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The Use of Remotely Sensed Data in Rapid Rural Assessment

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The Use of Remotely Sensed Data in Rapid Rural Assessment

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This article discusses how analysis of remotely sensed data can be applied in rapid rural assessment and how its application can expand the spatial analysis of land-use/land-cover (LULC) change. It describes the methodological steps to carry out an LULC analysis based on Landsat Thematic Mapper image analysis under time and budget constraints. The article presents intra- and intercommunity comparisons of different LULC patterns. The discussion focuses on the trade-off between the desirable degree of land-cover class complexity, the level of class detail, and the required ground-truthing associated with each of these choices. The authors conclude that remotely sensed analysis can enhance short-term, low-budget fieldwork. Analysis of remotely sensed data can reduce costs before fieldwork by helping to inform where to concentrate data collection efforts, during fieldwork by extending spatial analysis to areas where accessibility is poor and that otherwise would not be included, and after fieldwork by improving the spatial and temporal scope of the analysis.

Anthropological studies have traditionally relied on participant observation and on long-term, local-based research as a fundamental research method (Bernard 1988). This methodological strategy has generated rich local data and has been adopted by a growing number of social science disciplines outside anthropology, wherein it originated. A number of drawbacks have been cited for this most conventional anthropological method: among them, a lack of generalizability due to the limited spatial coverage of the study area,

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resulting from the intensity of participant observation, and both budgetary and temporal inefficiencies (Chambers 1991). In the past decade, a number of techniques have been adopted in local analysis to make data collection on human use of the environment more efficient and spatially comprehensive.

Time constraints have been overcome through the approach commonly known as rapid rural assessment (RRA), a methodological approach that relies on short-term surveys carried out by a multidisciplinary research team.[1] In general, the time frame of RRA varies between two and eight weeks and includes prefieldwork activities such as archival research, contacting local officials, statistical data collection and interviews, and postfieldwork data analysis and report writing (Shaner, Philipp, and Schmehl 1982; Beebe 1995). Due to the short time frame and its focus on policy intervention, RRA has been called "problem-solving research" (McCracken, Pretty, and Conway 1988; Molnar 1989). As a dynamic strategy that relies on a large set of methods, RRA is flexible and can be reshaped to meet changing needs. For example, local knowledge has been integrated with RRAs through participatory techniques (Chambers 1991), while regional analysis of land use/land cover has been based on maps and aerial photographs, when available (Poole 1995).

Spatial limitations have been partially overcome by application of remotely sensed analysis. Remote sensing (RS) can be defined as any information obtained through a device located far from the studied area (Lillesand and Kiefer 1999). Imagery data are analogic or digital, collected by sensors that can vary according to the level of spatial, spectral, radiometric, and temporal resolutions needed. Spatial resolution is measured as the smallest ground area (pixel size) in which average reflectance values are acquired. Spectral resolution is the discernible range of wavelength in which data is collected. Radiometric resolution is the range of light reflectance each pixel can discern. Temporal resolution is the time a sensor takes to revisit the same site.

The idea for this article comes from reading a report in the journal *Science* (Roberts 1991) that pointed out the productive use of satellite images by a biology rapid assessment team. That work required them to provide a precise assessment of habitats suspected of being rich in biodiversity in areas under pressure from developers. They used the satellite images to plan their brief but intense fieldwork around existing habitats visible in the images and to plan the best routes for efficient sampling. The report noted that this linkage of satellite data to the work of a mammologist, an ornithologist, a botanist, and an amphibian specialist had yielded rapid and important results acceptable to conservation organizations and the academic community. The similarities between these conservation-minded ecologists and the work of social scientists in RRA was pretty evident, but when we began to look for cases of such an application, we came out empty-handed. When asking colleagues in anthropology and sociology about this lacuna, they offered stories of the high cost of the images, the high cost and technical difficulty of working with UNIX, the poor spatial resolution of some of the satellite data, and the skill required to learn RS and geographic information systems. All of these perceived obstacles, present at one time, have been largely overcome in recent years. Our experience in a study in Colombia provided us with an example that we felt could alert other colleagues to the potential of this type of analysis in combination with ethnographic and environmental field methods to address a number of persistent limitations faced by social scientists, especially those working with serious time and budget limitations.

During the 1970s, applications of RS data in anthropology included the use of aerial photographs to define land-use zones from the perspective of the local population (Conklin 1980) and the use of Landsat Multispectral Scanner (MSS) images to locate villages (Reining 1979) and archaeological sites. The limited use of RS until the late 1980s was mainly due to numerous constraints related to coarse spatial resolution (80 m × 80 m pixel size), limited computing capacity to handle the large data sets produced by satellite sensors, lack of trained personnel, and the high cost of image requisition and equipment.

The launching of the Landsat Thematic Mapper (TM) sensor in 1984 was a breakthrough for the use of satellite data by social scientists interested in environmental issues. The combination of a finer spatial resolution (30 m × 30 m pixel size) with spectral resolution of seven electromagnetic spectra improved the ability of researchers to discriminate variation of the land cover necessary to associate with human activities (land use).[2] Although high-resolution SPOT data (10 m panchromatic and 20 m multispectral) has offered excellent data since the mid-1980s, its spectral resolution, lacking midinfrared wavelengths, has limited its application to land-cover discrimination studies. Landsat TM (and MSS) larger archives have provided more options, especially in regions of constant cloud cover such as the tropics.

The advent of the global positioning system (GPS) in the early 1990s has made it possible to link spatially explicit ground information with satellite data at a fine scale. A major problem faced by social scientists working with land use among smallholders was the limited accuracy of civilian GPS due to selective availability (SA), a random error of up to 100 m (about 3 × 3 pixels in TM images), which was introduced in coordinate readings for reasons of U.S. national security. The errors could be corrected only by using more sophisticated methods, such as differential correction using data simultaneously collected by two separate devices. Recently, SA has been eliminated, and information obtained in the field today with inexpensive GPS devices can be accurate to 1–5 m.

The potential of satellite imagery techniques to overcome spatial limitations in social analysis is illustrated in publications such as the special issue of *Human Ecology* on regional approaches to the study of indigenous land-use change in the tropics (Behrens 1994), *Cultural Survival Quarterly*'s issue on participatory mapping or "geomatics" (Poole 1995), and the book *People and Pixels* on applications of RS in social science research (Liverman et al. 1998). However, anthropologists have been reluctant to use RS data mainly due to the perception that the technique is costly, expertise is scarce, and training is not available in most collegiate anthropology departments. This has now changed, and digital satellite data have become economically accessible.

Landsat MSS data can now be acquired at low prices or even for free.[3] A full scene from Landsat TM (185 km × 185 km) varies in price, depending on the region of interest, processing level, product format (photographic or digital), and date, but if we take the most recent data from Landsat 7, it is available at affordable prices for educational and research purposes (about $600). In short, cost is no longer a major obstacle to widespread use of RS in social analysis. While powerful and complex software packages for satellite image analysis (e.g., ERDAS Imagine) can still be expensive at some institutions that have not acquired licenses for large groups or labs, there is a growing number of software packages that are either low cost or free on the Web and that meet the basic needs required for image processing and land-use classification. Most software available today is user friendly, can run in personal computers, and rarely requires UNIX.[4] With such capabilities, using a reasonably up-to-date laptop computer, one can enter fieldwork observations, classify the image on the spot, assess accuracy on a daily basis, and plan the next day's work based on image analysis priorities, a fundamental principle of RRA.

Like the changing cost of equipment and software, expertise has also become more accessible to social scientists. Training in the application of RS techniques in the social sciences, in both individualized and group formats, is available at a number of universities, for example, Indiana University's Anthropological Center for Training and Research on Global Environmental Change; the Summer Institute offered by the Center for the Study of Institutions, Population, and Environmental Change at Indiana University; Boston University's Remote Sensing Laboratory; and the Center for Remote Sensing and Spatial Analysis at Rutgers University.[5] Therefore, while competence in RS techniques to analyze social processes demands thorough training, a basic knowledge that permits effective collaboration with more technically trained personnel has become a realistic alternative for anthropologists and other social scientists interested in the integration of satellite imagery techniques with other methods.

If the use of RS data in social science has been limited, it is even more so in RRA, where researchers believe the limited time availability to obtain field data does not support digital data analysis. However, recent experiences in other fields, such as ecology, have shown that there are shortcuts in RS analysis for short-term research, mainly when the research team is knowledgeable about the study area (Roberts 1991). In addition to the knowledge of the research team, social-based RS analysis can benefit from emic data such as knowledge of local users (see Moran and Brondizio 2001). Thus, while not a panacea, satellite data seem to be powerful tools that can extend the capabilities of an RRA team.

GOALS AND OBJECTIVES

The goal of this article is to show how RS analysis can be integrated within RRA using our research in a region of the Colombian Amazon as an example. We did not undertake research in that region as an RRA, but we faced similar time and budget constraints. The fieldwork was part of a much larger research project addressing how soil fertility (biophysical factors) and different types of land use (socioeconomic factors) affected the rate of regrowth of secondary successional forests following deforestation (Mausel et al. 1993; Brondizio et al. 1994, 1996; Moran et al. 1994, 1996; Moran and Brondizio 1998, 2001). When we started work in Colombia, we had already examined four other regions of the Brazilian Amazon, two of them relatively nutrient rich in soil fertility and two considerably nutrient poor. However, in the literature it had become quite evident that the most extreme case of very acidic, nutrient-poor soils occurred in the Rio Negro Basin, of which the Vaupés is an important tributary (Dufour 1981; Jordan 1982a, 1982b; Clark and Uhl 1987; Moran 1991). Thus, we felt compelled to examine these processes in the most extreme case of biophysical limitation, and one managed by an indigenous population distant from markets.

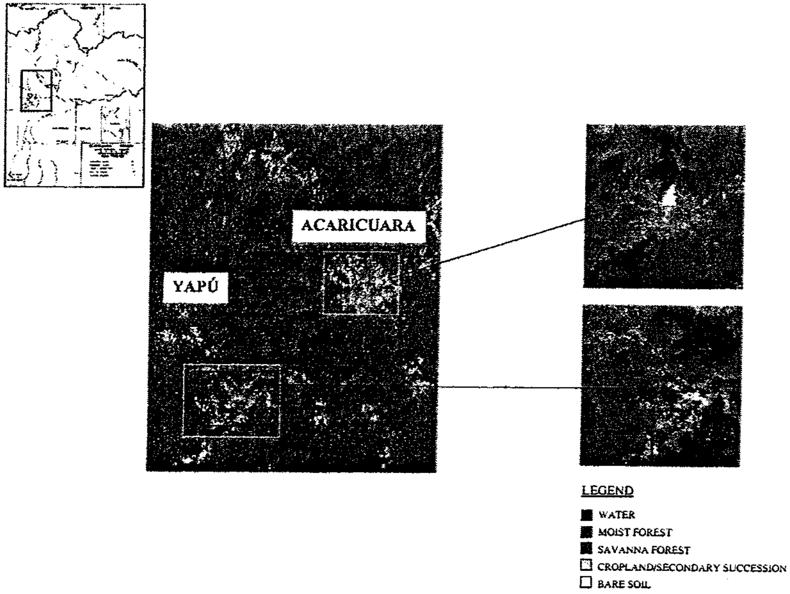
The white sandy spodosols of this region are associated with xeromorphic vegetation, resembling more closely a dry landscape than a tropical rain forest, despite more than 2,500 mm of annual precipitation. Human populations in this region historically have been able to live in the environment only by maintaining very low population densities, residing in patches that offer some production advantages (such as cataracts that facilitate fish capture), and by a complex system of regional hierarchy and mutualistic relationships between ethnic groups (Moran 1991, 1993). However, research in this region proved difficult. It was quite expensive to visit since it required contracting a private plane, and the time frame was limited due to logistic difficulties related to the degree of isolation of the study site (e.g., limited food supply) as well as security reasons (e.g., imminent guerrilla activity). Thus, while not an RRA, the goal of obtaining detailed field data on vegetation, soils, land use, and land-cover change faced the same limitations of time and funds often faced by RRA researchers. The on-site work accomplished in the Vaupés region was far from ideal. We were unable to collect as many training and soil samples or as complete a vegetation inventory as we had obtained at our other four sites. Nevertheless, despite this brief four-week effort by a team of only three persons, remarkably detailed examination of land-cover, land-use, and soil factors was achieved.

The use of RS allowed us to extend the spatial scope of our work to a rather large region that three people would have been unable to cover using conventional methods. Using RS analysis before going to the field permitted a focused research effort targeted at those aspects that seemed unclear from the unsupervised preliminary work, such as whether savanna vegetation was always associated with spodosols and whether the Tukanoan population ever used that type of land cover for crops and how its spatial distribution might affect their food production strategies. Furthermore, the use of RS as a preliminary way to define a sampling strategy allows a much more effective way to plan the limited time available for fieldwork to ensure spatial coverage of the environmental variability present in the landscape being studied. This is very difficult to do from a vehicle, where most of the landscape features may not be visible or may change substantially within a kilometer of the areas reachable by road. Our experience demonstrates that time and spatial limitations can be overcome, to a considerable extent, using RS data to provide basic land-use/land-cover (LULC) assessment at local and regional scales.

The use of remotely sensed images to elicit information from local people proved to be a very effective way to assist recall and to obtain a local perspective on biophysical phenomena that may not have been effectively gained in a purely verbal interview. It is beyond the scope of this article to provide a detailed discussion of RS analysis per se (for this matter, see Campbell 1996; Jensen 1996; Lillesand and Kiefer 1999; and more anthropological discussions in Moran and Brondizio 1998, 2001). The discussion in here is centered on introducing basic concepts, potential, and limitations of RS analysis, within the context of gathering data in short-term, low-budget social research and, more specifically, RRA.

FIGURE 1

Study Area: (A) Grey Scale of TM Landsat (January 1991) of the Study Site; (B) Classified Subset Images from A.1. Yapú and A.2. Acaricuara



STUDY SITE

We conducted this study in the village of Yapú in the Colombian Amazon (Vaupés region; see Figure 1). Yapú is in a blackwater region (Dufour 1981), located near the confluence of the Papurí River and the Yapú Creek. The region is located in a rolling terrain of isolated hills, with spodosols as a dominant soil type (Klinge, Medina, and Herreira 1977), characterized by very low fertility and high exchangeable aluminum content that reaches toxic levels for most crops (Alvarado 1982). Yet Wilshusen (personal communication to Warren Wilson 1993) found variations in soils with the presence of ultisols, oxisols, and spodosols in Yapú.

The climate of the region is humid year-round, with high levels of precipitation. In 1994, the total rainfall in Yapú was 2,515 mm, and the daily mean rainfall was 7 mm. The average maximum and minimum temperatures were 32°C and 23°C, respectively (Wilson 1997).[6] Moist forest and savanna dominate the region (RADAMBRASIL 1976; Klinge, Medina, and Herreira 1977; Prance 1978). Moist forest is characterized by tall trees, closed canopy, large lianas, and relatively sparse ground cover (Prance 1978). Savanna grows on spodosols, characterized by a litter deposit of partially decomposed organic matter, which in most cases is rich in fine roots found above ground (Klinge, Medina, and Herreira 1977). Savanna ranges from vegetation with canopy less dense than that of moist forest (high savanna) to areas dominated by grass cover growing on very acidic, low-fertility white sands (low savanna). Trees in high savanna are low in height and twisted, while trees in low savanna are laden with epiphytes.

The land-cover pattern of the Vaupés region has not experienced the environmental degradation common in other parts of Amazonia primarily because of its isolation and poor soils. The lack of roads and limited access by rivers with numerous cataracts are the major transportation constraints. In addition, the Colombian government returned large portions of the region to the indigenous inhabitants in 1989, limiting access to settlers in areas like the Yapú-Acaricuara region (Bunyard 1989). Yapú-Acaricuara is home to the indigenous group referred to in this article as Tukanoans (Dufour 1981; Wilson 1997). They subsist on swidden horticulture, fishing, and, to a lesser degree, hunting. More than 70% of their food energy comes from high-cyanide (bitter) manioc, while fish provide most of their animal protein (Dufour 1981). Manioc has traditionally been the most important product cultivated in the Upper Rio Negro region. The reliance on manioc, reflected in the more than one hundred named cultivars managed by the local population, has been explained as an adaptation to the chemically poor soils of the region (Chernela 1985a; Moran 1991; Wilson 1997; Wilson and Dufour 2002). In Yapú, manioc represents about 90% of the agricultural production (Dufour 1985). Other products are cultivated only where specific, suitable microenvironmental conditions are met (Wilson 1997).

In the 1960s, Catholic missionaries and government agents led many indigenous groups to abandon their longhouses in favor of individual houses for each family (Dufour 1981; Wilson 1997). A house-to-house census conducted by Wilson (1997) in Yapú in 1994 found a population of 196 living in thirty-two houses. A second village discussed in this article is Acaricuara, approximately 12 km northeast of Yapú. Acaricuara is a larger village with approximately 350 Tukanoan Indians (Metzger, personal communication to Warren Wilson 1994), with a large Catholic mission post and an airstrip large enough for a DC-3.[7] Acaricuara serves as the seat for a local indigenous-rights organization, Union Zona de Acaricuara.

Relations between the villages are congenial, and members of each community travel at least once a month to the other for various celebrations. A major difference between the two settlements may be related to the spatial distribution of vegetation types—moist forest and savanna—that are directly related to soil fertility. Patches of low-fertility soil (e.g., savanna) are irregularly distributed in the landscape, and their frequency directly affects access to cultivatable land. Therefore, only a spatially explicit analysis of LULC in the region can yield a better understanding of how the spatial distribution of natural vegetation influences the trends in land use in the region.

Researchers have conducted several studies in the Vaupés region (Goldman 1963; Hugh-Jones 1979; Dufour 1981; Clark and Uhl 1987; Chernela 1993; Wilson 1997). However, they have rarely addressed questions regarding the spatial pattern of LULC. Spatial analysis using conventional methods of analysis such as interviews, direct observation, and inventory is difficult. The Yapú-Acaricuara region is relatively isolated, has poor transportation infrastructure, and demands long-term fieldwork to cover any significant area. Large-scale maps of the region (e.g., 1:50,000 or larger), useful for the analysis of village-level processes, are not available due to national security on the Brazilian/Colombian border, restricting access to better maps of both sides. As a result, data available are either too coarse, such as the land-use description for the Vaupés region (Clark and Uhl 1987), or too fine, such as the detailed ethnographic studies of the Yapú community (Dufour 1981; Wilson 1997). In both cases, data are not spatially explicit enough to explore LULC patterns.

To unveil the role of soil fertility in defining spatial distribution of LULC classes, we developed a methodological strategy that provides a reliable picture of the regional patterns of land use compatible with short-term research. Three of the coauthors did one month of fieldwork in Yapú (July 1995) to acquire information to develop a classification of a TM satellite image of the area. In the next section, we discuss in detail the methodology we used and the problems we faced due to limited logistics.

METHODS OF ANALYSIS

The process of RS data analysis can be roughly divided into three stages, after one goes through the careful process of image searching and ordering: (1) preprocessing, (2) classification, and (3) postprocessing. Ideally, the satellite image should be of the same year or the same season as when fieldwork will take place. However, although temporal resolution of Landsat TM is sixteen days, environmental problems such as cloud cover, haze, and smoke limit the availability of appropriate images. The Upper Rio Negro is one of the highest rainfall regions in the Amazon, and, as expected, cloud-free images are limited. The most recent cloud-free image for our study site was of January 1991 (see Figure 1), and we did the fieldwork in July 1995.

Preprocessing

The preprocessing stage involves image preparation, including calibration, georeferencing, registering, and data transformation (creating new bands such as principal components analysis [PCA] and ratios). Image calibration is a technical procedure that involves a multistep analysis combining theoretical parameters and image-specific values related to the features of the sensor. Calibration includes radiometric and atmospheric corrections. The former corrects data distortion from the sensor by converting digital values of pixels into standardized radiance and reflectance values. The latter corrects value distortions due to atmospheric conditions at the time the image was taken. Image calibration is especially important to standardize pixel values across images from different dates for comparative purposes in multitemporal analyses. Since calibration is technically complex and time-consuming, and we did not intend to do a multitemporal analysis at that stage of the research, we decided to skip these procedures in our study, relying on basic calibration done by the data provider.

Georeferencing is the process of associating an image with a geographic coordinate system so that one can correct for geometric distortions and help to locate ground observation on the image. It is an essential step to integrate field observation in a spatially explicit fashion (ground truthing). Georeferencing can be done before fieldwork by using a cartographic map of the area. For this process, ground control points (GCPs) are collected simultaneously in both the map and the corresponding image. When reference maps are not available, GCPs of landmarks recognizable on the image are collected during the fieldwork by using a GPS device.[8] GCPs are then used to resample an image to the desirable coordinate system. In our study, georeferencing was not possible. Fine-scale reference maps necessary for our purpose (e.g., up to 1:100,000) were not available due to security restrictions imposed by Brazil and Colombia, and few ground control points were visible on the image due to the limited number of natural benchmarks in the region of continuous forest cover.

Another common step during the preprocessing stage is the registering of images from different dates when the research question involves multitemporal analysis. Through this process, images of the same area from multiple dates are combined into a stacked file. This procedure was not appropriate to our study since we were developing a classification for a single-date image. Finally, during the preprocessing stage, one can also use mathematic techniques to transform original image bands into derived values to enhance particular features in the image. Ratios of band combinations and PCA are among the most common techniques. Since we aimed at a basic classification of LULC classes, no band transformation was applied.

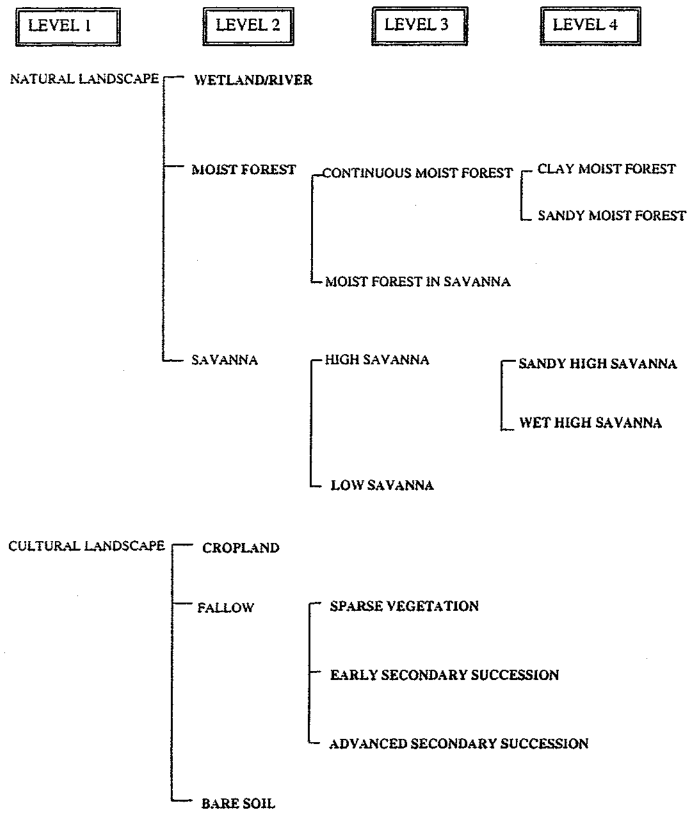
While we chose to skip some preprocessing procedures intentionally (calibration, registering, and data transformation), other procedures were not carried out due to logistic limitations (e.g., georeferencing). Therefore, the image classification demanded a more cautious definition of LULC classes to maintain a reliable level of analysis.

Classification

The classification stage usually involves a hybrid approach of combining unsupervised and supervised methods. Unsupervised methods rely on a multivariate statistical technique used to identify spectral groups or classes contained in an image (Campbell 1996). Spectral classes are translated into information classes (i.e., classes of features relevant to the research subject). Unsupervised classification offers advantages during the exploratory stage of digital image analysis because it can discriminate nonobvious spectral classes through statistical analysis, which is more difficult in conventional visual interpretation; adding previously collected information about the region can strengthen accuracy in distinguishing representative classes.

In this study, we initiated the unsupervised classification through a literature survey to learn about the ecological characteristics of the region. Subsequently, specific information on the Yapú-Acuaricuara region, such as vegetation types as well as location of gardens and settlements, was obtained through one of the coauthor's long-term experience with the Yapú community. Based on this information and our experiences in other studies, we developed a classification key listing classes to be distinguished (see Figure 1). The classification key was based on land-cover classes with land-use meaning but with distinguished structural components (e.g., vegetation height). Classes with lower human influence (natural landscape) and higher human influence (cultural landscape) were defined as a primary key level. A second level of classification subdivided natural landscape into wetland, moist forest, and savanna, and cultural landscape into bare soil, cropland, and fallow. The next levels described types of savanna (high and low, sandy and wet), and fallow (early and advanced secondary vegetation; see Figure 2).[9] Thus, classes focused on two major forest types related to soil fertility—moist forest and savanna—and three land-cover classes inferring land-use preferences and decisions of the population (bare soil, cropland, and fallow).

FIGURE 2
Key Used for Image Classification



We used the digital-image-processing software MULTISPEC 6.93 for Macintosh (Landgrebe and Biehl 1997) to run cluster analysis in several small image subsets. This is one of the software packages that is available free from the Web, is adequately sophisticated, and has user-friendly manuals online. Clusters interpreted as representative of a particular land cover listed in the classification key were saved as training statistics (reference spectral values with respective standard deviation, variance, and covariance). The suitability of cluster classes was evaluated by previous knowledge of the region, visual analysis (texture, pattern of distribution), and statistical distance test of separability (transformed divergence method). Transformed divergence is a multivariate method that measures the degree of overlap of each possible combination of classes. We aggregated selected clusters into land-cover classes, followed by a classification using a maximum likelihood classifier. The unsupervised classification served as the basis for a supervised classification after the fieldwork.

Supervised classification is a process of integrating ground data with digital information (ground truthing). It can be defined as the process of using samples of known identity from training samples (spatially explicit fieldwork data) or secondary data (maps, literature, or knowledgeable informants) to classify areas of unknown identity. Thus, fieldwork observation has a fundamental role in this process by increasing the reliability of the classification through integrating the observed variability of the land cover into the assigned classes. Training samples collected during fieldwork are incorporated in the statistical analysis to give a more realistic description of the classes. It provides an interactive process of checking and altering the classes previously assigned in unsupervised classifications. While supervised classification has the advantage of being controlled by the analyst, it faces a trade-off between detail and extent of the classification structure. A classification structure that is too detailed may be inconsistent with spectral groups/classes contained in the data (Campbell 1996). In addition, a classification is highly dependent on the quality, homogeneity, and representativeness of training samples. Therefore, a supervised classification is a continuous process in which the level of class disaggregation is traded off with the number and distribution of training samples.

As mentioned earlier, an essential step for ground truthing is georeferencing. Our lack of a georeferenced image in the field made ground truthing particularly difficult. The seasonal and four-year mismatch between the image and fieldwork dates created problems in locating classes that vary seasonally, such as wetlands, and classes that develop fast through time, such as secondary succession and cropland. Although limited by a nonreferenced image, knowledgeable informants were helpful in overcoming this constraint in ground truthing. The use of local knowledge to assess history of land use is essential to check past activities (Moran et al. 1994). We asked general information about the gardens in the settlement area and vegetation types in surrounding settlements. Once the informant became familiar with the image, he was consistent in his classification of land distribution, the history of land use, and type of vegetation. In this sense, local knowledge helped to solve both georeferencing and time-lag problems.

We compared the information on land-cover distribution provided by the key informants with the previous, unsupervised classification. Based on this analysis, we were able to check unknown classes. For example, "transitional vegetation," formerly defined as vegetation located between high savanna and moist forest, was locally recognized as "wet high savanna." Therefore, this class was maintained as it was ethnographically meaningful and spectrally separable. Similarly, cropland was consistently recognized in terms of spatial distribution and area. More ephemeral classes, such as secondary succession, were more difficult to acquire through ground truthing from local informants due to the dynamic nature of those classes. However, as the pattern and spatial distribution of sparse vegetation related to other cultural landscape units were confirmed by local information, we kept them for further analysis. Advanced secondary succession, on the other hand, presented an irregular spatial distribution pattern in some areas that could have been interpreted as earlier land use by other human groups, deciduous characteristics of some mature forest species at the time the image was recorded (giving a more open appearance than other parts of the forest), or just misclassification. Such an empirical question can be better explored in a more detailed study.

In short, input from local inhabitants enabled us to partially overcome the problems of limited ground truthing and to ensure classification accuracy. First- and second-level classifications could be checked with local informants, while the third level held a higher degree of uncertainty.

Postprocessing

The postprocessing stage mainly involves accuracy assessment and generation of statistical results, metrics (e.g., area extent of a given class), and thematic map printouts. The classified image is presented in Figure 1. We had more overlaps between continuous classes such as crop and early secondary succession, early and advanced secondary succession, moist forest and sandy high savanna, and wet high savanna and sandy high savanna (see Table 1). Yet the level of confusion was not surprising considering the expected gradient in the land-cover classes. As argued by Jensen (1996), overlapping values close to 1,700 are quite acceptable in transformed divergence terms.

The classified image provided information for both intracommunity and intercommunity comparisons of land-use patterns. Information gathered during the four-week fieldwork period was integrated into the image classification and enhanced our understanding of how the land is used in Yapú. We then extrapolated the classification to the Acaricuara community to understand how and why land-use systems can vary in the regional context. The analysis presented below focuses on spatial and proportional distribution of land-cover classes and is based on a subset of 8,154 ha (301 × 301 pixels) for each community (see Figure 1).

TABLE 1
Distance Values between Classes Generated by Unsupervised and Supervised Classifications

Class	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	—									
2	2,000	—								
3	2,000	**1,621**	—							
4	1,890	1,998	1,935	—						
5	1,920	2,000	2,000	1,989	—					
6	2,000	2,000	2,000	2,000	2,000	—				
7	1,999	2,000	2,000	1,976	2,000	2,000	—			
8	1,999	**1,755**	1,991	2,000	2,000	2,000	2,000	—		
9	2,000	2,000	2,000	2,000	2,000	1,948	2,000	1,890	—	
10	1,996	2,000	2,000	**1,716**	**1,748**	2,000	1,957	2,000	2,000	—

NOTE: 1 = wetland; 2 = early fallow; 3 = advanced fallow; 4 = moist forest; 5 = wet high savanna; 6 = bare soil; 7 = low savanna; 8 = crop; 9 = sparse vegetation; 10 = sandy high savanna. Distance values between classes were measured by a transformed divergence algorithm and generated from the image classification. Classes with values below 2,000 are statistically overlapped, but for our purpose, distance index above 1,800 was considered acceptable. The numbers in bold are below the acceptable index value of 1,800.

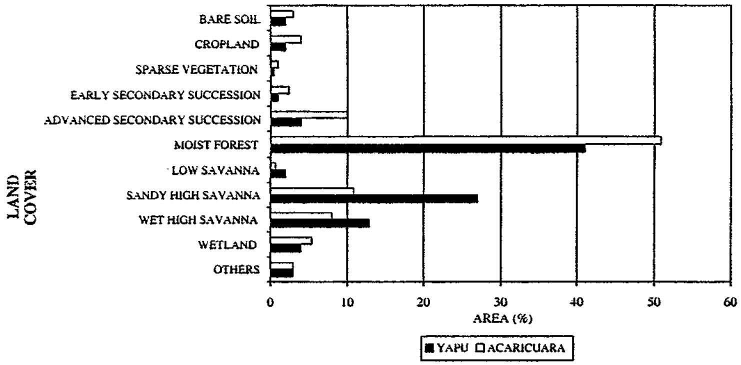
LULC ANALYSIS

Community-Based Analysis in the Yapú Settlement

The first-order classes—cultural landscapes and natural landscapes—are key classes needed to distinguish LULC patterns. While cultural landscapes provide information about the proximate human use of the natural system, natural landscapes provide information about the distribution of natural resources available for agriculture. In Yapú, the two classes of natural landscape—savanna and moist forest—present similar proportions (40% each), while the rest include all cultural landscape classes (see Figure 3). In particular, cropland encompasses approximately 197 ha, or an average of 1 ha per capita per year.

Savanna is particularly abundant in the settlement outskirts, constraining the land use in areas close to their houses (see Figure 1). The pattern of patchiness of savanna is a key factor in determining land use. According to informants, savanna soils are unsuitable for cultivation, and areas with this vege-

FIGURE 3
Distribution of the Proportion among Landscape Units in the Communities Studied



tation type are mainly used for hunting, extracting wood, gathering medicinal plants, and collecting roof thatch. On the other hand, moist forest has higher soil fertility that varies across three types: savanna moist forest (*monte de sabana*), sandy moist forest (*monte granitoso*), and clay moist forest (*monte greyoso*) (see Figure 1). Savanna moist forests are small patches of moist forest that occur inside large patches of savanna. Local residents consider this soil type the poorest among the moist forest types because fertility drops after two crop cycles. Sandy moist forest has a more fertile soil and can be used for manioc cultivation after many fallowing cycles, while clay moist forest represents the most fertile soil in the area and can sustain more nutrient-demanding crops, such as cocoa and maize, and produces higher yields of bananas and manioc.

Although sandy and clay moist forests did not show enough spectral differences to allow image classification, the combination of ethnographic data with visual image interpretation and soil analysis revealed that both sites are distinct in terms of access and availability of different soils. In general, sandy moist forests are located in the settlement and surroundings (community site) whereas clay moist forest is available further upstream along the Papurí River and Yapú Creek (upstream sites). Soil analyses of both sites revealed that upstream sites present significantly higher content of nitrogen and calcium and a higher pH due to lower content of aluminum (Wilson 1997). While most residents have gardens in the sandy moist forests located near the settlement, many also keep gardens in the more distant clay moist forests to benefit from higher yields of manioc and to grow a larger variety of cultigens (Wilson 1997).

The patchy distribution of the two soil types is reflected in the spatial distribution of the land used for gardens, in which garden size seems to increase with distance from the settlement. Smaller garden plots are located close within a 2-km radius of the community site, while larger garden plots are located beyond a 4-km radius (in the upstream sites; see Figure 4). In general, individuals reach closer garden plots on foot and the more distant plots by boat. The two sites, separated by a large patch of savanna, have different patterns of land use due to the time and energy needed to reach the garden plots. The presence of waterways creates a new opportunity to reach out to larger, distant agricultural sites where soil fertility is slightly higher. In other words, this pattern reveals how distance and access to plots play a role in agricultural activity, as previously noted by Dufour (1985), who observed that time allocation and energy expenditure are key factors in decisions about manioc production.

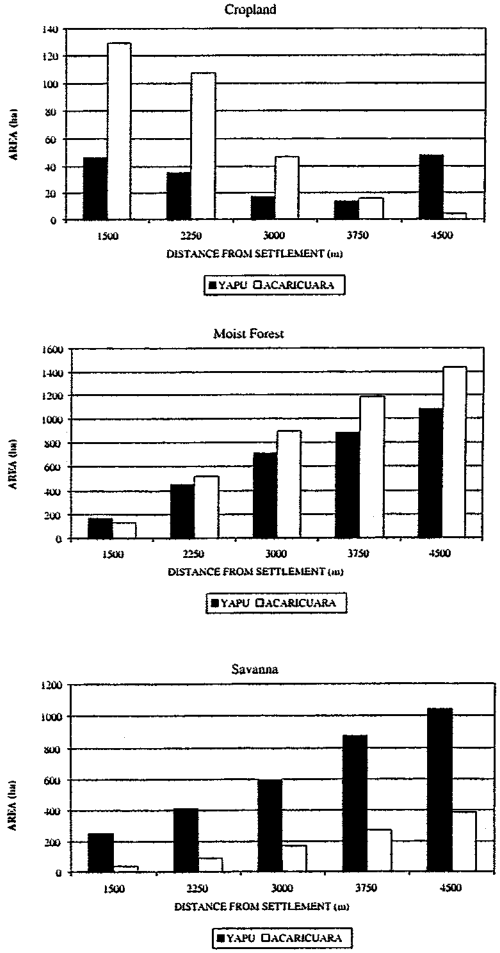
Although upstream sites yield higher manioc production than the community site (Wilson 1997), cropland has similar total area at both sites (see Figure 5), which are currently in use. A few remarks by local informants on property systems suggest that only some of the Yapú residents manage cropland at the upstream sites. Efforts should be made to determine why cultivated patches in the upstream sites are larger than patches in the community site and whether they are used by distinct groups of families reflecting hierarchy, age, or some other factor. Such an analysis may reveal features that influence different access and use of those two sites by specific households, as observed by Chernela (1985b) in regard to ownership of fishing spots in the Vaupés region.

In sum, land use and land cover in Yapú are strongly related to the presence of a savanna patch nearby as it spatially separates two major patterns—settlement site and upstream sites. To test the importance of such an environmental factor, we conducted a similar analysis of land use and land cover in the neighboring settlement of Acaricuara.

REGIONAL-LEVEL ANALYSIS

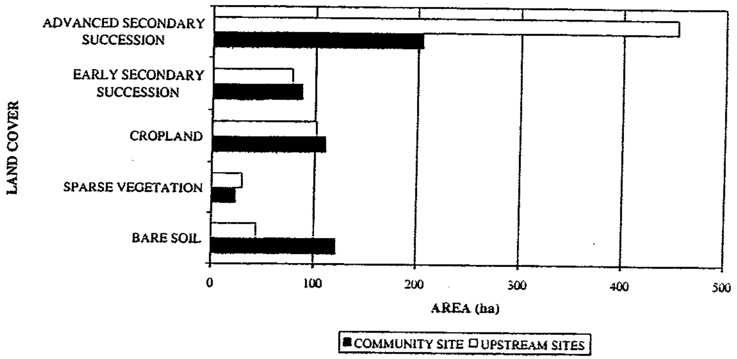
In addition to the analysis of land use on a community level, discussed above, the classified satellite image was extrapolated to a larger spatial scale. The reliability of such extrapolation was based on the assumptions that Yapú and Acaricuara share (1) similar cultural backgrounds and social organizations since they are part of the same ethnic group, (2) similar types of agricul-

FIGURE 4
Distribution of Cropland, Moist Forest, and Savanna in Nested Concentrated Area Covered from the Community Center



ture (e.g., slash-and-burn techniques and manioc crops), and (3) some similar ecological characteristics (e.g., same vegetation structure and soil type). Such assumptions are supported by researchers who are familiar with the region (including one of the coauthors) and by local informants. In addition,

FIGURE 5
Distribution of Cultural Classes in the Community Site and Upstream Sites of Yapú



the proximity of the two communities makes the extrapolation of the Yapú classification to Acaricuara more tenable (see Figure 1).

Holding those variables the same, aspects related to landscape structure can be compared. Despite similar ecological characteristics, the spatial distribution of vegetation and soil fertility are quite different (see Figure 1). Therefore, the classification of the satellite image can provide a better understanding than conventional methods of how distinct spatial distribution of ecological opportunities and constraints affect the LULC pattern. Interestingly, the proportion of cropland in Acaricuara is similar to that in Yapú. The 356 ha of total area of cropland in Acaricuara (compared to 197 ha in Yapú) is proportional to the population size of approximately 350 inhabitants (compared to 196 residents in Yapú). Thus, production area is the same per capita—approximately 1 ha per person per year.

While similar in its area of manioc, the distribution of the area in natural landscape is strikingly different. Moist forest is more common in Acaricuara (51%, compared to 41% in Yapú), whereas savanna (including low savanna, sandy high savanna, and wet high savanna) is half as frequent (20%, compared to 42% in Yapú) (see Figures 3 and 4). This difference in proportions is coupled with a very different spatial distribution of these two vegetation types, which seems to play an important role in the land-use pattern in each community.

Yapú is characterized by occupation along the waterways and irregular penetration into the forest according to the pattern of fertile soils (e.g., moist forest) and infertile soil (e.g., savanna patches), whereas Acaricuara presents a more regular elliptical shape expanding outward from the settlement (see Figure 1). As a result, the average distance of gardens from the settlement is lower in Acaricuara, mainly within a 2-km radius (see Figure 4). A more detailed analysis of land ownership and social relationships with the neighboring communities would help clarify the implication of garden distance from the settlement with regard to the boundaries of other settlements. For example, the more distant plots belonging to Yapú residents are probably close to other communities on both sides of the river and stream, whereas Acaricuara residents seem to maintain greater distances from neighboring communities.

The comparison between Yapú and Acaricuara presented above shows that differences in the distribution of ecological opportunities and constraints that would have required long-term fieldwork can be detected in short-term fieldwork through the analysis of satellite images. The satellite image research also yields information that raises questions for further investigation, at both community and regional levels.

DISCUSSION

This article demonstrates the ability of RS analysis to enhance the understanding of LULC patterns in short-term fieldwork. The research had three stages. During the prefieldwork stage, unsupervised classification of the satellite image provided a preliminary understanding of the Yapú environment and land-use patterns and enabled us to generate questions regarding these issues. This stage was particularly important to provide basic information on the spatial distribution of LULC classes. It helped us plan the data collection and directed our sampling, important issues in short-term fieldwork research. During fieldwork, determining different landscape classes in the satellite image greatly enhanced our understanding of the Yapú environment and land-use patterns and facilitated elicitation of information from the indigenous population. Finally, during the postfieldwork stage, supervised classification determined the abundance and spatial distribution of different LULC classes in Yapú and the garden areas. Extrapolating from what we learned in Yapú, RS analysis also generated useful information for the neighboring village of Acaricuara to provide a broader comparative regional LULC analysis. Several differences were noted between the villages, and preliminary explanations were offered for these differences. In short, this study reveals that some of the weaknesses of conventional, short-term research may be partially overcome with the use of RS data. Specifically, RS enabled a rapid understanding of the regional distribution of LULC classes that would not have been possible through conventional RRA methods.

TABLE 2
Comparison of Methodological Strategies Taken in Anthropological Studies

	Conventional Anthropological Methodology	*Rapid Appraisal*	*Remote Sensing Application*	*Yapú*
Spatial scale	Micro-meso	Micro-meso	Meso-macro	Meso
Class detail	High	Low	High	Medium
Budget	Medium	Low	Medium	Low
Fieldwork time	Long	Short	Long	Short

As a new technique in the repertoire of methods in social science, RS can influence four aspects of research: spatial scale of analysis, detail of the analysis, budget, and fieldwork time. Historically, the conventional methodology of participant observation has provided highly detailed information at a community level when carried out in a long-term framework. Despite the detail of analysis that can be generated, this approach is time-consuming, economically inefficient, and restricted to local processes that limit comparison and generalization.

The development of new methodological techniques such as RRA has dropped the cost of the research budget and the required fieldwork time. Although this approach is not designed to address questions in detail, it can provide a general overview of the system to raise questions to be pursued on a long-term basis. This article suggests that classification of satellite images can enhance RRA case studies in terms of spatial coverage and by directing sampling and field efforts to environmental variables identifiable in advance through the RS imagery. However, the reliability of an image classification is a function of the balance between time frame, spatial scale, and classification detail desired. If a short time frame is a key characteristic of the methodology, either spatial scale or the level of the class detail may be sacrificed (see Table 2).

In particular, two factors play important roles in defining the level of detail of an image classification in short-term research: (1) the ground-truthing limitations and (2) the complexity of LULC patterns. Ground truthing can be hindered by georeferencing or mobility constraints, namely, the research team size or access limitation (lack of roads or stream channels).

In this study, we have partially overcome this problem by using local knowledge. However, the use of local knowledge has drawbacks when applied only qualitatively. A more appropriate approach should include cross-checking information among different groups (such as gender and age categories) to measure the variability of perceptions. In addition, informants should first be trained to interpret image features (scale, color, texture), and their information accuracy should always be checked through direct field observation. If it is possible to compare local information with controlled training samples, an accuracy test can strongly improve the methodological value of ground-truthing techniques. This approach should be strongly considered when distinctions of LULC classes is complex.

The relatively homogeneous LULC pattern found in the Yapú-Acaricuara region, based mainly on manioc cultivated through slash-and-burn techniques, has made it possible to accept a simplified classification since the data extracted were limited to quantification of production areas primarily in manioc and the role of two major vegetation types in the land-use pattern.

Any further detail in the analysis depends on a more accurate ground-truthing strategy. Despite the usefulness of the analysis, the present classification is by no means free of problems. For example, the high proportion of advanced secondary succession in the Yapú area should be cautiously analyzed as it could be a result of misclassification, an old occupation in the area, or devastating fires in the past, as suggested by Sanford et al. (1985) and Saldarriaga and West (1986) for other areas in the region. In addition, culturally relevant classes that were apparent in the ethnoecological survey but for which we did not detect spectral differences remain to be improved. Those issues remain for future research.

In sum, the most appealing value of the RS data in RRA is to enhance the spatial analysis (see Table 2).[10] The patchiness of soil distribution was the main scale-related issue raised in this case study. Our analysis revealed distinct patterns of soil distribution in Yapú and Acaricuara. Clark and Uhl (1987) assumed a proportion of 20% of soil available for cultivation in the Venezuelan Upper Rio Negro region. Through the classification of the vegetation, which is directly related to soil quality, our estimation of available soil for cultivation varied in the two communities from 50% in Yapú to 90% in Acaricuara in an area totaling 100 km^2. In other words, regionwide statements on LULC issues can be made more precisely by using RS analysis than by using conventional methods in social science. Even in two proximate communities, the availability of cultivable soils can differ in significant ways that can result in different population densities, if not different resource-use strategies altogether.

CONCLUSIONS

Remotely sensed data analysis is a promising tool in linking local and regional levels of analysis. The involvement of social scientists with regional analysis and RS data has opened an important area for issues related to monitoring environmental change. Besides increased spatial extent, statistical analysis of digital images is also helpful for studies carried out under time and budget constraints, such as RRA.

The advantage of using RS analysis in RRA is threefold, as it fits in the model of three stages: prefieldwork, fieldwork, and postfieldwork activities. During the prefieldwork stage, it improves the cost and time efficiency in planning temporally limited fieldwork by revealing spatial patterns that should be the focus during the fieldwork, especially in areas where availability of spatial data is low. During the fieldwork, RS helps to extend spatial dimensions of analysis where accessibility is poor. Finally, in the postfieldwork stage, it improves the spatial and temporal horizon in defining priorities for further investigations.

The application of RS analysis is not, by any means, free of technical problems. This article shows that technical problems posed by lack of referenced maps and lack of natural benchmarks limited the ground truthing and accuracy test, two major features of RS analysis. We demonstrated how LULC analysis could be completed under those constraints by privileging local informants' knowledge, and we believe that had we not faced those problems, we could have provided a more detailed analysis. Thus, the process of classification in RRAs should start with an assessment of material available for the image preprocessing stage, followed by an analysis of the diversity of land use and the environmental and cultural variability of the region, to later define the detail of the classification and the extent of ground truthing. This initial evaluation can give an appropriate level of classification for a given study. In this regard, support from trained personnel is fundamental to make the classification process more efficient and reliable. Many problems can arise in each step of the process, and any attempt to solve a problem without proper training can result in misleading results. Yet the collaboration with a person trained in RS techniques is more efficient when the technician has at least a minimal social background, as well as when the social investigators have at least a minimal RS background.

The applications of RS analysis in social science have evolved rapidly. In only ten years, problems of spatial scale and detailed analysis have been overcome. The development of methods to help overcome the limits of short-term fieldwork is in its infancy. This article is an attempt to show the feasibility of combining a powerful technique not previously used in rapid appraisal with environmental monitoring approaches.

NOTES

1. Rapid rural assessments emerged to solve three problems faced by social scientists in the design of development projects: (1) to fill information gaps that top-down approaches had overlooked, (2) to reduce the fieldwork time frame to stay within budgetary constraints, and (3) to provide policy recommendations in a timely fashion (Khon Kaen University 1987).

2. A pixel size of 30 m still may not be able to discriminate land-cover features related to smallholder activities. For example, cropland size below 1,200 m^2 may be in mixed pixels that include both cropland and other classes such as bare soil, fallow, or forest.

3. See the Internet homepages of EROS (http://edcwww.cr.usgs.gov/) and NASA Pathfinder Project (http://xtreme.gsfc.nasa.gov/pathfinder/path_sites.html).

4. One of the most widely used packages is IDRISI from Clark University, available at a cost of less than $500 (lower for students and citizens of developing countries). IDRISI performs basic and advanced data-processing and spatial data analysis procedures. Another software product, MULTISPEC, developed by Purdue University, can be downloaded free from the Web (http://dynamo.ecn.purdue.edu/~biehl/multispec/) for Windows and Macintosh platforms.

5. See the Anthropological Center for Training and Research on Global Environmental Change at http://www.indiana.edu/~act/, the Center for the Study of Institutions, Population, and Environmental Change at http://www.cipec.org, the Boston University Center for Remote Sensing at http://www.bu.edu/archaeology/centers/crs.html, and the Center for Remote Sensing and Spatial Analysis at http://deathstar.rutgers.edu/.

6. Data collected between 26 January 1994 and 25 January 1995.

7. Yapú has a small airstrip, built in the late 1970s, that is suitable for single-engine planes.

8. In either case, the points must be spread over the image; otherwise, spatial distortions can be generated.

9. Further distinctions resulted from the ethnoecological survey conducted in the field with informants when they checked the unsupervised classification developed in the lab.

10. When multiple-date images are available, analysis of land-use/land-cover change is also possible.

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