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Land-Cover Assessment of Conservation and Buffer Zones in the BOSAWAS Natural Resource Reserve of Nicaragua

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ABSTRACT / The BOSAWAS Natural Resource Reserve of Nicaragua was established in 1991, to protect a portion of the remaining tropical rain forest and to promote the sustainable use of the region's resources. Information required to effectively manage the reserve includes the extents and locations of present land-cover types and recent land-cover changes in the management use zones that were delineated by local indigenous communities. These zones include areas designated for conservation, limited resource extraction, agriculture, and watershed protection. Land-cover for 1986 and 1995 was identified for three of the communities from remotely sensed images and then input into a geographic information system database to identify land-cover types within these management use zones. For both dates of the analysis, advanced forest was the dominant land cover, with the conservation zones entirely forested. The amount of both agricultural land and scrub/early secondary forest increased between the two dates, with much of these land-cover classes occurring in the agriculture zones. Conflicts between the land-cover present and designated use were identified in some of the limited-use buffer and watershed protection zones. Changes between 1986 and 1995 were identified by overlaying the two land-cover data sets. Three change processes were identified as occurring: deforestation, reforestation, and reconversion. Changes were concentrated in the agriculture zones but were found to occur in every type of zone, except for conservation. The results of this study will establish baseline information for the future management of the BOSAWAS Reserve, an important component in uniting conservation areas along the Central American isthmus.

In recent years, concern about the deforestation of tropical forests has led to increased interest in assessing and conserving the forest that remains (Downton 1995). Conserving tropical rain forests is highly problematic, because most of the remaining tropical rain forest is located in developing countries, whose rural areas are often quite impoverished. Also complicating conservation efforts is the fact that areas of high biodiversity, where protection is most critical, are often areas where indigenous peoples still reside and maintain their culture (Dasmann 1991, Chapin 1992). The result is a balancing act between conservation goals, economic development, and local self-determination. Such balancing is increasingly being met by creating protected areas that set aside portions of land for conservation, while incorporating economic development projects and local control of resources (Wells and Brandon 1993, IUCN 1994, Alpert 1996, Zimmerer and Young 1998).

Traditionally, protected areas were in the form of national parks, which involved drawing a fixed boundary around an area and focusing management efforts within the designated area. The goal was to create an area free of human influence and thus often involved the eviction of local peoples (Stevens 1997). In contrast, many newly established protected areas, known as nature reserves, involve focusing management efforts outward from a boundary, incorporating core conservation areas and protective buffer zones that serve to limit impacts in the core, while allowing for sustainable resource utilization (Hales 1989, Castro and others 1995, Miller 1996). Another goal of the buffer zones is to incorporate the needs of local peoples into the management process, so as to gain their support (Wells and Brandon 1993). Public participation of local peoples in reserve planning and management has been found to promote environmentally sound development, by introducing a broader range of solutions and reducing the potential for serious conflicts (Saunier and Meganck 1995, OAS 2001). A key component in the success of public participation has been the sharing of information in a transparent planning process, thus transcending the people versus park paradigm (Zimmerer and Young 1998).

One reserve incorporating the core–buffer model and local participation is the BOSAWAS Natural Resource Reserve in Nicaragua, which encompasses 7300

KEY WORDS: Protected areas; Conservation; Land cover; Land use; Remote sensing; Nicaragua

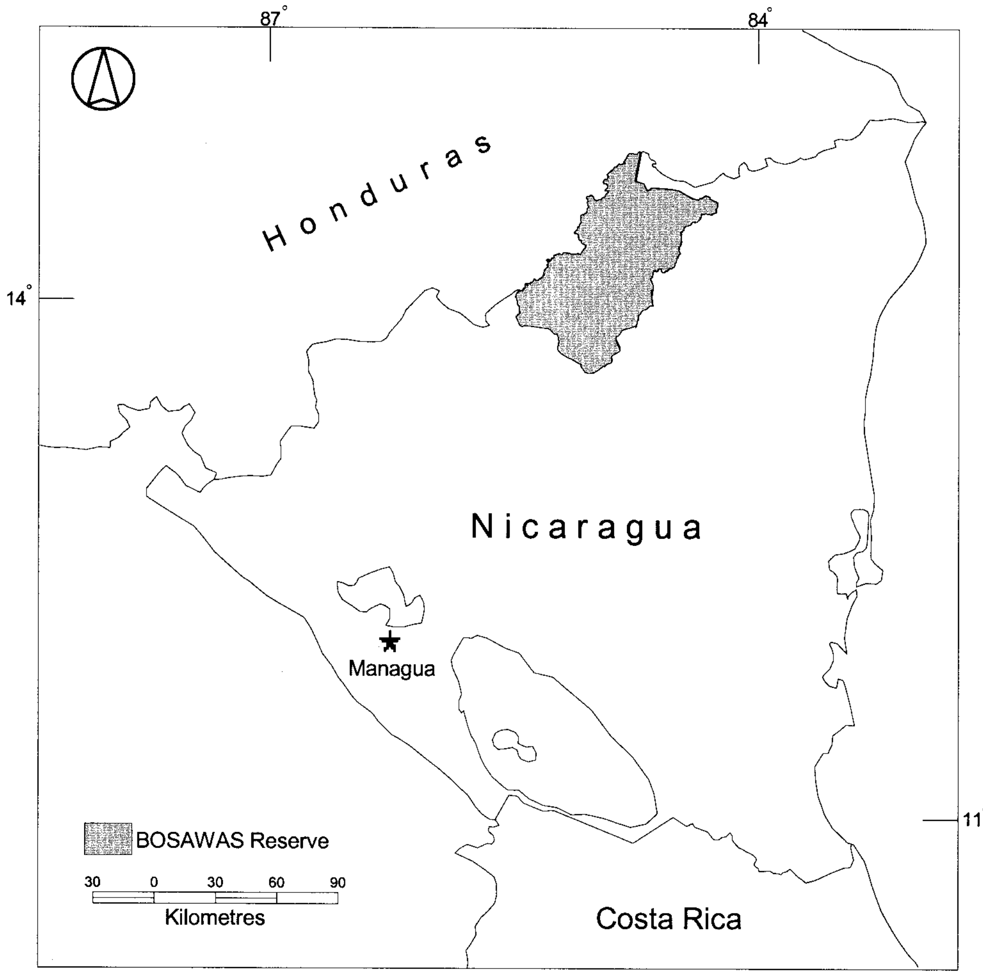

Figure 1. BOSAWAS Natural Resource Reserve of Nicaragua.

sq kms, including portions of the largest remaining stand of tropical rain forest north of the Amazon basin (Stocks 1994) (Figure 1). The reserve contains the largest concentration of valuable mahogany (*Swietenia macrophylla*) remaining in Nicaragua and is home to many threatened species, including jaguar (*Panthera onca*), mountain lion (*Felis concolor*), ocelot (*Felis pardis*), and macao (*Ara macao*) (Stocks 1994). As part of the reserve's management plan, local residents and government officials divided it into a number of management use zones, delineating the activities allowed in each.

The goals of this study are to assess the compatibility of the delineated management use zones of the reserve with the land-cover types present, as well as identify possible threats to the core conservation area by analyzing land-cover changes. Locations of agricultural plots and secondary forest patches within an older forest matrix, signifying human alteration of the landscape, were identified in the various management use zones for two time periods: 1986 and 1995. It should be noted that this study was conducted before Hurricane Mitch devastated the area in 1998. No major natural disturbance had occurred in the area for many years before this study; thus all land-cover alterations in the area were assumed to be caused by human actions. Identifying such alterations will aid in the management of the BOSAWAS Reserve, an important component uniting the proposed Meso-American biological corridor (Illueca 1997). In addition, this land-cover analysis will help conservationists understand the forces impacting tropical forests, while developing methodologies promoting comprehensive nature reserve planning.

Study Area

The BOSAWAS Natural Resource Reserve was created in 1991, in response to a large influx of mestizo

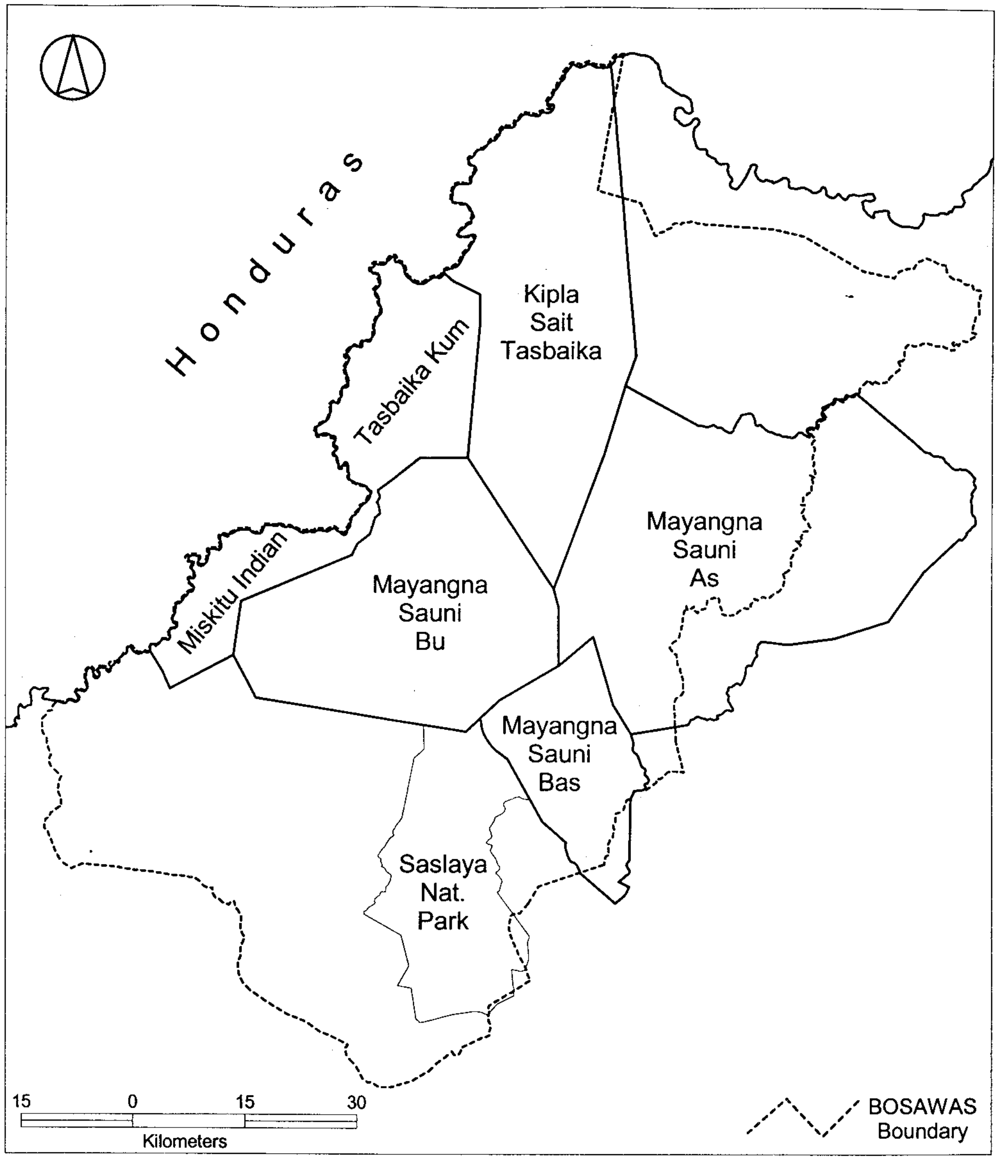

Figure 2. Indigenous community claims of the BOSAWAS region.

settlers, who were moving into the area at the end of the Nicaraguan civil war. Mestizos are descendants of European colonists and native Americans who originally settled in the western half of the country, but who have been moving eastwards in search of new lands to occupy. Conservationists were alarmed by this influx, because of the propensity of these new settlers to clear large areas of forest for cattle pastures. The reserve was created to prevent such wide-scale deforestation and promote the sustainable use of the region's resources.

When the reserve was created, local peoples were not consulted, even though it contains the formal territorial claims of five indigenous communities (Figure 2). These communities are made up of two indigenous groups, the Miskito and the Mayangna, both of whom have been seeking to obtain title to the lands they utilize and thus retain control over their ancestral lands and resources. Both peoples reside along the river valleys in small villages, or individual settlements, practicing swidden, or slash and burn agriculture. Major crops include corn, beans, rice, and yucca. All five of the communities under study are relatively isolated, possessing no roads and relying on dugout canoes for transportation and trade. Population numbers in the early 1990s varied from 500 for Mayangna Sauni Bas to 3400 for both May-

Table 1. Indigenous land use management zones

Land use zone	Purpose
Agriculture	Grow crops and graze domesticated animals
Gold panning	Pan for gold deposits in stream beds
Watershed protection	Protect water supplies near villages
Frequent use	Hunting, gathering and selective logging
Infrequent use	Limited hunting and gathering
Conservation	Ecological preservation
Saslaya National Park	Ecological preservation

angna Sauni As and Kipla Sait Tasbaika (Stocks 1998, Stocks and others 1998).

Potential conflicts between reserve management officials and the indigenous residents were reduced by incorporating the communities into the reserve's planning process. This incorporation was best exemplified by having the communities develop land-use zoning plans compatible with the reserve's conservation goals. The various zones designate the range of human actions allowed in each (Table 1), with most of the conservation zones designed to form a contiguous centralized core, with surrounding buffer zones (Figure 3). Conservation zones designate areas where no resource exploitation will be conducted, limiting human incursions to research, education, and low impact tourism. Local peoples will benefit from these areas as they replenish game populations that are hunted in the buffer zones. The conservation zones, in conjunction with Saslaya National Park, will form the core conservation area of the reserve (see Figure 2).

Also delimited were agricultural zones, delineating those areas devoted to growing crops and grazing livestock. These zones generally encompass the valleys of major rivers. They are relatively large in size and include a wide range of land-cover types, because only a small percentage of the zone will be utilized for crops at any one period of time. Plots would be used for a couple of cropping cycles before they become infertile, with the farmers then abandoning them and clearing new plots. This cycle results in the river valleys being made up of a mosaic of crops and pastures, along with secondary and mature forests.

Between the agricultural zones and the conservation areas, buffer zones of frequent and infrequent use were established, with the purpose of providing areas for hunting, traditional gathering, and selective timber harvesting, while protecting the ecological functioning of the conservation zones. Frequent-use zones are designated for daily or weekly use, while infrequent-use zones would be utilized far less intensively, for example, during droughts or special events. Land cover in these zones will generally be maintained as advanced forest, but selective logging would be allowed in the frequent-use zone, resulting in secondary forest being found in the gaps created by tree harvesting.

In addition to these four major zones, two specialized zones were also created. Watershed protection zones were designed to ensure that water supplies near villages were not contaminated by increased sedimentation or by herbicides and pesticides, which are often used on the agricultural plots. Forest cover has been found to ensure stream quality by reducing sediment transport and filtering out pollutants, hence no agriculture, or timber harvesting would be allowed in these zones (Peterjohn and Correll 1984). Watershed protection zones require intensive monitoring, because they are often in high demand for agricultural plots due to their close proximity to villages. Gold panning areas, the other specialized zone, were delineated around streams with known gold deposits to allow for their exploitation. As with the watershed protection zones, advanced forest will be maintained in this zone, but clearings would be established along the rivers where the gold is extracted.

Methods

Information required to assess the delineated zones and actively manage the BOSAWAS Reserve includes the amounts and distribution of land-cover types, as well as recent land-cover changes. Such information will allow an assessment of the reserve's resources and identify possible threats to its conservation goals. The only practical method to gather land-cover information over such a large, isolated area is to utilize remotely sensed images. While remote sensing is a critical component of comprehensive land-cover analyses, acquisition of the necessary images in the tropics is hampered by the prevalence of cloudy conditions, which makes many images unusable.

Preliminary plans for this study called for the use of four Landsat thematic mapper (TM) images, two acquired in the mid-1980s and another two acquired in the mid-1990s. However, examination of the candidate images revealed a large amount of cloud cover on many images, limiting their usefulness. All of the TM images acquired during the 1980s were of insufficient quality, as were most acquired in the 1990s. Due to a lack of cloud-free images, management use zones for the two western communities (Miskitu Indian Tasbaika Kum and Mayangna Sauni Bu) had to be dropped from this study. In order to analyze the three remaining commu-

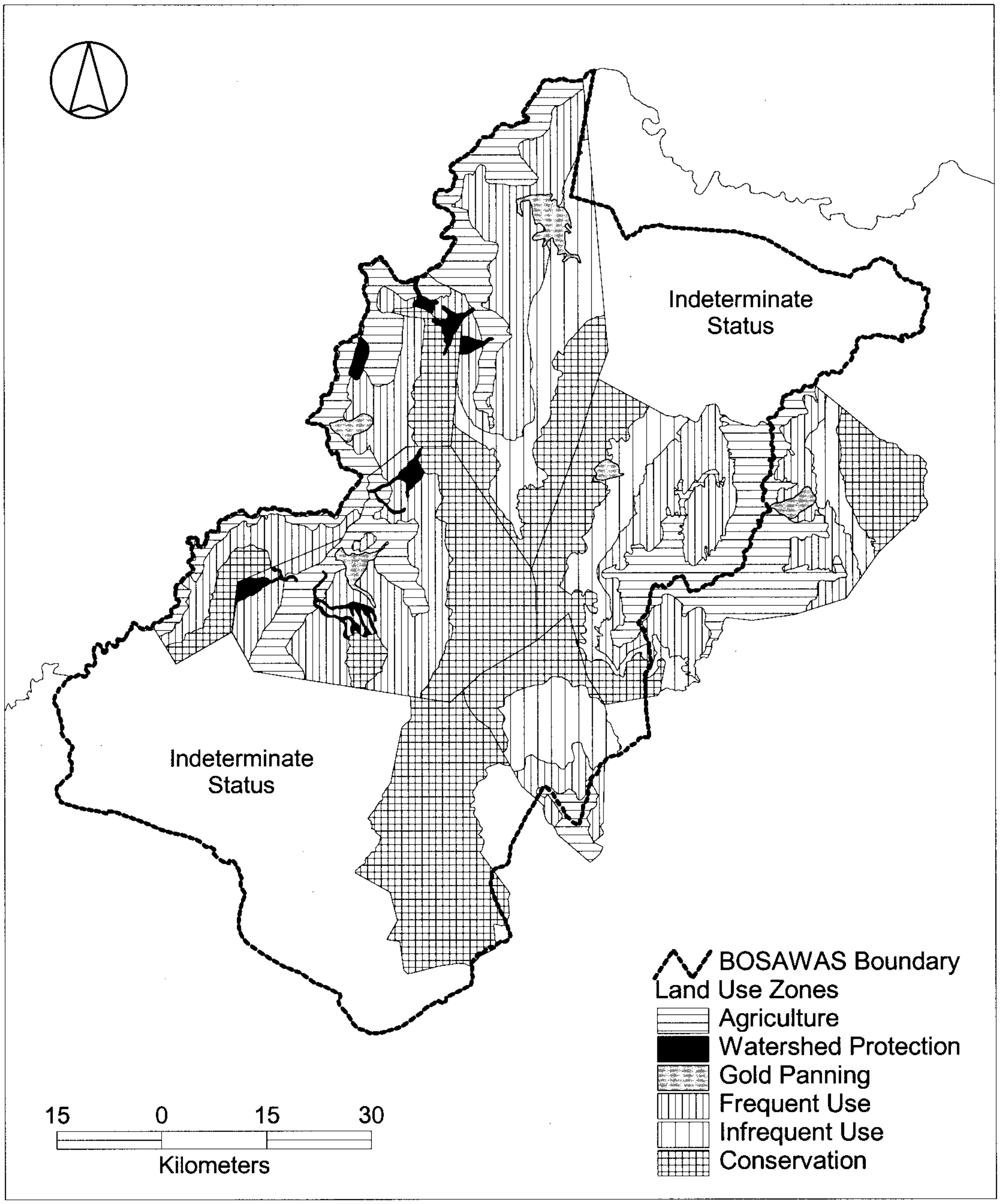

Figure 3. BOSAWAS land-use management zones.

nities (Kipla Sait Tasbaika, Mayangna Sauni As, and Mayangna Sauni Bas), other image sources were evaluated. For the earlier date, it was decided that two Landsat multispectral scanner (MSS) images would suffice (Table 2). Utilization of the MSS was not optimal, because of its relatively coarse spatial and spectral resolution, both of which inhibit its ability to detect small clearings in a forested landscape.

As for the latter date, 74 attempts were made by the SPOT satellite system to acquire images of the communities during the 1996 dry season (generally December through April), but none were of sufficient quality. It was finally decided to utilize four 1995 images, one Landsat TM image used for coverage of Mayangna Sauni Bas and western portions of Kipla Sait Tasbaika and three SPOT panchromatic images covering the remaining portions of Kipla Sait Tasbaika, as well as Mayangna Sauni As in its entirety. Panchromatic refers

Table 2. Images utilized

Sensor and date	Path/row	Spatial resolution (m)	Root-mean-square error (pixels)
Landsat MSS			
January 28, 1986	16/050	80	±0.4
January 28, 1986	16/051	80	0.5
Landsat TM			
January 21, 1995	16/050	30	0.6
SPOT Panchromatic			
March 19, 1995	620/321	10	0.9
March 19, 1995	620/322	10	0.9
January 22, 1995	620/323	10	0.9

to the fact that these images consist of a single band, as opposed to the multispectral MSS and TM sensors, which consist of four and seven bands, respectively. The panchromatic images, however, possess a greater spatial resolution, allowing them to identify features 10 m on a side (see Table 2). This greater spatial resolution has allowed for accurate identification of deforested areas and land-cover boundaries (Girou and Beauchéne 1992, Campbell and Browder 1995).

In addition to the images, maps also provided source information. Existing maps provided a common coordinate system for image georectification, as well as information about the three communities. Specifically, these maps included: 1:50,000-scale topographic maps produced in 1987 by the Instituto Nicaragüense de Estudios Territoriales (INETER); 1:50,000-scale indigenous management land-use zoning maps produced by the Center for Environmental Anthropology (CEA) at Idaho State University; and a 1:50,000-scale map of Saslaya National Park produced by The Nature Conservancy (TNC). The topographic maps were utilized to provide ground control for rectifying the satellite images, as well as a digital map of the BOSAWAS boundary. A verbal description of the boundary's landmarks was included in the decree creating the reserve, and these landmarks were used to trace the boundary on the topographic maps, which were then digitized. The indigenous land-use zoning maps were developed by TNC anthropologists and community elders, with the anthropologists conducting workshops on how to demarcate the various land-use zones the communities decided to establish (Stocks and others 1998). Delineation of the zones was based on each community's historical use of their territories, as well as their perceived future needs.

Source data were also collected during two site inspections. These inspections were conducted to gather ground-truth information on the study area, acquire maps, and meet with BOSAWAS officials. The first inspection occurred in July/August 1995 and lasted approximately four weeks. In order to facilitate the gathering of ground-truth information on existing land-use and land-cover conditions, hardcopy color prints of portions of the satellite images were taken to the study area. Field work included an aerial survey of the area and a reconnaissance by canoe along the western boundary of the reserve. Hand-held photographs were acquired during the aerial survey to obtain ground-truth information in the inaccessible portions of the reserve.

The second site visit was conducted during January/February 1996 for three weeks and involved collecting information on land-cover sample areas to be used in the image classification process. In addition, sample areas for a final map accuracy assessment were also identified. Locations of these sample land-cover classes were determined in Universal Transverse Mercator (UTM), North American Datum of 1927 (NAD27) ground coordinates using a Trimble Geoexplorer global positioning system (GPS) receiver. The NAD27 was utilized so as to make the final land-cover maps comparable with the 1:50,000 scale topographic maps. At each GPS sample point, a labeled diagram was sketched of the surrounding landscape and ground photographs acquired. Locations of points were severely limited due to large portions of the study area being deemed too dangerous to survey at that time. The lack of access to interior portions of the reserve resulted in only a small number of points including mature forest.

Before this ground-truth information was utilized, the images were rectified to the UTM ground coordinate system, Zone 16, NAD 27, using ground control obtained from the topographic maps. Points selected for ground control were mainly hydrologic features such as lakes and rivers, but were augmented in the southern portion of the study area with road intersections and turns. Root-mean-square errors (RMSExy) of

Table 3. Classification scheme

Category	Definition
Agriculture	Currently cleared areas containing grasses and crops
Scrub/early secondary forest	Formerly cleared areas with dispersed woody vegetation, or with continuous low (<5 m) woody vegetation
Advanced forest	Tall (>5 m) woody vegetation

planimetric check points varied from 0.4 to 0.9 pixels (see Table 2).

Once all of the images were rectified, representative land-cover areas were identified by overlaying one half of the gathered GPS sample points onto the images. This overlaying allowed image characteristics such as spectral reflectance and relative texture (smooth versus rough) to be linked with specific land-cover classes. Using this information, a land-cover classification scheme was developed that could be utilized with the wide variety of images employed in this study. This scheme consisted of three classes, advanced forest, scrub/early secondary forest, and agriculture (Table 3). A more detailed classification scheme would have been desirable, but was made impossible by the limited spectral resolutions of both the MSS and SPOT panchromatic imagery. The advanced forest class encompasses those areas that were not cleared for approximately 15 years. That is the period of time required for secondary forest to become spectrally inseparable from older forests utilizing multispectral data in the tropics (Moran 1993). Accordingly, scrub/early secondary forest designates those areas that had been used for agriculture in the past 15 years and subsequently abandoned. The last class, agriculture, designates those areas covered with crops or grasslands during image acquisition.

Due to the multiple image types utilized, with their varying spatial resolutions, it was decided that the land-cover information would be analyzed and presented in a vector format, as opposed to the image-based raster format. Additionally, TNC desired that the maps be as user-friendly as possible, while meeting the cartographic standards of the Nicaragua government. The result was that all of the image-derived land cover had to be converted from a raster to a vector format. This was accomplished by digitizing the boundaries of various land-cover types on the image itself through visual interpretation, or digitizing the boundaries of classified land-cover patches derived from the images through supervised classification.

Supervised classification was utilized to classify the TM image and involves an analyst identifying areas of sample land-cover classes and then using the computer to identify all areas on the image that are spectrally similar to that sample (Lillesand and Kiefer 1994). This process is repeated until all of the classes' spectral variation is incorporated into the sample areas and results in a raster land-cover image being created. After this raster image was created, it was smoothed with a 5 × 5 majority filter and then converted to a vector format by digitizing patch boundaries.

The two MSS and three SPOT images were classified through visual interpretation, which involves an analyst delineating the various land-cover class patches directly on an image using a cursor on a computer screen (Mas and Ramirez 1996). Supervised classification could have been used on the MSS data, but the images possessed some striping making accurate classification problematic. Efforts to remove the striping through automatic methods were not successful. Visual interpretation has been found to be a useful classification method in tropical regions due to a human interpreter's ability to identify features in very heterogeneous landscapes (Sader and others 1990, Batista and Tucker 1991). Delineation of the land-cover classes on the images was based on both their reflectance values and texture characteristics. Agricultural plots are very smooth and bright, while advanced forest presents a much darker and rougher appearance, with scrub/early secondary forest exhibiting characteristics somewhere in between these two.

Once all six images were classified and vectorized, land-cover data sets from the same acquisition year were appended together to create two seamless land-cover data sets, one for 1986 and one for 1995. These data sets were then overlayed on the individual digitized community land-use zoning maps, thus isolating land-cover types within each of the communities, for each date. Through these overlay procedures, all patches were assigned a land-cover class, as well as a land-use zone. A total of six community land-cover data sets were created, two for each community. The final step of the analysis involved overlaying the individual community land-cover maps, thus identifying the changes that had occurred during the period 1986–1995.

Accuracy assessment of the 1995 classification was performed at one half of the GPS sample points gathered during the second site visit. Assessment of the 1986 classification was not possible due to a lack of adequate reference data for the area. Errors of omission varied from 6% to 11%, while errors of commission varied from 0 to 14%. Overall, 92% of the sample land-cover types were correctly classified.

Table 4. Land cover in the communities' land-use management zones (number of patches and km^2)

	1986						1995					
	Agriculture		Scrub/early secondary forest		Advanced forest		Agriculture		Scrub/early secondary forest		Advanced forest	
Zones	Patches	Area	Patches	Area	Patches	Area	Patches	Area	Patches	Area	Patches	Area
Mayangna Sauni As												
Agriculture	2	0.27	31	29.93	8	434.1	68	16.31	96	76.05	25	370.94
Gold panning	0	0	1	0.04	2	22.74	0	0	3	0.1	2	22.68
Frequent Use	0	0	1	0.2	5	449.56	8	0.69	25	17.8	12	431.27
Infrequent Use	0	0	0	0	3	278.82	1	0.03	0	0	3	278.78
Conservation	0	0	0	0	3	420.75	0	0	0	0	3	420.75
Mayangna Sauni Bas												
Agriculture	1	0.09	14	10.26	4	35.89	40	3.86	20	4.07	4	38.3
Watershed Protection	0	0	3	0.97	3	0.29	8	0.55	5	0.42	4	0.29
Frequent Use	1	0.1	18	7.9	1	64.16	23	1.63	9	0.82	5	69.71
Infrequent Use	0	0	1	0.82	2	161.14	7	1.43	2	0.25	1	160.28
Conservation	0	0	0	0	1	124.03	0	0	0	0	1	124.03
Kipla Sait Tasbaika												
Agriculture	12	2.55	35	8.03	6	206.05	56	5.56	103	13.37	18	197.55
Gold Panning	0	0	2	0.07	5	36.6	2	0.04	4	0.16	8	36.46
Watershed Protection	4	0.09	2	0.06	5	12.65	9	0.5	12	0.95	13	11.38
Frequent Use	2	0.14	6	0.72	4	361.41	0	0	8	0.47	3	361.8
Infrequent Use	0	0	0	0	1	291.32	0	0	0	0	1	291.32
Conservation	0	0	0	0	1	219.86	0	0	0	0	1	219.86

Results and Discussion

The first set of overlays identified the amounts and distribution of the three land-cover classes within the various land-use zones for both 1986 and 1995 (Table 4). In 1986, all three communities were dominated by advanced forest, while containing very little agricultural land. Each Mayangna community contained two agriculture patches, with both of Mayangna Sauni As' located in its agriculture zone, while Mayangna Sauni Bas had one in its agriculture zone and one in its frequent-use zone. Kipla Sait Tasbaika contained relatively more agricultural land cover, most of which was located within its agriculture zone, but it also had some located in its watershed-protection and frequent-use zones. Scrub/early secondary forest was much more prevalent than agriculture in all three communities, both in area covered and number of patches. Most of it was located within the agriculture zones, but all three communities also had scrub/early secondary forest within their frequent-use zones. Additionally, it was located in the watershed protection zones of both Mayangna Sauni Bas and Kipla Sait Tasbaika. In fact, scrub/early secondary forest was the predominant land-cover in Mayangna Sauni Bas' watershed protection zones.

Analysis of the 1995 land cover reveals that the amounts of both agriculture and scrub/early secondary forest has increased dramatically (see Table 4). Agriculture increased in all three communities, while the amount of scrub/early secondary forest increased in two, Mayangna Sauni As and Kipla Sait Tasbaika. For Mayangna Sauni As, agricultural land cover was found in three zones, agriculture, frequent use, and infrequent use, while scrub/early secondary forest was found in the agriculture, gold panning, and frequent-use zones. Both agriculture and scrub/early secondary forest were found in four of Mayangna Sauni Bas' zones, the sole exception being its conservation zone. Kipla Sait Tasbaika possessed agricultural land cover in three of its zones, agriculture, gold panning, and watershed protection, while scrub/early secondary forest was found in these same three zones, as well as its frequent-use zone. As with the 1986 land cover, most of the zones were predominantly covered with advanced forest, the lone exception again being the Mayangna Sauni Bas watershed protection zones.

Land-cover change was identified by analyzing those areas that possessed different land-cover classes in 1986 and 1995. Analysis of the change processes within the various management use zones provides information

Table 5. Land-cover change processes occurring in the management zones (km^2)

Zone	Deforestation	Reconversion	Reforestation	Remaining agriculture	Remaining scrub/early secondary forest	Remaining advanced forest
Mayangna Sauni As						
Agriculture	67.56	8.4	4.5	0.18	16.12	366.53
Gold panning	0.06	0	0	0	0.04	22.68
Frequent use	18.29	0	0	0	0.2	431.27
Infrequent use	0.03	0	0	0	0	278.78
Conservation	0	0	0	0	0	420.75
Totals	85.94	8.4	4.5	0.18	16.36	1520.01
Mayangna Sauni Bas						
Agriculture	2.56	2.52	4.97	0.08	2.77	33.33
Watershed protection	0.14	0.43	0.14	0	0.4	0.15
Frequent use	0.99	0.81	6.54	0.09	0.56	63.18
Infrequent use	1.45	0.19	0.59	0	0.04	159.7
Conservation	0	0	0	0	0	124.03
Totals	5.14	3.95	12.24	0.17	3.77	380.39
Kipla Sait Tasbaika						
Agriculture	13.68	0.52	6.57	0.76	2.99	192.04
Gold panning	0.18	0	0.03	0	0.01	36.43
Watershed protection	1.34	0	0.07	0.03	0.04	11.3
Frequent use	0.36	0	0.75	0	0.11	361.05
Infrequent use	0	0	0	0	0	291.32
Conservation	0	0	0	0	0	219.86
Totals	15.56	0.52	7.42	0.79	3.15	1112

on the human processes affecting the landscape of each zone. Three processes were identified as occurring: deforestation, reforestation, and reconversion. Deforestation refers the removal of all or some of the tree cover and is exhibited by those areas that were advanced forest in 1986 and agriculture or scrub/early secondary forest in 1995. In contrast, reforestation refers to an increase in tree cover, which is said to have occurred in those areas that were agriculture or scrub/early secondary forest in 1986 and advanced forest in 1995, as well as those areas that were agriculture in 1986 and scrub/early secondary forest in 1995. The final change process was reconversion, referring to those areas covered by scrub/early secondary forest in 1986 and agriculture in 1995. Table 5 lists the amount of area that had undergone these changes, as well as those areas whose land-cover classes were unchanged.

All three change processes were identified as occurring in each of the communities. Deforestation was the most prevalent change process occurring in two of the communities, Mayangna Sauni As and Kipla Sait Tasbaika. Most of this deforestation occurred in their agriculture zones, with smaller amounts occurring in all of the other zones, except for conservation. Changes outside the agricultural zones were relatively small, the exception being the 18 km^2 in Mayangna Sauni As' frequent-use zones. The most prevalent change occurring in Mayangna Sauni Bas was reforestation, which impacted over 12 km^2, much of which was located in its frequent- and infrequent-use zones. Occurring in lesser amounts was reconversion, which was concentrated in the agriculture zones. It was the least common change process in two of the communities, the exception being Mayangna Sauni As, where it was the second most prevalent change process.

Overall, most of the changes occurred in agriculture zones. For Mayangna Sauni As and Kipla Sait Tasbaika, over 80% of the changes occurred in these zones. In contrast, the agricultural zones only accounted for 47% of the change occurring in Mayangna Sauni Bas. Troublesome changes identified include deforestation in the infrequent use zones of both Mayangna communities, as well as large portions of Kipla Sait Tasbaika's watershed protection zones. However, no land-cover changes were identified as occurring in the conservation zones.

Conclusions

Examination of the 1986 land cover reveals that little of the three communities were covered by crops or pasture at that time. Their paucity results from the fact that the region was a battleground during the civil war that occurred during the 1980s, with many residents fleeing to Honduras or forcibly removed by the Nicaraguan government, thus abandoning their agricultural lands (Stocks 1994). The large amount of scrub/early secondary forest also reflects this abandonment. When the civil war ended in 1989, the former residents, as well as new settlers moved into the area. The distribution of land-cover types in 1995 reflects this return, with major increases in both agriculture and scrub/early secondary forest, as well as the concomitant losses of advanced forest. Thus, the fears of government officials and conservationists that the end of the war would result in increasing immigration and decreasing amounts of forest were realized.

Three land-cover change processes were identified as occurring during the period 1986–1995: deforestation, reforestation, and reconversion. These changes were concentrated in the agriculture zones, with smaller amounts occurring in the gold-panning, frequent-use, infrequent-use and watershed-protection zones. The conservation areas did not experience any anthropogenic land-cover alterations, and for the most part are adequately protected by the buffer zones that have been delineated. However, conflicts between land cover and the zoning plan have been identified in both infrequent-use and watershed-protection zones, with most of them occurring in a single community, Mayangna Sauni Bas. Increased enforcement of land-use policies in these areas is necessary to protect village water supplies and ensure adequate protection of core conservation areas. The land-cover analysis also reveals that the zoning plan encourages maintenance of traditional slash and burn agriculture, with the agricultural zones large enough for fallow management. Overall, the land-cover types present are compatible with the management use zones, offering a chance for conservation, while providing for the continuation of traditional agricultural, hunting and gathering practices.

The results from this study, as well as future updates, will allow investigators to locate and quantify noncompatible land-cover types within the land-use zones, ensuring compliance with conservation objectives. In addition, they will enable local communities make knowledgeable decisions involving land-use. Remote sensing and GIS will continue to be important tools for assessing land-cover and integrating the wide variety of information required to successfully manage the BOSAWAS Natural Resource Reserve. The use of such tools will only increase as nature reserves, with their multiple goals and numerous involved interest groups, become more common as lands suitable for conservation decrease.

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