9 pixels or about 1 hectare in the case of a Landsat TM image). Depending on field conditions, TS can be collected by observing areas along a roadside or river, during field visits with local farmers or informants, and many other creative ways. It is also important to ensure a wide spatial distribution of TS for land cover classes of interest, in order to avoid clustered samples biased towards only one part of the image/landscape. TS areas can be located with GPS in georeferenced image printouts or through real-time links to the digital imagery loaded on portable laptops, to allow for immediate adjustments/revisions.

A supervised classified image output is generated containing the classes represented by training samples. This procedure has a number of advantages: the user “trains” the classification algorithm based on their expert knowledge and desired targets; field (and other ancillary) data can be integrated into the classification process, and it is generally easier to test the overall classification accuracy. However, it also has several disadvantages: it requires high quality and broadly distributed field data, collected intensively and extensively to represent variability among landscape feature classes. It also assumes that a given training sample represents some level of homogeneity in order to serve as a reference to other pixels of that cover class in the image^{iv}. Several users prefer to use a combination of supervised and unsupervised methods. For instance, preliminary spectral clusters derived from unsupervised classification may be used as training sites in combination with field-derived data in a second-stage classification using supervised techniques. In either case (i.e., unsupervised, supervised or hybrid), one should use a combination of visual, spectral, and statistical tools to evaluate classes and improve class discrimination, making use of overlay techniques such as blending, swiping, and flickering layers, and charting spectral signatures and their separability statistics (e.g., transformed divergence).

Preparing and using images for fieldwork and interviews

Preparing data products for fieldwork is an important step for anthropologists using RS and GIS. Preparation of maps usually involves the use of GIS to represent an image (black and white or color composite) within a coordinate grid, juxtaposed with other layers of interest (e.g., municipal/community/reserve boundaries, roads, river systems), and, if applicable, legends (symbols representing different thematic features). Although basic cartographic information is always important, the degree of detail varies according to the goals of the map, but should at least include scale, north orientation, data source, and legend.

The selection of the area/subset to be used for preparing image printouts depends on the stage of research and sampling goals. In general, image printouts can be prepared at three scales which can be used from exploratory to advanced stages of research and fieldwork, as illustrated in Figure 1. These include a regional scale (i.e., relative to the whole area of the image and representing the larger landscape), a sub-regional scale (i.e., representing compartments/areas within an image that reflect social/environmental variability relevant to the research questions), and a local scale (i.e., representing the most disaggregated level of interest). While the definition of map/printout scale will depend on the size of the whole area of interest and the resolution of the image, experience shows that the following scales for print-outs are useful to most applications of Landsat and SPOT data: Regional (~1:50k), Sub-regional (~1:30k to 1:50k), and local (~1:15 to 1:30k). The sub-regional and local-scale maps

may be defined in a systematic sampling of the whole image (e.g., subdivided into quadrants), or led by particular regions/strata of interest (e.g., topographic gradients, institutional regimes, or forest protection status). Likewise, preparing images to be used at the local level with land managers and key informants will depend on sampling goals, but in general these images should represent the landscape most immediate to those managers or residents (Figure 1).

Additional considerations in preparing these images for use in interviews include the selection of color composition, coordinate systems, and their production using materials durable in field conditions. The selection of spectral bands and colors to depict their combinations (composites) should aim to balance familiarity of human vision with detailed information about the environment. Using data from Landsat series 4, 5, or 7 as an example, the most common color composite used for image printouts (one which offers a good trade-off between appearance and spectral information) assigns spectral bands 5 (mid-infrared), 4 (near-infrared), and 3 (red) to the red, green and blue color guns respectively. This will produce an image which resembles somewhat our own perception of the environment, i.e., vegetation will be greenish, water will be bluish, and soil will be reddish.

Image printouts should also include a coordinate system (e.g., geographic latitude/longitude or UTM) which one can use, for instance, to locate a reference point collected with a GPS. Since one can measure distances more easily in planar coordinates (e.g., meters), a UTM coordinate system or equivalent is the most practical for field purposes. A GPS locational reading can then be easily located within the image's UTM grid. Although the interval for a coordinate grid will depend on the scale of the map, 1km or 500m grid spacings are very useful for subregional and local scales (e.g., printed at a scale of ~1:15k – 1:30K). One should also consider whether an image printout can sustain field conditions, i.e., rain and humidity, constant manipulation, etc. If possible, it is always advisable to laminate image printouts/maps before going to the field and use permanent markers to make notations on top of it. Finally, one should always have extra copies of images to be donated during fieldwork to collaborators and/or institutions, such as to the interviewed farmer, to a community, or to a public agency that may benefit from it.

Using images in interviews during field research require a series of steps to avoid possible intimidation of interviewees, confusions during interpretation, and to maximize benefits to both parties. The use of images and maps should be preceded by a clear explanation of the project, confidentiality guarantees, and the the interviewee's informed consent. One can start by explaining the origin of the image one is using, including its availability to the public (*vis-à-vis* a privileged or exclusive data). One can donate/present an image to the interviewee at this stage or later depending on the situation. Depending on interview goals, the researcher may consider a three step process for using images, addressing discussions from the regional to local scales (e.g., figure 1). Following an explanation of the research project and imagery provenance, the regional-scale image may be used to contextualize the specific place where the conversation is occurring within the broader study area, utilizing major landmarks familiar to the interviewee. Concurrently, the researcher should explain to the interviewee the symbology and color composition utilized in the map products, enabling the interpretation of how colors map to landscape features and cover classes recognizable by local land managers/farmers (e.g. in the Landsat 543 composite described above, light-dark shades of green representing herbaceous-arboreal vegetation, blue as water, and reddish/yellowish as exposed soil or

infrastructure). This preliminary orientation may then be followed by detailed images at larger cartographic scales (subregional or local) to discuss landscape features in environments progressively more immediate to the interviewee. Patterns of environmental variability, management practices, land tenure, land use systems and local environmental knowledge are appropriate themes at this level of detail. Depending on research interests, a more local-scale (e.g., farm-level) image can then be utilized in conjunction with interviews eliciting calendars of land use/economic activities, management practices and land tenure, or ethnoecological research to distinguish landscape compartments and spatially explicit land use histories, further aided by local-scale sketch maps (e.g., D'Antona et al 2008).

Detecting land change

As with land cover characterization, analysis of land transformation over time may refer to continuous or categorical changes using multi-temporal datasets. Techniques vary with research/application goals (e.g., urban expansion, agricultural intensification, deforestation, forest degradation etc.). Continuous land cover change analyses can focus on shifts in reflectance (as captured in noise-corrected spectral bands), or on changes in computed land cover indices (e.g., vegetation/soil/impervious surface indices) across multiple image dates. Categorical change detection, on the other hand, proceeds with comparisons of classified images from multiple dates. The reliability of change analysis results is linked to the change detection technique employed, and depends fundamentally upon the quality of image geo-referencing and registration (i.e., precision of alignment between dates), the quality of atmospheric and radiometric correction (especially when comparing spectral reflectance directly across dates), and the consistency and robustness of the classification system used for each date. A comprehensive review of change detection techniques is presented by Lu and colleagues (2004).

Continuous change detection between two image dates includes techniques such as image differencing (calculating differences in per-pixel reflectance values, vegetation indices, etc), image ratioing (performing a per-pixel ratio operation between the two images), or image regression (wherein the image from time 1 is treated as an independent variable and time 2 as dependent variable to estimate a regression coefficient for each pixel, which is used to create a "predicted" image for time 2 for comparison with the actual time 2 image). These techniques need to be used with care, since their applicability is affected by underlying data quality (e.g., atmospheric effects) as well as patterns of spatial autocorrelation (e.g., violating regression assumptions of independence of observational units), necessitating refinements (e.g., radiometric enhancement or modifying spatial sampling regimes). Once applied correctly, these techniques are typically followed by thresholding (Singh 1989) to determine whether calculated shifts are significant changes or part of "natural" variability. Again, research objectives (e.g., type of land cover change of interest) will influence the application of these techniques, e.g. the choice of specific bands to compare (Lillesand and Kiefer 1987: 650-655).

Continuous change analysis using multiple (more than 2) image dates may entail multi-temporal composites for visualization or further processing, change vector analysis (CVA) or other time series analysis (TSA) techniques. Creating multi-temporal image composites (after geocorrection and image-to-image registration) is a powerful tool for depicting and detecting change over time. Subtle color differences produced by spectral change among dates may

reflect changes in land cover, that can be further assessed. For instance, a multi-temporal, unsupervised classification of composited bands from different dates can yield output classes represent different kinds of change. These forms of output may be validated or investigated (e.g., fieldwork, ancillary data; historical records) to characterize the kind of changes being detected.

CVA calculates (1) the Euclidean distance between a pixels position in n-band space in time 1, and its corresponding band-space location in time 2, and (2) the direction (angle) of the change vector as measured by its angle. The direction of change indicates the quality/type of change (e.g., vegetation loss or regrowth). Lambin and Strahler (1994), for instance, used CVA successfully to capture distinct processes of land cover change operating at distinct time scales, by using NOAA AVHRR imagery and applying the technique to three RS indices of land cover: vegetation, temperature and landscape structure. Another powerful analytical approach to TSA involves Principal Components Analysis (PCA). When PCA is applied to time series images, it can serve to array the sources of change in order of most to least significant. Eastman and Fulk (1993), for instance, applied PCA to examine vegetation changes over a three-year period in Africa. They found that the first standardized principal component captured the typical NDVI signal over the time period for the region, while successive components described changes in the NDVI signal over the period (with components 2-4 summarizing seasonal changes, 5-6 capturing satellite orbital shifts, and 7-8 depicting rainfall anomalies related to the 1987 El Niño/Southern Oscillation).

Categorical change detection is appropriate if images are not atmospherically and radiometrically corrected, or if the primary research objective is to assess changes in locally relevant land use/cover categories rather than continuous cover indices. In this case, each image is geometrically corrected and subjected to unsupervised, supervised or hybrid classification (with comparable/identical target classes in each time), following which a post-classification comparison is performed using GIS overlays. The categorical change detection produces a third, transition image depicting spatial changes along with a transition matrix indicating the frequencies of transitions from classes in date 1 to those in date 2. For instance, a pixel classified as forest in date 1 and herbaceous cover in date 2 can be interpreted to reflect deforestation, while the reverse may indicate reforestation. Inconsistencies in transition matrices and images may appear because of differences in geo-correction (pixels in some parts of the image may not match exactly between dates), or classification error (similar pixels classified differently in each date, or impossible transitions, such as a pixel of bare soil transitioning to dense forest in 5 years). It is worth remembering that spatial errors compound multiplicatively with data integration: two land cover maps of 90% overall classification accuracy, when overlaid for change detection, will yield a transition image whose accuracy may not exceed 81% overall.

Understanding and analyzing land patterns/change

Research in environmental anthropology focuses on multiple spatiotemporal processes of human-environment interaction. RS and GIS tools have the potential to aid in the analysis of causal, contextual, and cognitive realms of these interactions. Many anthropologists, particularly archeologists, are interested on the study of spatial patterns (e.g., the distribution of land cover and settlement classes across landscapes) and the processes structuring them.

One may seek to understand factors affecting land use decision making, and changes in population, environment, food supply, technology, and productivity relationships (Hunt 1995: 176-177). Land change studies are frequently concerned with the extent, direction and rate of land use/cover change across multiple units/scales of analysis (e.g., buffer zones, farm lots, settlements, community areas, indigenous reserves, municipalities, etc). Spatially explicit GIS models are frequently used to explore causal relationships (e.g., Roy Chowdhury 2006; Evans and Moran 2002), permitting the examination of space and time as variables in human-environment interaction. For instance, the distribution of cultural artifacts and/or land use patterns may be analyzed in relation to varying “bins” (classes) of spatial variables derived in GIS, such as concentric/nested zones of varying widths from a river, road or another feature of interest, distinct elevation classes, etc. Such secondary data are readily produced from primary spatial layers (e.g., elevation models, river networks) with basic GIS tools for distance and buffer generation and attribute data reclassification.

Historically, however, anthropologists have used RS and GIS to gain a comparative perspective of how these processes unfold in distinct social/environmental contexts (Reining 1979). This interest continues today, investigating complex questions regarding the location, association, and spatial-historical contexts within which human groups, settlements, biophysical resources, and infrastructure influence each other over time (Guyer et al 2007; Pinedo-Vasquez et al 2002; Hirsch and O'Hanlon 1995). Within such contexts, geospatial technologies can offer ancillary help (e.g., locating a village within a large region, or considering rural-urban areas). They also offer empirical datasets and analytical power (e.g., cross-referencing kinship alliances and the organization of territories, or assessing agricultural intensification/disintensification in the context of regional transformations).

Anthropologists concerned with environmental cognition are increasingly using geospatial tools to represent local environmental perceptions, local topology (designation of places/features and their interrelations), and symbolic meanings. Ethnoecological methods have long provided tools to relate etic and emic views of landscapes and land use systems, and understanding how social groups understand, materially and symbolically, their local and regional landscapes. These tools can range from ethnohistorical descriptions of landscapes, to ethnobotanical knowledge, and the construction of agricultural calendars and symbolic representations of territories. These methods, in conjunction with GIS and RS tools, can now aid in the development of classification systems, image interpretation, and resource mapping in general.

Concluding remarks: ethical issues, representation, and challenges in spatial-temporal analysis

The challenges of incorporating geospatial technologies in anthropological and social sciences have not been ordinary (Behrens 1994; Liverman et al 1998; Fox et al 2003; Goodchild and Janelle 2004; NAS 2007). While GIS/RS tools have enabled anthropologists to scale up their research from local to regional scales and engage with applied problems, they have simultaneously raised theoretical, methodological and ethical issues. Rindfuss and Stern (1998) summarized some of these issues within the social sciences as related to (sub)disciplinary differences in favored perspectives and variables, such as how to bridge ‘why’ questions about

the underlying basis of human behavior with those examining the manifestations of that behavior ('where,' 'when' and 'how much'). Another important challenge lies in reconciling alternate classifications of the environment emanating from distinct cognitive and cultural standpoints (Hirsh and O'Hanlon 1995).

Whether intentionally or not, RS and GIS convene different forms of representation of people and their landscapes, rendering some aspects visible and others invisible (Pickles 1995; Porro 2000; Turner and Taylor 2003). The nature of these problems can be related to the spatial, temporal, and spectral resolution of the data. For instance, while subtle land use systems (e.g., small-scale swidden agroforestry) can be difficult to detect and measure or mostly likely be identified as something else (e.g., fallow vegetation), clear cut deforestation may be readily apparent in an image (Brondizio 2004). This renders some aspects of land use of the same farmer visible, and others invisible, possibly leading one to draw very different conclusions from the same data. Likewise, the temporal availability of data (i.e., date of acquisition, quality and seasonality) may allow one to capture a particular set of activities (e.g., the growing season of a crop) or not (e.g., the fallow season).

Another dimension of the problem relates to the way different land use systems and social groups are classified/named. The categorical nature of land classifications inevitably mask some degree of internal variability (e.g., a general class of 'forest' may actually encompass several forest types). Nested classification systems and/or continuous indices of land cover, as discussed earlier, are important to address such problems. A related challenge in the development of classification systems is the mismatch between technical definitions of land use and cover classes (e.g., using parameters from vegetation ecology, forestry and agronomy) and the definition and conceptualization used by local stakeholders. Local populations tend to use multiple ecological and/or social criteria to describe landscape features, and are usually more cognizant of their heterogeneity. Robbins and Maddock (2004), for instance, demonstrate empirically how the selection of externally imposed expert classification vs. in-situ cover categories derived from local knowledge result in fundamentally different depictions of land cover in Rajasthan, India. They argue persuasively for recognizing the socially constructed nature of land covers, and that "...categories are theory-laden metaphors and occur epistemologically prior to any clustering algorithm" (ibid).

Additional ethical issues pertain to the sharing of data and knowledge, and the publication of sensitive information of high spatial/temporal detail. These challenges extend to broader uses of geospatial data, as highlighted in a publication of the National Research Council of the National Academy of Sciences (NAS 2007). Images and maps represent a form of power: selected sectors have access to that power (e.g., datasets), and fewer still have the ability to manipulate it (e.g., represent or transform them). Geospatial data can be used to assert one's territory over another, to formalize ownership, to show the distribution of valuable resources revealed by local knowledge, or to portray illegal activities or settlements which may endanger local people directly or indirectly. Thus, anthropologists and other professionals need to carefully consider their choices depicting and/or describing thematic classes, locations of particular features and social-ecological relationships. As maps and images can serve to assert power or as incriminatory "evidence", there is growing attention to the ethics of their publication.

To some extent, and for some areas, Google Earth and other internet sources may have rendered moot concerns over spatial data privacy. Anthropologists cannot assume that these data have a neutral quality, however. In the 1990s, a period of heated debate ensued between GIS practitioners and critics over the ethics of geographic information technologies and positivism in general (Schuurman 2000). This eventually led to improved collaboration between the two groups, more nuanced critiques, and the inception of Initiative 19 of the National Center for Geographic Information and Analysis (NCGIA) focused on the social and ethical dimensions of geographic information technology. Both Initiative 19 and the NAS report cited above provide valuable guidelines regarding ethical issues in geospatial technologies and GIS/RS research (NAS 2007), emphasizing, among other factors, data sharing and the protection of vulnerable subjects. The sharing of data should be an essential part of all phases of a research project using RS and GIS. Research questions should design participatory elements for greater local relevance, applicability and salience. Whenever possible, researchers should provide copies of relevant GIS databases as well, thus aiding local applications, management and empowerment. Wherever data sharing or publication are involved, professional guidelines pertaining to the protection of human subjects should be strictly adhered to^v to protect the confidentiality and security of sensitive information embedded in the data or at any level of analysis.

Finally, it is important that users understand clearly the trade-offs embedded in the type, use and manipulation of spatial data. This chapter provided an introductory overview of their use in Environmental Anthropology. This process requires collaboration and commitment to overcome the often steep learning curve involved with each stage of expertise development. The rewards, however, are worth the effort. In the context of global environmental change and the growing spatial and functional connectivity of landscapes, resource use systems, economies and social groups, RS and GIS will continue to assume a central role in human-environmental research.

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ⁱ The Landsat 1-3 WRS-1 notation assigns sequential path numbers from east to west to 251 nominal satellite orbital tracks, starting with number 001 for the first track. The Landsat 4 and 5 WRS-2 system notation assigns sequential path numbers from east to west to 233 paths numbered 001 to 233. Info on WRS1 and 2 can be found at: <http://edcwww.cr.usgs.gov/glis/hyper/guide/wrs.html>

ⁱⁱ Common supervised algorithms can be parametric or non-parametric depending on the statistical assumption about the normality of data distribution. Non-Parametric classifiers include spectral angle, Euclidian distance, parallelepiped, neural networks, among others, while parametric classifiers include maximum likelihood, ECHO (combines textural/spectral classifier and maximum likelihood), and tree classifiers.

ⁱⁱⁱ Accuracy assessment is based on “areas of reference” representing classes from your classification system; these areas are used to assess whether your classification performance is acceptable; a common reference to consider a thematic class as acceptable for most purposes is to present a classification accuracy above 85%. Kappa statistics (expressed in percentages) which represent a measure of omission and commission errors is the most standard measure of accuracy for thematic classifications (Janssen and van der Wel 1994).

^{iv} These descriptions emphasize “hard” classification procedures, i.e., each pixel is assigned to only one class. Algorithms to account for fuzzy membership and probability assignment are available, but require advanced technical expertise.

^v Among many techniques used to protect human subjects and hinder the manipulation of sensitive datasets are: data aggregation, substitution of names for IDs, protection of sensitive location and association between personal data and location, purposely misrepresentation of location and sampled units, among others.

Selected list of specialized remote sensing and GIS journals: *Photogrammetric Engineering and Remote Sensing; International Journal of Remote Sensing; Remote Sensing of Environment; Geocarto International; Canadian Journal of Remote Sensing; Remote Sensing Review; GIScience and Remote Sensing ; Cartography and Geographic Information Systems; International Journal of Geographical Information Science, Transactions in GIS, Journal of Geographical Systems, GeoInformatica*

Spatial Data Sources: A Sample of Sites of Interest

Key Places to Begin: contain both satellite images and other spatially explicit data

- Earth Explorer <http://edcns17.cr.usgs.gov/EarthExplorer/> or new Earth Explorer <http://edcns17.cr.usgs.gov/NewEarthExplorer/>
- GIS Data Map Studio <http://gisdata.usgs.net/>
- Global Land Cover Facility: <http://glcf.umiacs.umd.edu/index.shtml>
- Earth Resources Observation and Science (EROS) Center: <http://eros.usgs.gov/>
- Land Processes Distributed Active Archive Center: https://lpdaac.usgs.gov/lpdaac/get_data
- National Geospatial Program <http://www.usgs.gov/ngpo/>
- National Map Seamless Server <http://seamless.usgs.gov/index.php>
- USGS Global Visualization Viewer: <http://glovis.usgs.gov/>
- USGS Geographic Data Download: <http://edc2.usgs.gov/geodata/index.php>

Specific Raw Satellite Images:

- ALOS PALSAR: <http://www.palsar.ersdac.or.jp/e/index.shtml>
- LPDACC MODIS and ASTER data: <https://lpdaac.usgs.gov/lpdaac/products/>
- RADARSAT: <http://www.radarsat2.info/>
- SeaWiFS <http://oceancolor.gsfc.nasa.gov/>
- Spot Image, French SPOT Satellite Images <http://www.spot.com/>
- Quickbird/Worldview: <http://www.digitalglobe.com/>

Other Resources:

- Earth Observatory – Blue Marble: <http://earthobservatory.nasa.gov/Features/BlueMarble/>
- Landsat Program Info: <http://landsat.gsfc.nasa.gov/>
- NASA: <http://www.nasa.gov/home/index.html>
- NASA Earth Observatory: <http://earthobservatory.nasa.gov/>
- National Spatial Data Infrastructure: <http://www.fgdc.gov/nsdi/nsdi.html>
- Visible Earth: <http://visibleearth.nasa.gov/>

Spatially explicit datasets/information:

- Cartographic Boundary Files – U.S. Census Bureau: <http://www.census.gov/geo/www/cob/index.html>

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- FAO: <http://www.fao.org/>
 - Geospatial One Stop: <http://gos2.geodata.gov/wps/portal/gos>
 - GIS Data Depot: <http://data.geocomm.com/>
 - GIS Resources at IUB: <http://www.indiana.edu/~gis/>
 - Global Land Project: <http://www.globallandproject.org/>
 - International Human Dimensions Programme on Global Environmental Change: <http://www.ihdp.unu.edu/>
 - TIGER/Line Shapefiles – U.S. Census Bureau: <http://www.census.gov/geo/www/tiger/tgrshp2009/tgrshp2009.html>
 - UNEP/GRID: <http://www.grida.no/>
 - U.S. Fish and Wildlife Service Geospatial Data Inventory: <http://www.fws.gov/data/datafws.html>
 - USDA Geospatial Data Gateway: <http://datagateway.nrcs.usda.gov/>
 - The International Geosphere-Biosphere Programme (IGBP): <http://www.igbp.net/>

Digital Elevation Models:

- ASTER Generated DEM: <http://www.gdem.aster.ersdac.or.jp/index.jsp> ; <http://asterweb.jpl.nasa.gov/gdem.asp>
- Hydrosheds: <http://hydrosheds.cr.usgs.gov/hydro.php>
- Shuttle Radar topo/DEM data: <http://srtm.usgs.gov/index.php>
- Shuttle Radar Topography Mission Digital Terrain Elevation Data (DTED) · http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/SRTM_DTED
- Shuttle Radar Topography Mission Water Body Dataset · [http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/Shuttle Radar Topography Mission Water Body Dataset](http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/Shuttle_Radar_Topography_Mission_Water_Body_Dataset)

Regionally Specific Datasets:

- Brazil spatial and tabular data: <http://www.ibge.gov.br/>
- Indiana Geological Survey: <http://igs.indiana.edu/arcims/index.cfm>
- INPE (Instituto Nacional de Pesquisas Espaciais, Brasil) <http://www.inpe.br>

GIS/RS Software

- ArcGIS: www.esri.com
- ENVI: <http://www.itvis.com/ProductServices/ENVI.aspx>
- ERDAS IMAGINE/ER Mapper: <http://www.erdas.com/>
- Google Earth, free GIS software: <http://earth.google.com/>
- GPS TrackMaker: <http://www.gpstm.com/>
- GRASS: <http://grass.osgeo.org/>
- IDRISI: <http://www.clarklabs.org/>
- MapWindow Open Source GIS: <http://www.mapwindow.org/>
- Multispec (Purdue/LARS) <http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/>
- NASA World Wind: <http://worldwind.arc.nasa.gov/java/>

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- Open Source GIS <http://gislounge.com/open-source-gis-applications/>
 - PCI Geomatics: <http://www.pcigeomatics.com/>
- SPRING GIS Software: <http://www.dpi.inpe.br/spring/english/index.html>

Figure 1. Regional stratification approach.

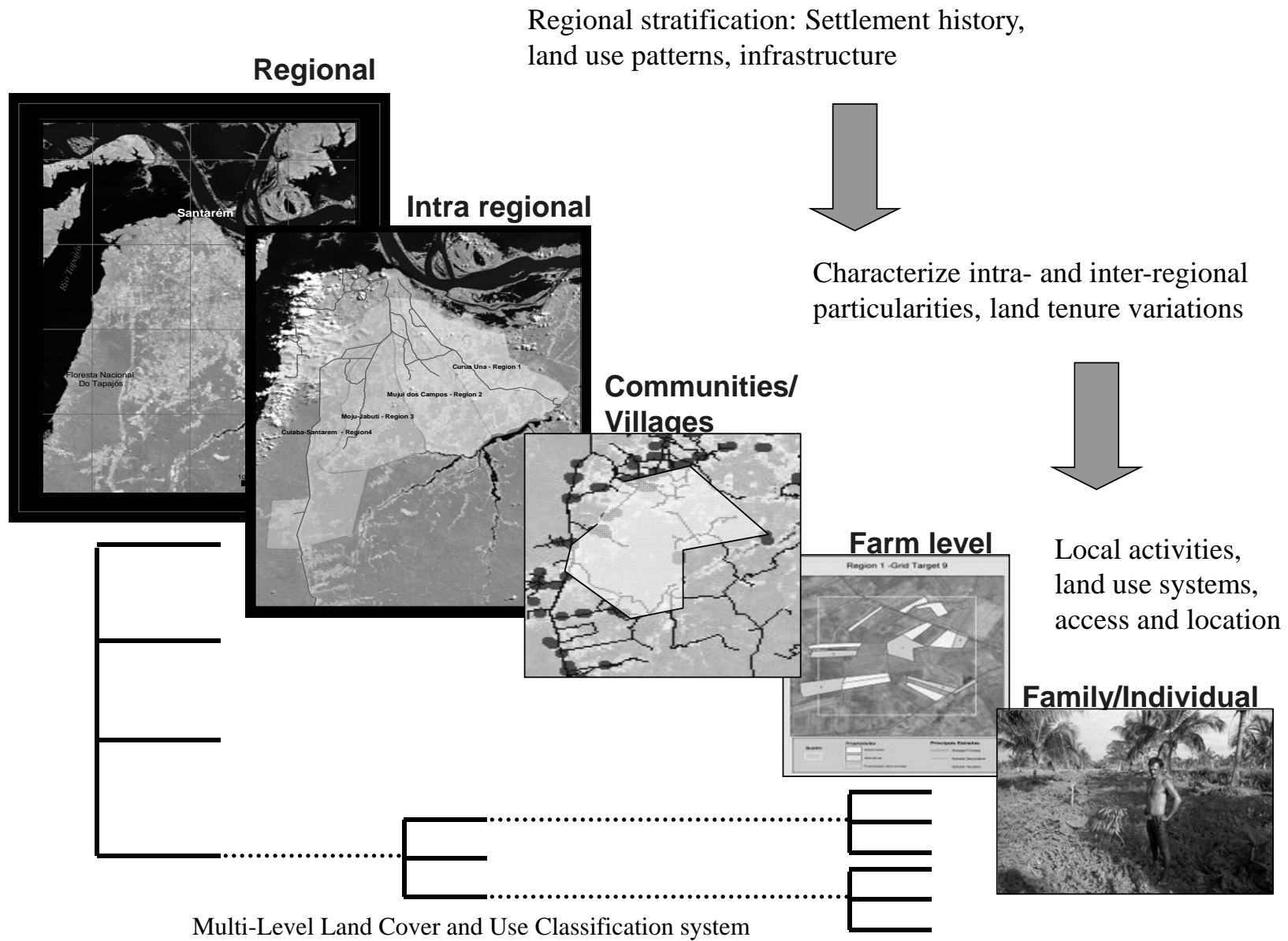


Figure 2. Steps in image/data search and research design.

1. Define study area name and location

(e.g., use UTM coordinates X and Y):

Latitude: from _____ to _____

Longitude: from _____ to _____

1.2 Find, select, and bookmark area using Google Earth, with overlays of roads, rivers, administrative maps and other relevant layers. Observe the regional topography and land cover, with particular attention to settlement patterns vis-à-vis land use and land cover.

1.3 Landsat WRS grid location:

WRS 1 (Landsat 1, 2, 3) Path____/Row____

WRS 2 (Landsat 4, 5) Path____/Row____

Quadrant (if applicable): _____

Data quality (e.g., cloud cover)

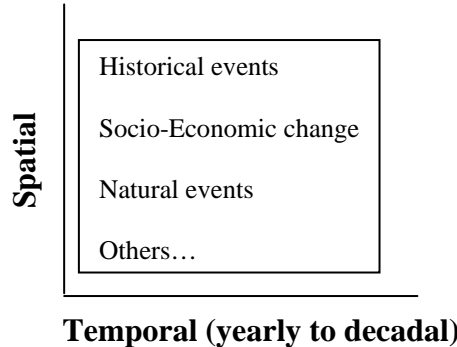
1.4 Identify other data/sensors:

Sensor (airflight mission, satellite and sensor)

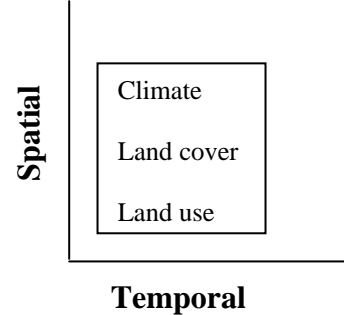
Data type (analogic or digital)

Format (if applicable)

2. Define a time-line of relevant events



3. Characterize seasonality and vegetation phenology



4. Graph or cross-tabulate 'IDEAL' sampling and IDENTIFIED available remote sensing data and maps in the context of each research question

Temporal resolution and data

(e.g. bi-yearly, Spring and Fall)

Spatial resolution and data

(e.g., Landsat TM, Path 20/Row 47)

5. Decide on data selection, refine/revise research questions according to available data (temporal sampling) and data resolution (spatial). Consider data temporal availability and spatial resolution to land use and cover spatial-temporal patterns, and define minimum mapping units and processing needs.

Figure 3. A general training guide for social scientists developing expertise in RS & GIS

