Online Journal of Space Communication

Volume 2
Issue 3 *Remote Sensing of Earth via Satellite (Winter 2003)*

Article 23

January 2003

Pattern of Forest Regeneration in Celaque National Park, Honduras

Alexis Aguilar

Alexis Aguilar
UCLA

PATTERNS OF FOREST REGENERATION

IN CELAQUE NATIONAL PARK, HONDURAS

by

Alexis Aguilar

Dept. of Geography
UCLA
1255 Bunche Hall
Box 951524
Los Angeles, CA 90095-1524
alexagui@ucla.edu

PATTERNS OF FOREST REGENERATION IN CELAQUE NATIONAL PARK, HONDURAS

INTRODUCTION

Conversion of tropical forest land to anthropogenic landuses has led to the loss of soil, water resources, and biodiversity, and has been recognized as an important source of global atmospheric carbon (Houghton, 1991; Myers, 1992; Rotmans and Swart, 1991). Agriculture is by far the most extensive landuse in the tropics. The level of forest clearance for agriculture varies greatly, ranging from short-term cultivation of subsistence crops in sub-hectare plots to clearing hundreds of hectares for export agriculture and/or cattle grazing. Yet, much of this agricultural land is cyclically or permanently abandoned and reverts to secondary forest (sensu Cortlett, 1994). The area under secondary forests in Latin America alone has been estimated at 1.65 million square kilometers (CIFOR, 1998). Other authors estimate that 30% of previously cleared land in the Amazon and 31% of all tropical closed forests are secondary (Brown and Lugo, 1990; Walker *et al*., 1999). Though not a substitute for primary forests, secondary forests have demonstrated their value by providing many environmental services. Secondary forests provide valuable wildlife habitat, protect water sources, alleviate pressure on primary forests by serving as local sources of firewood, and hold the soil against erosion, particularly in mountainous areas (Corlett, 1995). Regenerating tropical forests can act as a considerable carbon sink. Since they regenerate vigorously and absorb carbon at rapid rates (Brown and Lugo, 1990; Brown *et al*., 1992; Lugo and Brown, 1992).

Forest ecosystems in different regions and settings respond differently to the release of anthropogenic disturbance. This response determines the quality and quantity of any subsequent regeneration. Tropical forests vary greatly in their resilience or ability to regenerate depending on many factors including disturbance history, the spatial pattern of the surrounding landscape, and the characteristics of the physical environment. Regeneration rates can vary from the rapid recovery of forest structure within a decade to a state of arrested succession where regeneration is virtually non-existent for hundreds of years. Despite the importance of the response of tropical forests to the removal of disturbance, detailed studies are lacking for many tropical regions and ecosystem types such as montane and dry forests as most studies have focused in lowland wet forests such as the Amazon. One tropical, high-altitude area where extensive post-agriculture regeneration has been observed is Celaque National Park (CNP) in Honduras, Central America. This study used remote sensing analysis, landscape statistics, and ground observations to examine forest recovery dynamics in a montane tropical forest environment in CNP between 1987 and 1998. The following hypotheses were tested:

1. Forested area increased in CNP during the study period.
2. The density of forests in large areas of CNP increased during the study period.
3. Forest fragmentation decreased during the study period.

Study Area

The study area is in the highlands of Honduras, Central America. Celaque National Park (CNP) covers 266 km^2 in southwestern Honduras (88º 42' W, 14º 33' N). The park has a rugged topography with slopes greater than 60° over two thirds of its surface. It ranges in elevation from 1000 m to 2849 m above sea level (Figure 1). Dozens of streams originate within its limits providing water to 120 surrounding villages. The 34 villages located within the park's boundaries total some 2800 inhabitants mostly of Lenca origin, an indigenous group that has inhabited the region for thousands of years. They practice subsistence agriculture growing primarily corn and beans. Because of the Lenca practice of maintaining patches of forest adjacent to their fields, anthropogenic areas of Celaque consist of a patchwork of forest and agriculture.

Annual mean precipitation ranges from 1600 mm at lower to 2400 mm at higher elevations. Climate is characterized by a wet season followed by a distinct dry season. Both seasons are of approximately equal length with high precipitation from May to October. Mean annual temperature is 21ºC at lower elevations and 10ºC at higher elevations (AFE-COHDEFOR and CONSULT, 1999; Zúniga-Andrade, 1990). Floristic zones in CNP vary with elevation and location. Broadleaf and mixed forests are predominant in the moister north and pine forests are more common in the drier south. Vegetation shows a markedly North American influence. At elevations below 1800 m, the park consists mainly of *Pinus-Quercus* forests (Fonseca *et al.*, 1999). At higher elevations, the pine-oak forest gives way to broadleaf cloud forest.

METHODS

A time-series of three Landsat scenes acquired in March 1987, May 1992, and December 1998 were used to reconstruct the successional dynamics of the CNP forests from 1987 to 1998 (Table 1). Significant changes in the landscape took place during this 11-year span. The 1987 and 1992 images were geometrically rectified to the 1998 image using image-to-image registration and a nearest-neighbor transformation with a Root Mean Square Error (RMSE) < 1.0 pixel (30 m).

Atmospheric, Seasonal, and Topographic Correction

All digital number (DN) values were converted to exoatmospheric reflectance values to account for differences in solar azimuth, solar elevation, and time of year between the scenes. A Dark Object Subtraction (DOS) technique was performed on all the images to reduce atmospheric scattering effects (Chavez, 1988). To reduce seasonal differences, a set of spectrally stable pixels were selected from an area of mature cloud forest not expected to have had significant successional or structural changes during the study period. Changes in reflectance values in these control sites were assumed to have arisen mainly from seasonal and residual atmospheric differences. The 1998 and 1992 images were calibrated to the 1987 image using the mean reflectance values of these sites and a simple linear regression model. Clouds and dark shadow areas were masked out of the analysis. CNP's high relief resulted in strong shadows cast on slopes facing away from the sun. To reduce the effects of topography, the image was first partitioned into a sunlit and a shadow area. An unsupervised classification was performed on the dark part of the image separately. Also, several layers of ancillary data (Table 2) were input into a GIS to create a decision tree to iteratively refine the classification in shadow areas.

Ground-Truthing and Accuracy Assessment

Fieldwork was conducted in the summers of 1998 to 2000. Ground-truthing was done by sampling thirty widely distributed and representative sample sites in different stages of regeneration and by recording observations in the field. Ground sample sites were divided into four successional stages: 1) agriculture/grassland (AG), 2) early regrowth (ER), 3) young forest (YF), and 4) mature forest (MF). An additional class, open forest (OF) was included because it was common in anthropogenic areas. Open forests was defined as those with less than 70% canopy closure. Furthermore, recent (1998 and 2000) high-resolution (1:10,000) black and white aerial photographs were visually interpreted to collect twenty additional training areas and to verify the accuracy of results. The training sites were used in a supervised maximum likelihood classification of the 1998 image using TM bands 2, 3, 4, 5, and 7. The 1987 and 1992 images were classified using training sites whose spectral signatures closely matched those of the 1998 image.

Since the images had been radiometrically normalized, the accuracy of the 1987 and 1992 classifications was assumed to be similar to that of the 1998 classification.

The Kappa coefficient was used to measure the accuracy of the classification results (Rosenfield and Fitzpatrick-Lins, 1986). The present analysis resulted in a Kappa coefficient of 0.885 (88.5% better than random). Overall accuracy was calculated by dividing the sum of all correctly classified pixels by the total number of pixels resulting in an overall accuracy of 90.8%. The principal source of classification error was confusion between the least separable classes (ER and YF, AG and OF).

Results

Changes in Forest Cover

The results from the classifications of the three Landsat TM scenes are shown in Figure 2. Landscape dynamics between 1987 and 1998 are summarized in Figure 3 and Figure 4. Table 3 shows transitions between different forest classes during the study period. 11,016 ha of the 24,130 ha study area (45.7%) underwent a transition. MF increased from 35.4% to 57.3% of the study area. In 1987, OF and MF occupied approximately equal proportions of the study area (36.7% and 35.4% respectively). By 1998, OF had decreased to 22% of the study area while MF had become the largest forest class at 57.3%. MF experienced the largest net increase (5228 ha) while OF experienced the largest net decrease (3624 ha). Clearance of mature forest (i.e., MF→AG and MF→ER) totaled only 137 ha, and MF→OF degradation was only slightly greater (191 ha) suggesting that, for the most part, MF was not disturbed over the study period.

Spatial Pattern of Regeneration

Most of the increase in MF occurred at higher elevations and originated from OF (3154 ha) south of the central core of the park, and from YF (2387 ha) east of it. Interviews with local people and park data indicate that by 1998 these high elevation areas (>1800m) had been abandoned within the last 15-20 years. OF→MF mainly occurred in the southern section where most OF was originally located (Figure 5a). This transition was 70% greater in the 1992-98 period than in the 1987-92 period pointing to a recent release of disturbance in this, more anthropogenically-disturbed, section of the park. YF→ MF mainly occurred in the eastern section of the park where most YF was originally located (Figure 5b). But this transition actually decreased by 33% in the 1992-98 period in relation to the 1987-92 period. More of the YF→MF transition occurred in the earlier period because these lands were apparently abandoned earlier and subjected to little recent disturbance.

Decrease in MF Fragmentation

For the purpose of this study, a landscape is an area of land containing a mosaic of forest patches in various stages of regeneration whereas a patch is a discrete unit of area classified under a single stage of regeneration. The spatial pattern of forested landscapes has been found to be strongly related to physical processes such as soil erosion, wind-throw, greenhouse emissions, and the spread of fire (Baker, 1989; Neptstad *et al*., 1996; Laurance *et al*., 1998), and biological processes such as predation, invasion by exotic species, seed dispersal, and genetic exchange (Simberloff, 1994; Smith, 1997). Landscape pattern can be quantified by calculating indices (metrics) sensitive to the presence and spatial arrangement of patches. Two types of landscape metrics important for successional studies are those that quantify area and degree of isolation.

Area metrics measure the amount of vegetation types. Particularly valuable is the index that measures core area, which is the internal area of a patch a minimum distance from its edge. Core area will in part determine a patch's overall susceptibility to edge effects. Forest fragments with greater core areas should exhibit a greater potential to regenerate since they will contain more large, seed-producing mature trees, which are mostly absent from smaller patches. A second type of index, degree of isolation, measures distance from other patches of the same or different forest type. A patch far from mature forests will have a smaller seed rain of mature species and less visits from seed-dispersal fauna inhabiting these forests. On the other hand, a patch near recently disturbed patches is more likely to be the recipient of disturbance originating in or transmitted by these patches. Isolation metrics are commonly used to measure the level of fragmentation of healthy forest in the landscape.

Two 32-km^2 landscapes in CNP were chosen to demonstrate the decrease in the fragmentation of MF between 1987 and 1998. Landscape A (Figure 6a) had a relatively gentle topography and contained a village. By contrast, Landscape B (Figure 6b) was more remote, had a more rugged topography, and, unlike landscape A, was probably already experiencing widespread land abandonment in 1987. Extensive regeneration was experienced by both landscapes, but the decrease in MF fragmentation was more rapid in landscape B. We focus our attention on the two forest classes that changed the most, OF and MF. MF is particularly important because it is the most ecologically valuable of the regeneration classes. In both cases fragmentation metrics—i.e., Number of Patches (NumP), Mean Patch Size (MPS), and Mean Nearest Neighbor (MNN)—indicated a decrease in fragmentation for MF and an increase for OF (Figure 7). This is also apparent from the corresponding increases in class area (CA) and total core area (TCA) for MF and decreases for OF.

MF fragmentation was considerably higher in landscape B than in landscape A in 1987. Yet, by 1998, MF fragmentation had decreased and was approximately the same in both landscapes. For example, 1987 MF MPS was 11 ha in landscape A and 5 ha in landscape B. By 1998 MF MPS had increased to 25 ha in landscape A and to 27 ha in landscape B. Landscape A began with a smaller proportion of MF (36%) than landscape B (19%). But, by the end of the period, the proportion of MF in both landscapes was approximately equal (58% vs. 54%). OF decreased correspondingly in both landscapes as most of this gain in MF came from OF. Regeneration was not only greater in landscape B but, perhaps more significantly, the increase in MF core area (TCA) was considerably greater in landscape B vis-à-vis the increase in MF class area (CA). MF TCA in landscape B increased by 303% versus an increase in MF CA of only 209%. On the other hand, the increase in MF TCA in landscape A was similar to the increase in MF CA (58% vs. 52%). Hence, while there was a greater increase in MF area in landscape B than landscape A, the most important difference between the dynamics in the two landscapes was the much greater increase in MF core area experienced by landscape B. Core area represents the least disturbed forest, and core habitat is preferred by many sensitive plant and animal species.

Discussion

Landscape pattern in CNP was considerably altered between 1987 and 1998. The main trends were a decrease in OF with a concomitant increase in MF leading to a decrease in the fragmentation of MF. The spatial pattern of regeneration was not random. Regeneration was more prevalent in higher elevation, more remote areas, closer to the center of the park, and nearer mature forest. Amount and rate of regeneration were most affected by three factors: a) the nature of the original and recurring disturbance, b) the local physical environment, and c) the nature of the surrounding landscape. The original disturbance in most of Celaque was shifting agriculture, and therefore, it could support more rapid regeneration than places subjected to more disruptive disturbances such as cattle grazing. Recurring disturbances such as fire and wood extraction were more prevalent in the southern anthropogenic section of the park. Consequently, forest was more likely to remain in the OF and AG stages there while elsewhere transitions to ER and YF were more common. More regeneration was observed at higher elevations and northwest-facing slopes where moister conditions promoted growth and reduced susceptibility to fires. Also the remoteness and steeper slopes of these locations isolated them from anthropogenic disturbance. Finally, more regeneration took place in areas with a greater proportion of MF in 1987. MF adjacent to regenerating patches acted as a source of seeds and as a buffer against disturbances such as invasion by exotic species originating outside the park.

The fact that the largest transitions resulted in MF is a sign of the permanence of forest regeneration in Celaque since it takes 20-25 years for forest to become MF following shifting agriculture. A ring of regeneration developed around the core of mature forest in the center of the park mainly in the form of new YF and MF. Averaging 4.4 km in length this new secondary forest can act as a buffer against large-scale edge effects and disturbance originating outside the park (Laurance, 2000). A marked decrease in the level of fragmentation of structurally developed forest was observed.

Carbon Uptake

Much of the gain in secondary forest in CNP stemmed from the recuperation of degraded forests, that is, from an increase in the density of open forests. The net balance in carbon storage is hence positive since secondary forest did not originate at the expense of mature forest during this period, but instead originated from the abandonment of agricultural land and the restoration of degraded forests. The magnitude of the increase in carbon reserves in CNP can only be approximated without taking detailed biomass inventories and growth measurements. Yet, an informed approximation shows that regenerating forests sequestered large amounts of atmospheric carbon during the study period.

An approximation of the total increase in above-ground carbon content of forests in CNP was calculated using the equation for post-agriculture regeneration given in Silver *et al.* (2000): $BIOMASS = 9.79*(AGE)^{0.71}$ and the net changes in class cover from Table 3. During the study period, the carbon reserves of CNP increased by roughly 148,000 metric tons (Table 4). At an international market value of approximately $10/tC, this gain in carbon would result in revenues of $1.48 million for the eleven-year period or $134,000/year (Smith and Scherr, 2002). Although Silver *et* al.'s equation was derived mainly from data for fast-growing lowland forests, highland pine-oak forests in Mesoamerica have been shown to accumulate biomass nearly as rapidly (Gonzalez-Espinosa *et al.*, 1991; De Jong *et al.*, 2000). Undoubtedly, even $100,000 per annum would be a substantial sum in low-income countries such as Honduras to help compensate farmers who abandoned their fields and/or help pay for park management.

CONCLUSION

The objectives of this study were to investigate the process of forest regeneration through the use of remote sensing data, field data, and spatial analysis techniques. The dynamics of forest regeneration in Celaque National Park were characterized at a landscape scale. Three hypotheses were tested to address these objectives. The results are reviewed below.

1. Forested area increased in CNP during the study period.

Our results show that the area of mature forest cover (MF), that is, dense forest at least twenty years old, increased from 35.4% of the study area in 1987 to 46.6% in 1992 to 57.3% in 1998. A 7% decrease in dense young forest (YF) did not offset the increase in MF forest cover. In fact, most of the loss of YF resulted from its conversion into MF. Based on the classification results, the hypothesis was not rejected.

2. The density of forests in large areas of CNP increased during the study period.

The largest transition during the study period was from open, degraded forest (OF) to dense mature forest (MF). Thus, a large amount of regeneration did not originate in open, abandoned agricultural fields, but rather in forest areas that either had a) been farmed but had not been completely cleared, b) been abandoned previous to 1987 and were already in a process of recovery, or c) become park-like woodlands as a result of anthropogenic disturbance. Change detection analysis showed that 4024 ha of OF developed into either dense YF or MF while only 554 ha of YF and MF deteriorated into OF during the study period. Based on these results, the hypothesis was not rejected. Extensive increase in the density of degraded forest has also been observed in another protected area in Honduras (Gómez, 1998).

3. Forest fragmentation decreased during the study period.

This hypothesis was tested by determining changes in MF fragmentation of two 32-km^2 landscape units as measured by several landscape metrics. The two landscapes had very different levels of MF fragmentation 1987, but by 1998 they had become more similar as regeneration progressed and MF became dominant. For example, MF Mean Nearest Neighbor (a common measure of fragmentation) decreased by 38% (from 97.7 m to 61.5 m) in landscape A and by 44% (from 97.4 m to 55.3 m) in landscape B. Regeneration was more prevalent in landscape B than in landscape A possibly because Landscape B was more remote, higher in elevation, and with a more rugged topography, resulting in earlier, more widespread abandonment, and the lack of recurring disturbance. More generally, in 1987 the south of CNP exhibited much higher fragmentation than the north. By 1998 the landscape over the entire park had become more homogeneous as fragmentation decreased everywhere in the park, but more rapidly in the southern central less accessible section of the park. Based on these results, the hypothesis was not rejected.

CNP experienced vigorous forest regeneration after anthropogenic pressure was relieved. This is not necessarily the case in other parts of the tropics. For example, in Costa Rica's Guanacaste National Park, forest regeneration was possible only after intense hands-on management because a long history of extensive clearings and cattle ranching had led to the loss of seed sources and the invasion of exotic grasses, effectively preventing natural regeneration (Janzen, 1986). CNP's anthropogenic areas, on the other hand, consisted of a mosaic of agriculture, grassland, and forest in various stages of regeneration. Because of this checker-board pattern of disturbance seed sources and dispersal fauna were readily available. In contrast, other patterns of fragmentation have been shown to create serious barriers to seed dispersal and regeneration (Sarmiento, 1997). Additionally, subsistence agriculture generally maintains the soil's fertility and its ability to recover. Lastly, cattle-grazing was rarely practiced by the Lencas at CNP. The lack of grazing meant the lack of introduced exotic pasture grasses. When combined, these conditions allowed for vigorous forest regeneration with little management. Landscape pattern and disturbance history should be considered when assessing the potential of a deforested or degraded area to naturally regenerate.

Despite their impoverished floristic composition vis-à-vis primary forests, secondary forests remain the best option to rehabilitate large expanses of already deforested and degraded land (Smith and Scherr, 2002). Degraded protected areas such as CNP should be prime targets for the type of natural forest restoration documented in this study. Allowing and encouraging the natural regeneration of their forests not only enhances their conservation value, but it does so at a minimal cost (Lamb *et al*., 1997). Re-linking of the landscape by secondary forests has the potential to revert some of the biophysical and ecological losses due to deforestation and fragmentation. This may have important implications for the conservation of biodiversity as many species are adversely affected by reduction and fragmentation of habitat and may benefit by a reversal of this process.

TABLES

Table 1: Landsat scenes used in study of successional development in CNP.

Sensor	Date	Path/Row	Zenith	Azimuth
LANDSAT 5 TM	25/03/87	19/50	53.19	107.49
LANDSAT 4 TM	01/05/92	19/50	54.45	84.22
LANDSAT 5 TM	04/12/98	19/50	45.22	144.08

Table 2: Layers used to improve classification of dark areas of CNP.

Digital elevation model (DEM)
NDVI Image
1998-2000 ground truth data
1980, 1998, and 2000 aerial photos

Table 3: Transition matrix showing changes in regeneration stage in Celaque National Park between 1987 and 1998. All values are in hectares.

	1998 State					
1987 State	**AG**	**OF**	**ER**	**YF**	**MF**	***Decrease***
AG		1154	214	69	96	1534
OF	819		580	870	3154	5423
ER	25	90		213	130	459
YF	89	363	224		2387	3062
MF	68	191	69	211		539
Increase	1001	1798	1087	1364	5767	11016
Net change	**-533**	**-3624**	**627**	**-1698**	**5228**	

Table 4: Increase in carbon content of forests in CNP. Each class was assigned an age value based on field observations. For example, OF was assigned a mean age of 10 years because it includes both very sparse forest that is most similar to AG, and forest with up to 70% cover consisting mainly of mature trees, which is most similar to MF. The tC column (tons of Carbon) shows that because the AG, OF, and YF classes decreased in area, their change in carbon content is negative while that of the ER and MF classes is positive because they increased in area.

Class	Age	tC/Ha	Ha	tC
AG	1	9.8	-533	-5218
ER	5	30.7	627	19245
OF	10	50.2	-3624	-181958
YF	15	67.0	-1698	-113696
MF	20	82.1	5228	429388
			Change =	147761

.

FIGURES

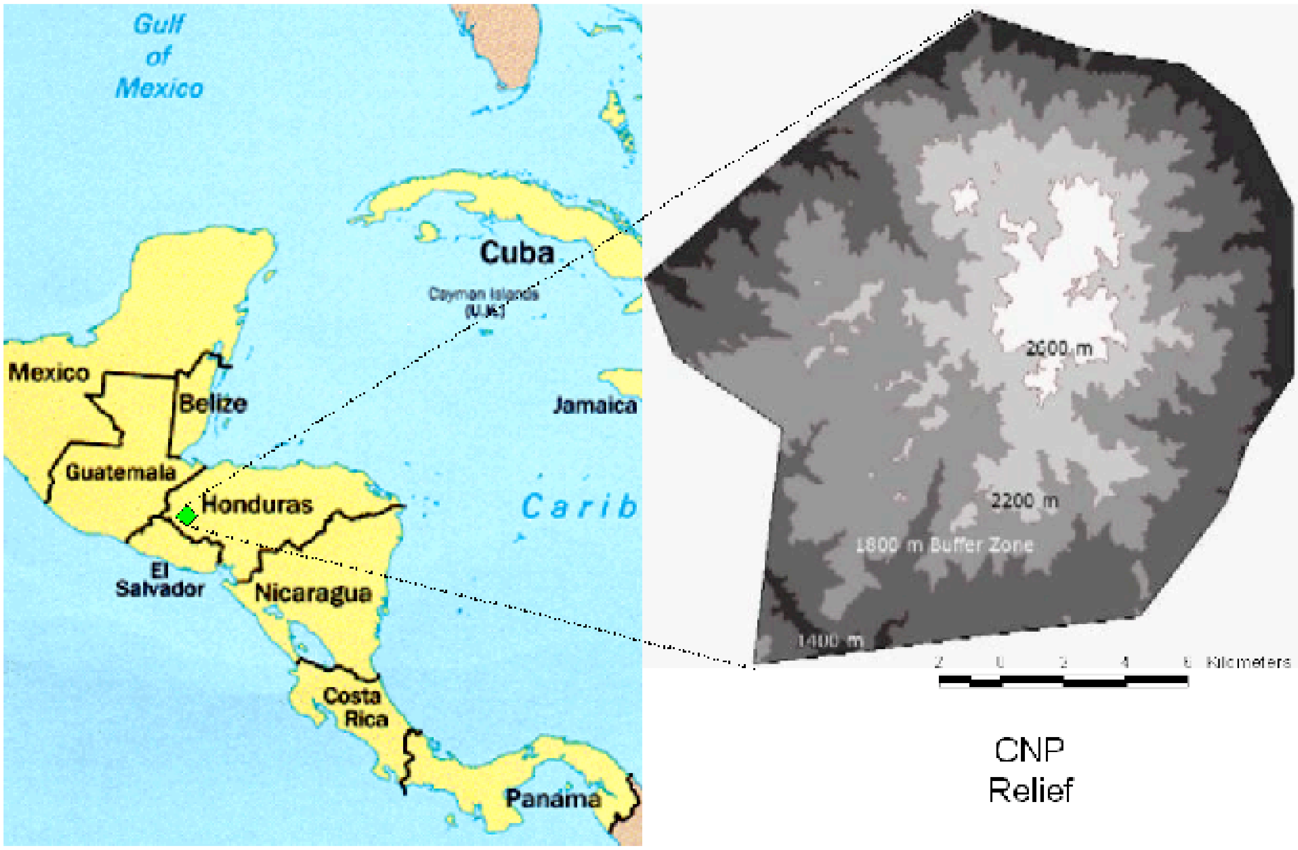
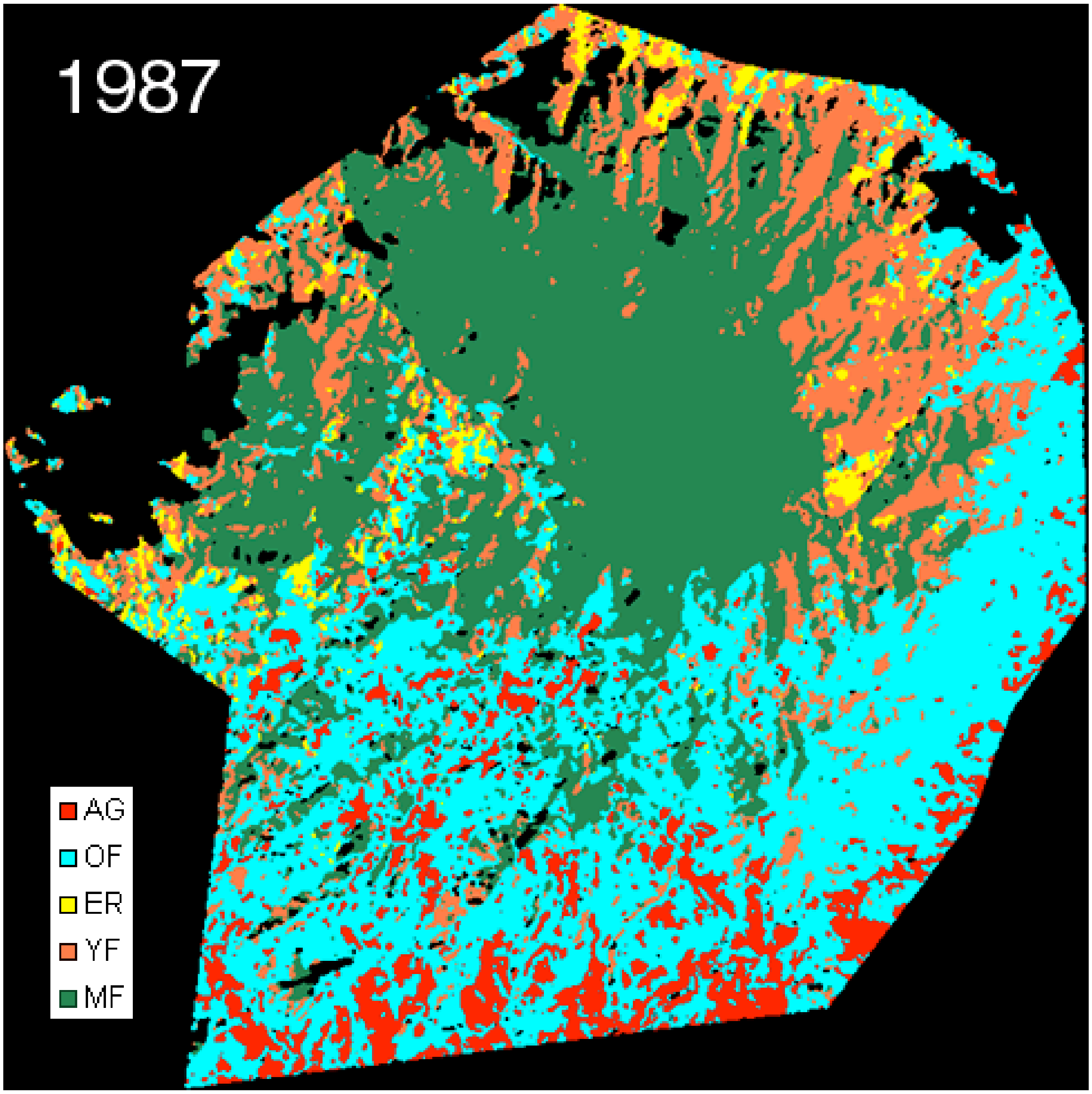
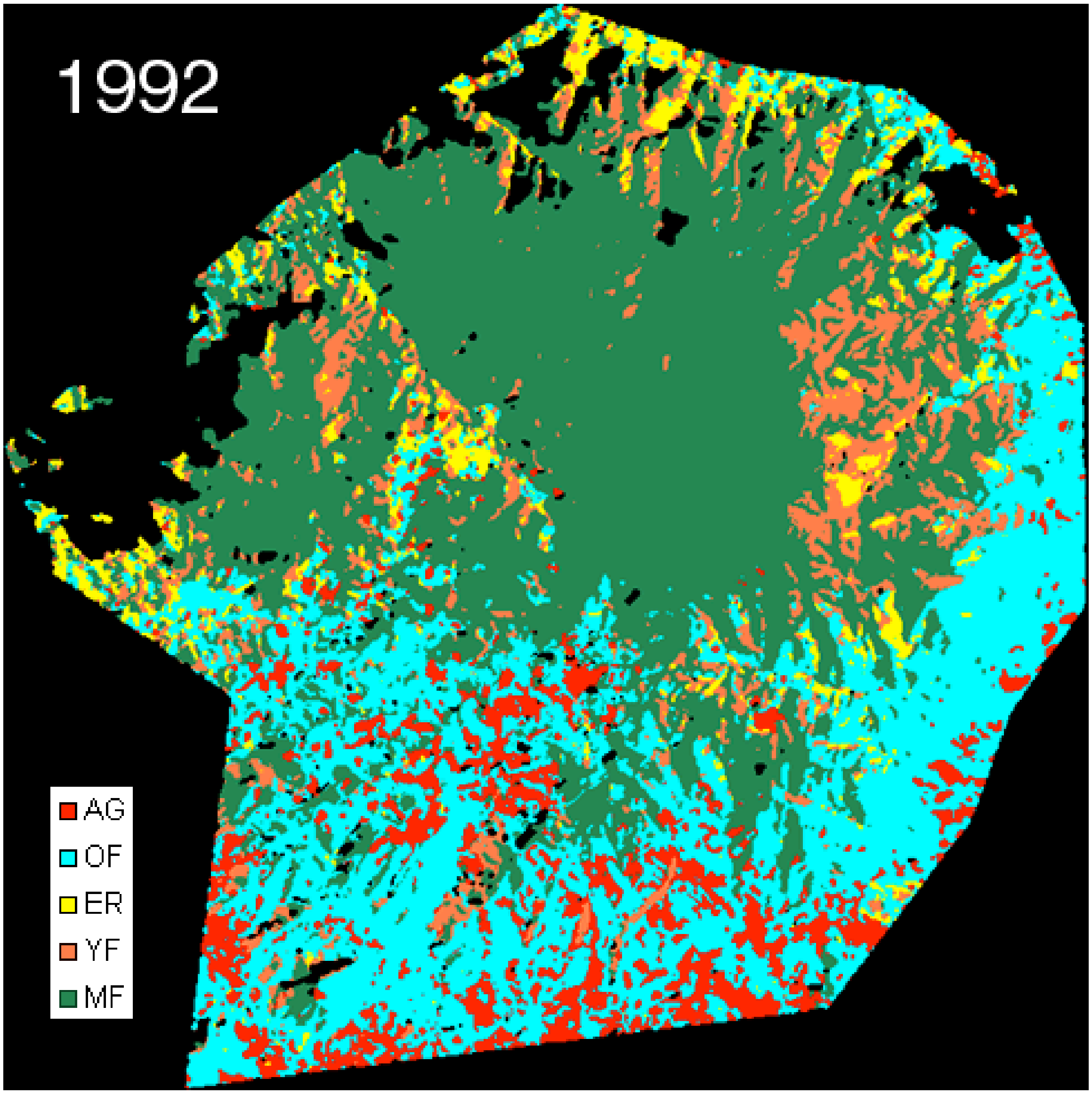


Figure 1: Location and topography of Celaque National Park. The 1800 m buffer zone is the core area of the park enclosed by the 1800 m elevation contour. This area has the highest level of protection. For a detailed view of CNP and its surroundings, follow this link (right-click to zoom) http://www.garrobo.org/celaque/topolocat50k.html. To view an mpeg flyover follow this link http://www.garrobo.org/morazan/celaque/celaque_flyover.html.



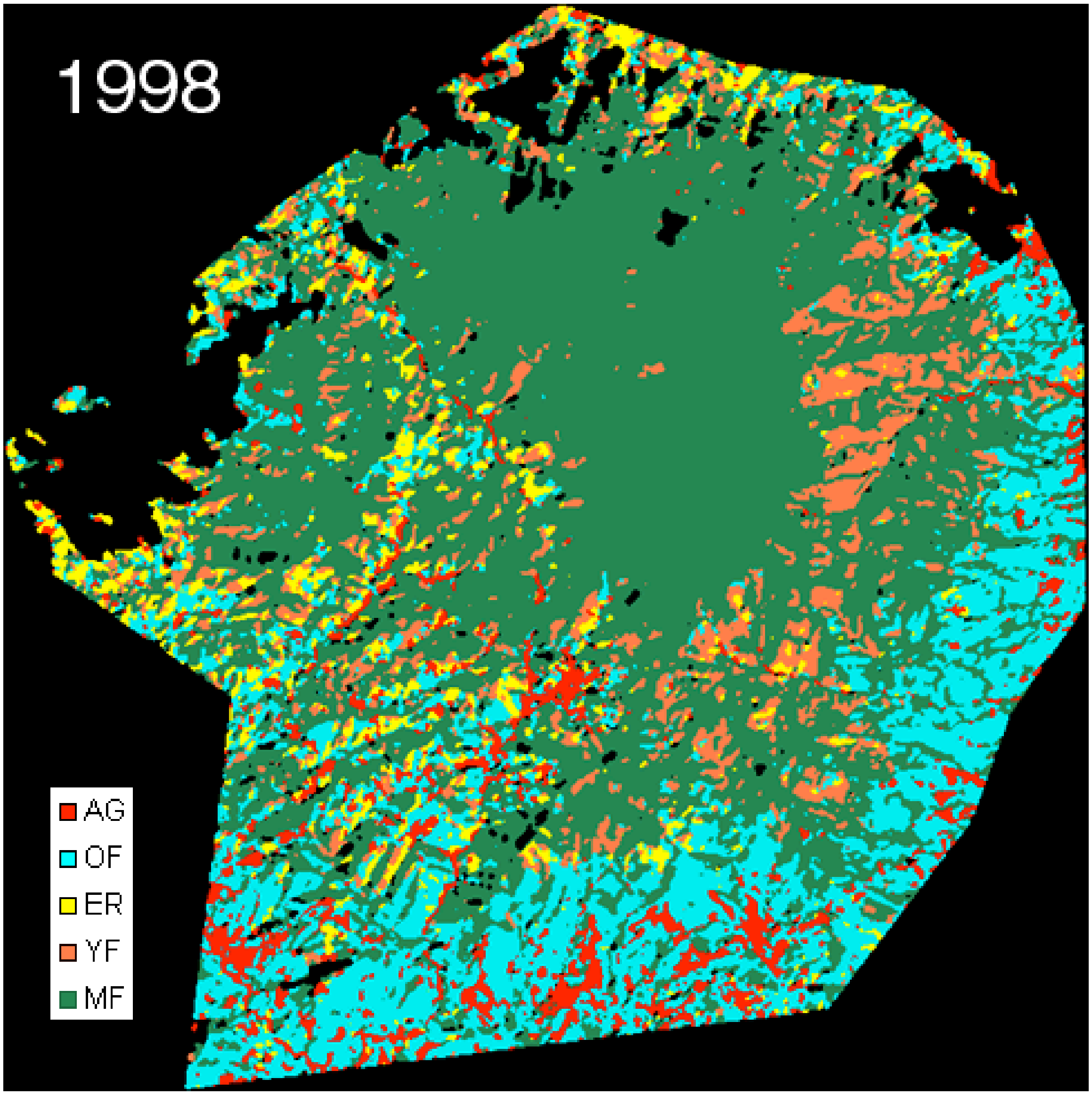
(a)

Figure 2: Classification of CNP according to forest regeneration stage: a) 1987, b) 1992, c) 1998.



(b)

Figure 2: (*continued*).



(c)

Figure 2: (*continued*).

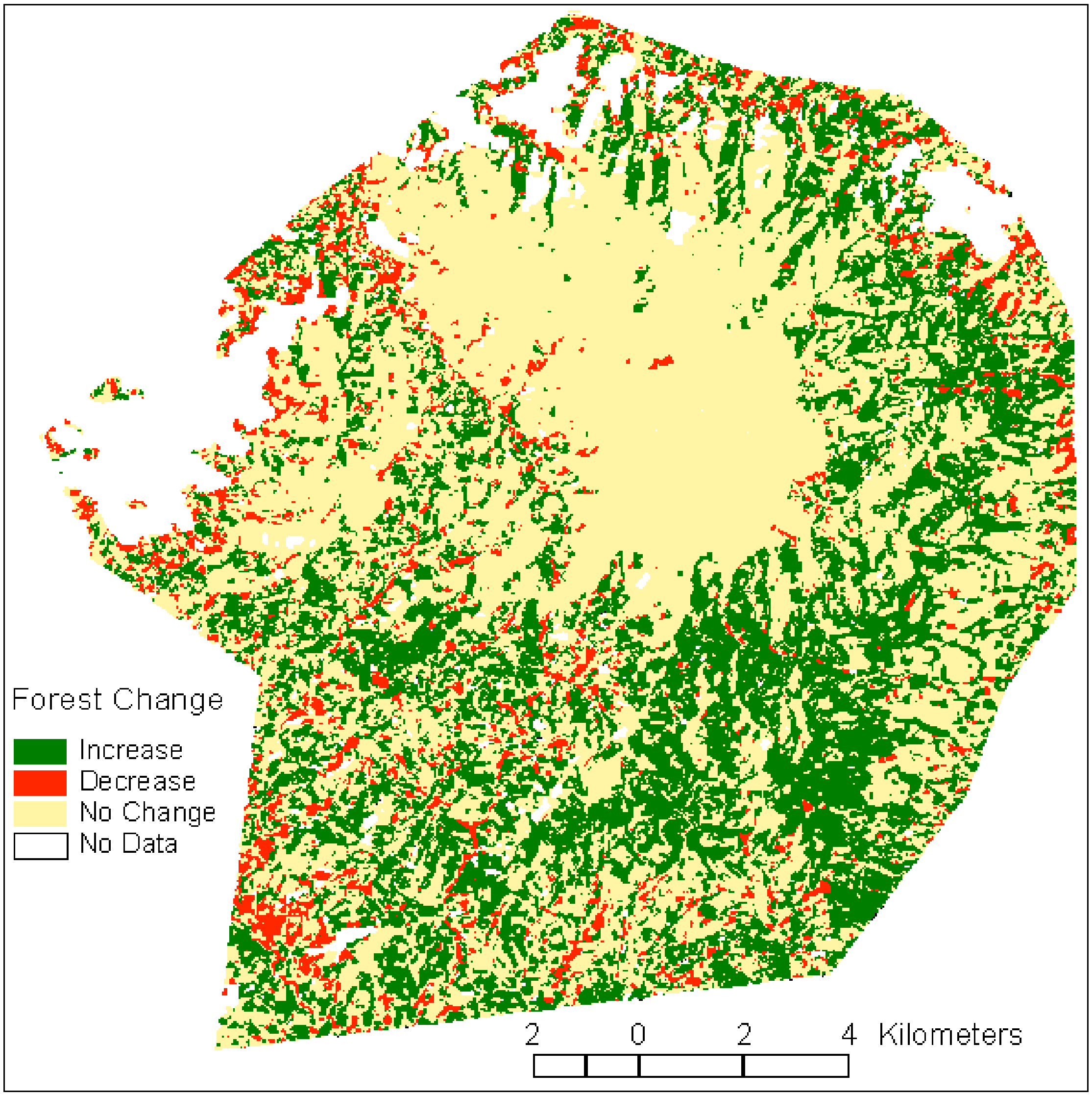


Figure 3: Landcover transitions in Celaque National Park (1987-1998). 46% of the study area changed state, of this 80% increased in forest vegetation cover and 20% decreased. Areas that remained constant include the outer edges of the park where disturbance was continuous, and the central core where little disturbance occurred. Increase in vegetation cover was defined as any transition in the direction of the sequence: AG→OF→ER→YF→MF (e.g., AG→YF), and a decrease in forest vegetation as any transition in the opposite direction (e.g., YF→AG).

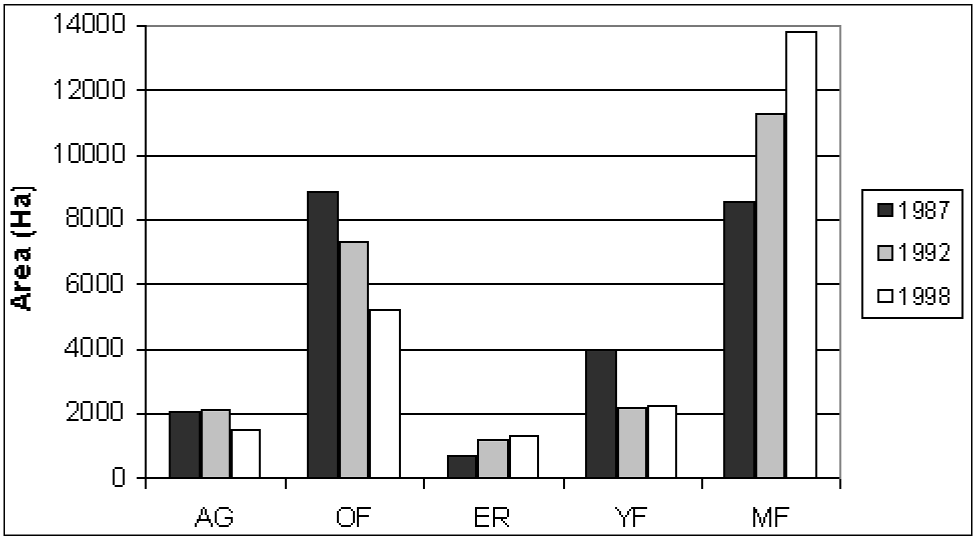
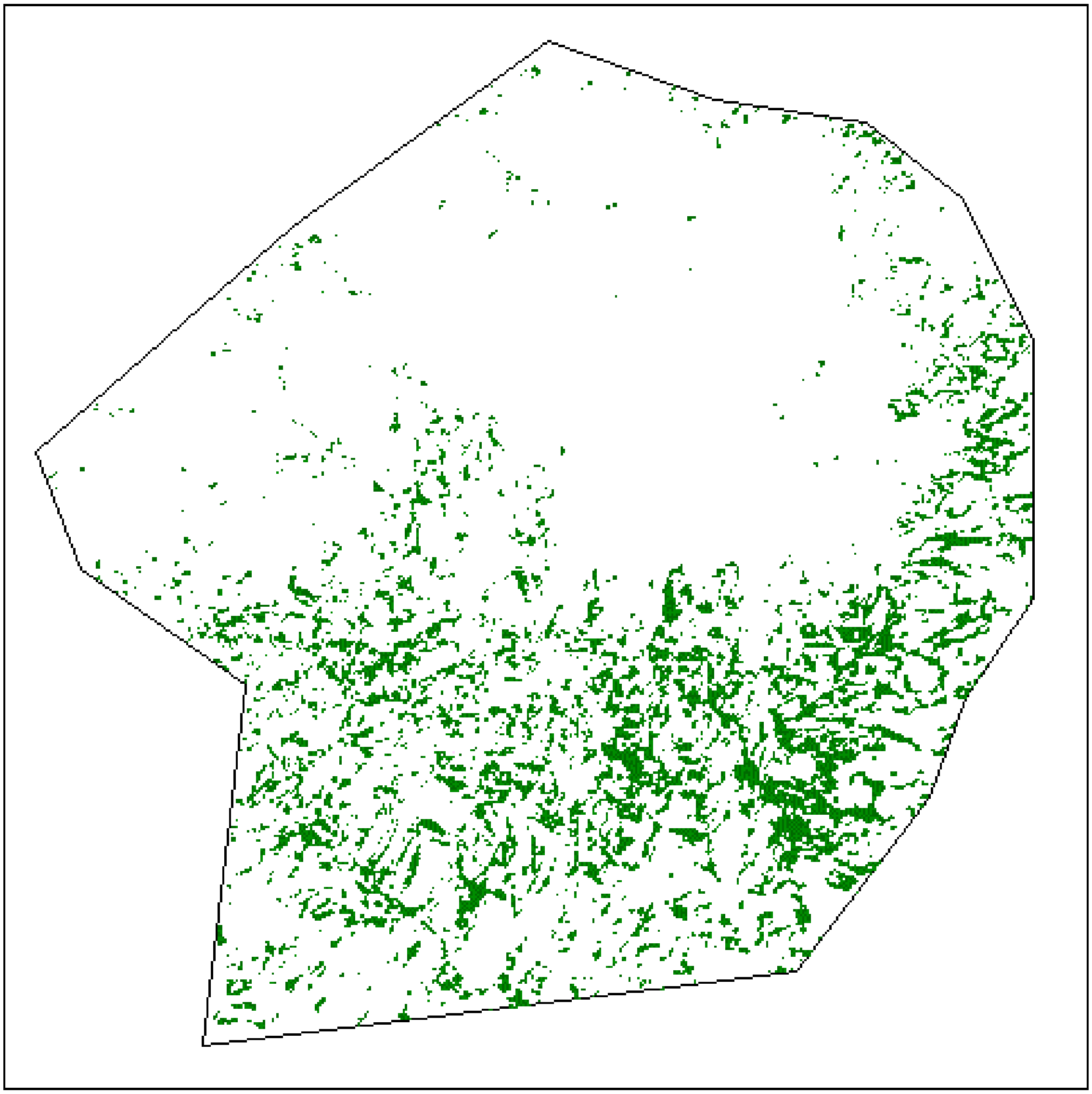
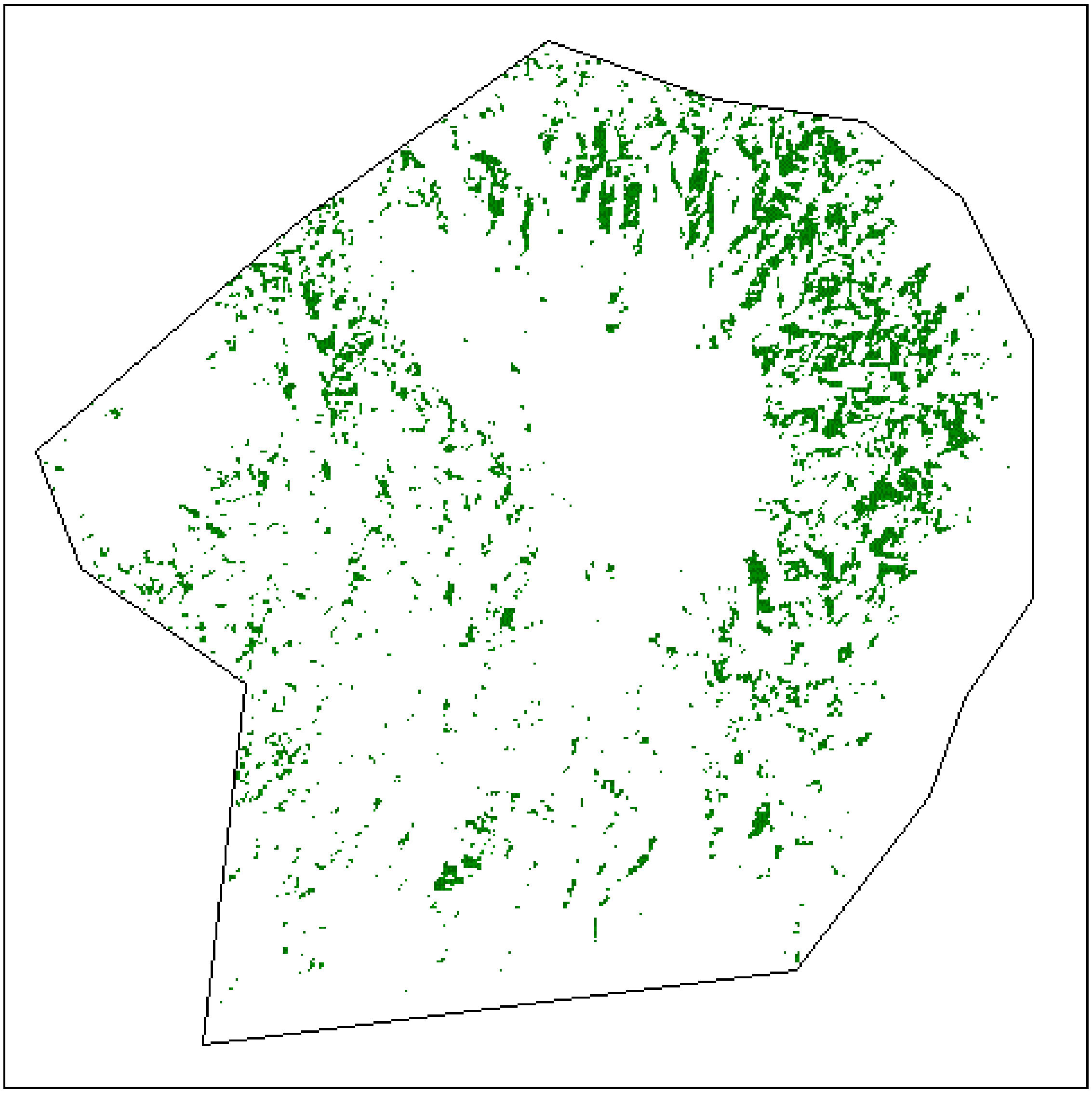


Figure 4: Change in forest cover proportions between 1987 and 1998.



(a)

Figure 5: Main transitions in forest regeneration stage in CNP, 1987-98: a) OF→MF, b) YF→MF



(b)

Figure 5: (*continued*).

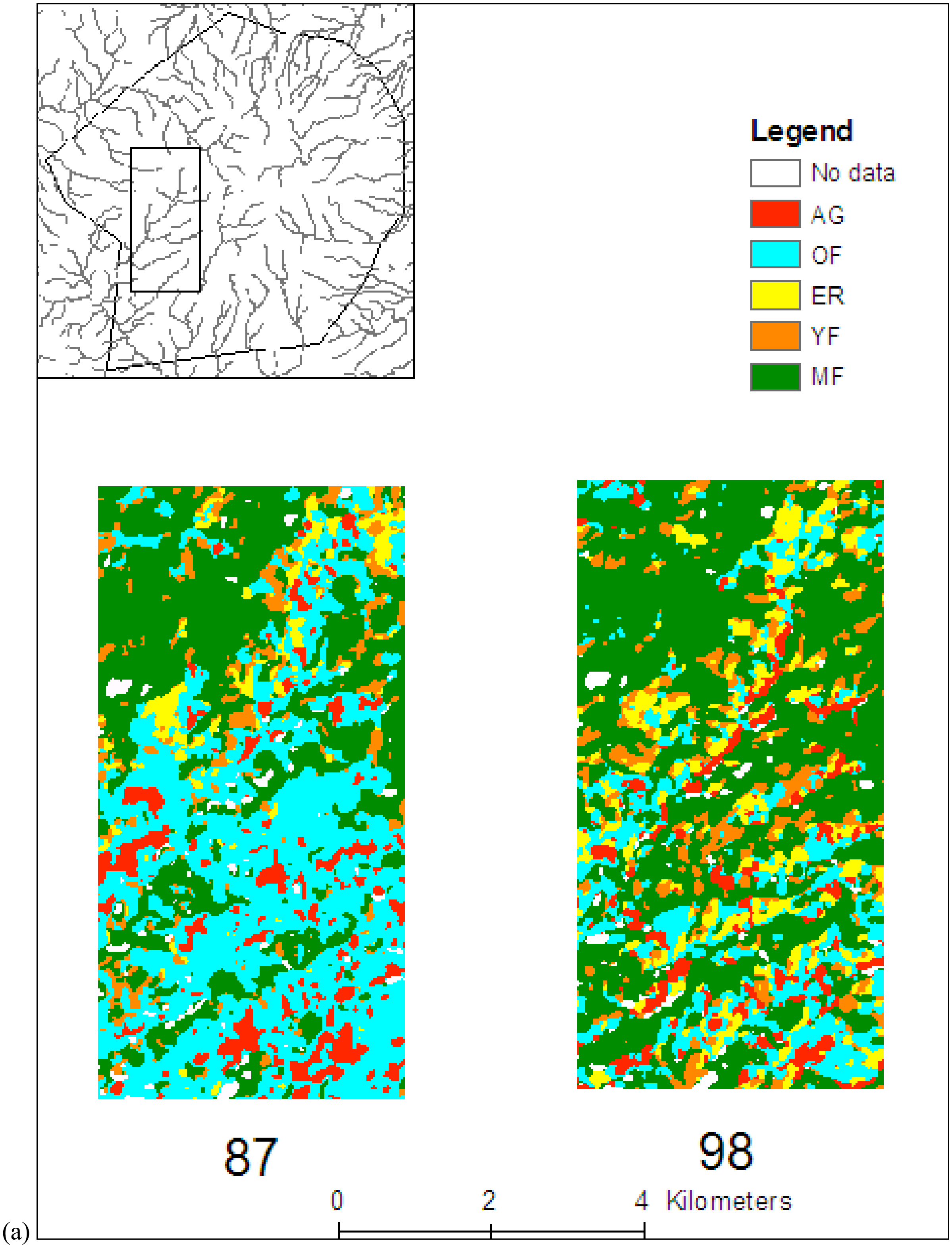
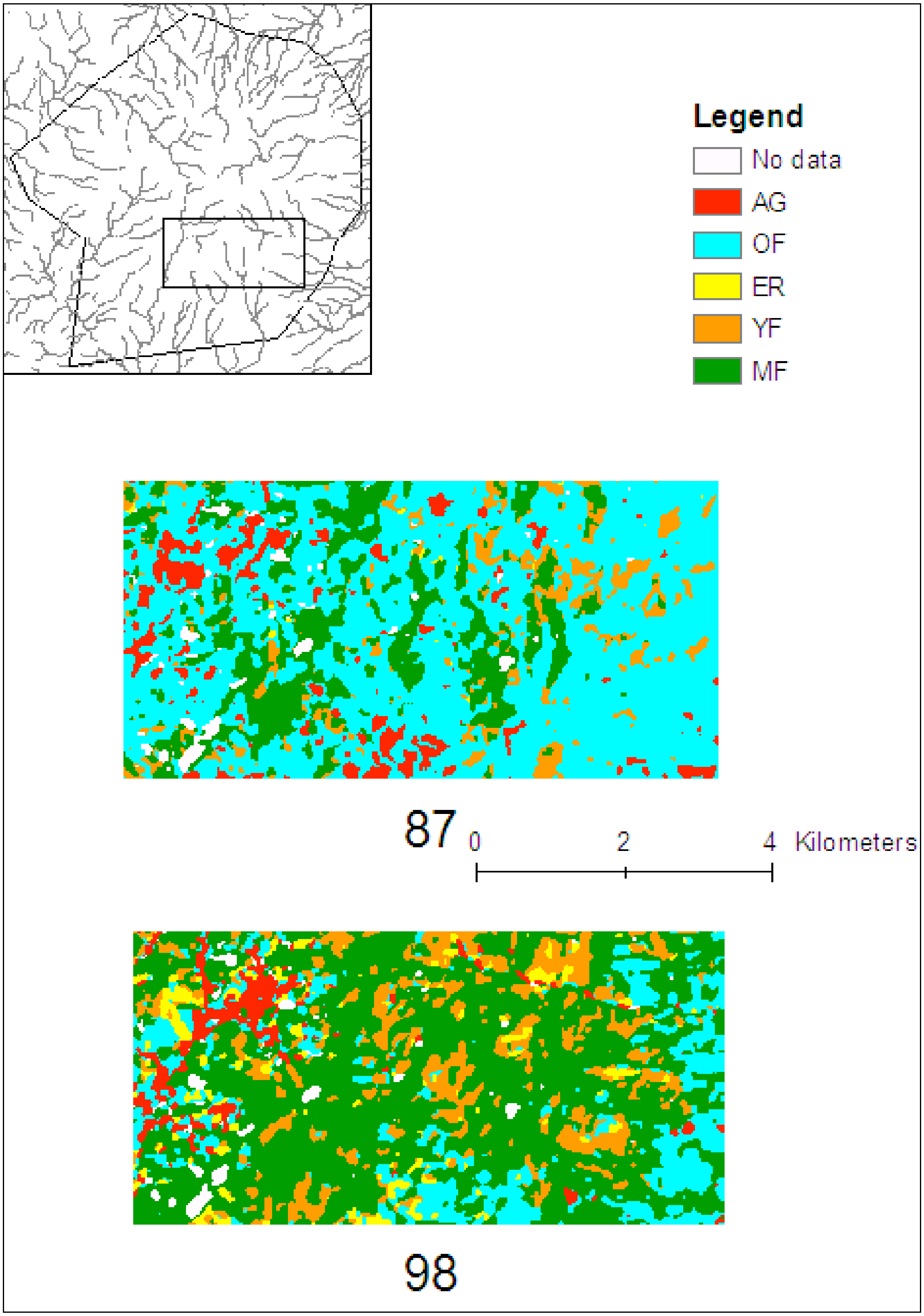
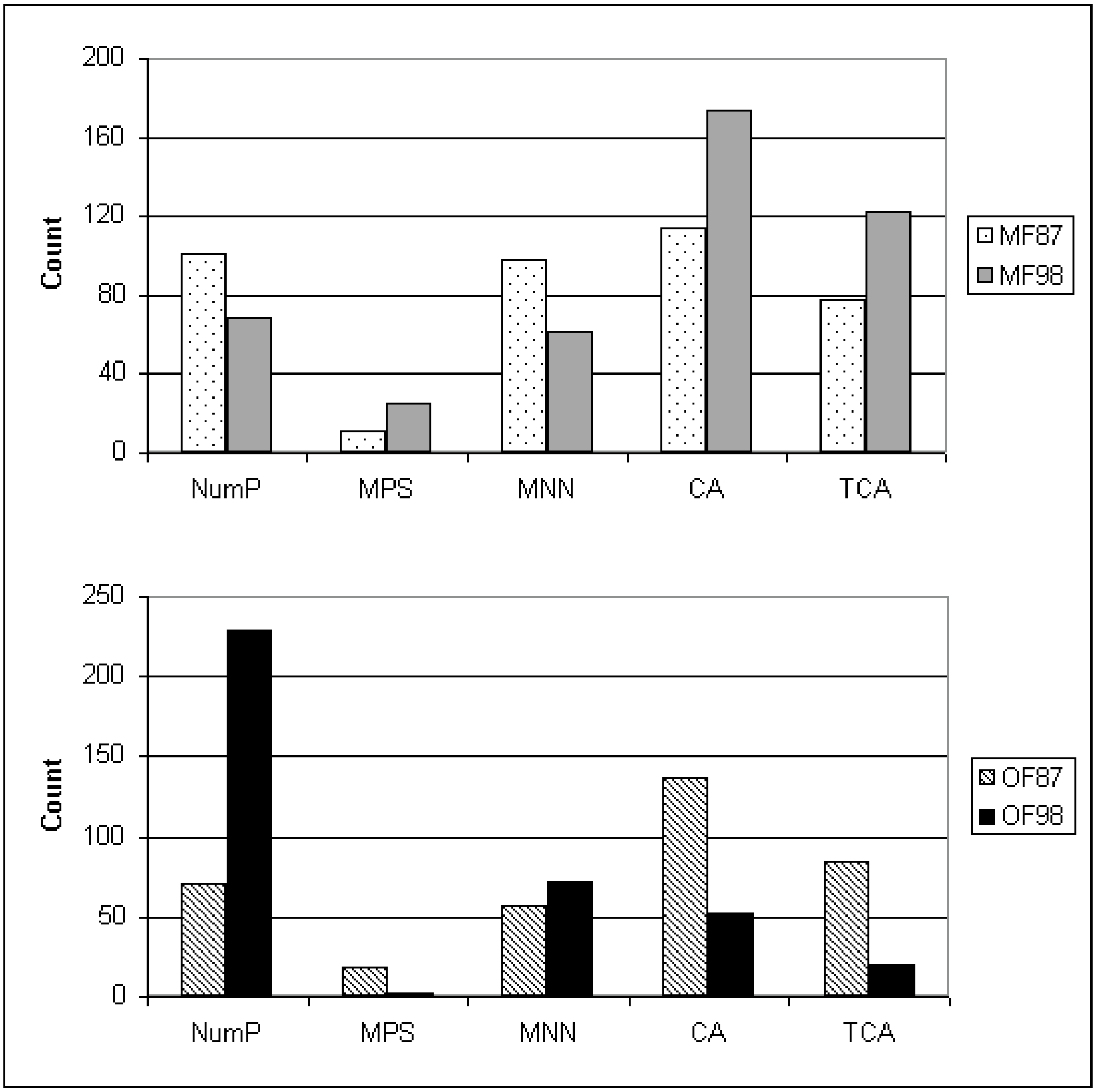


Figure 6: Forest regeneration in two 32-km^2 landscapes between 1987 and 1998. Inset shows the landscapes' location along with the network of streams in and around CNP: a) landscape A, b) landscape B.



(b)

Figure 6: (*continued*).



(a)

Figure 7: Change in selected metrics in landscapes A and B. OF and MF metrics experienced similar but inverse changes between 1987 and 1998. MPS is given in ha, MNN is given in m, CA and TCA are given in ha x10: a) landscape A, b) landscape B.

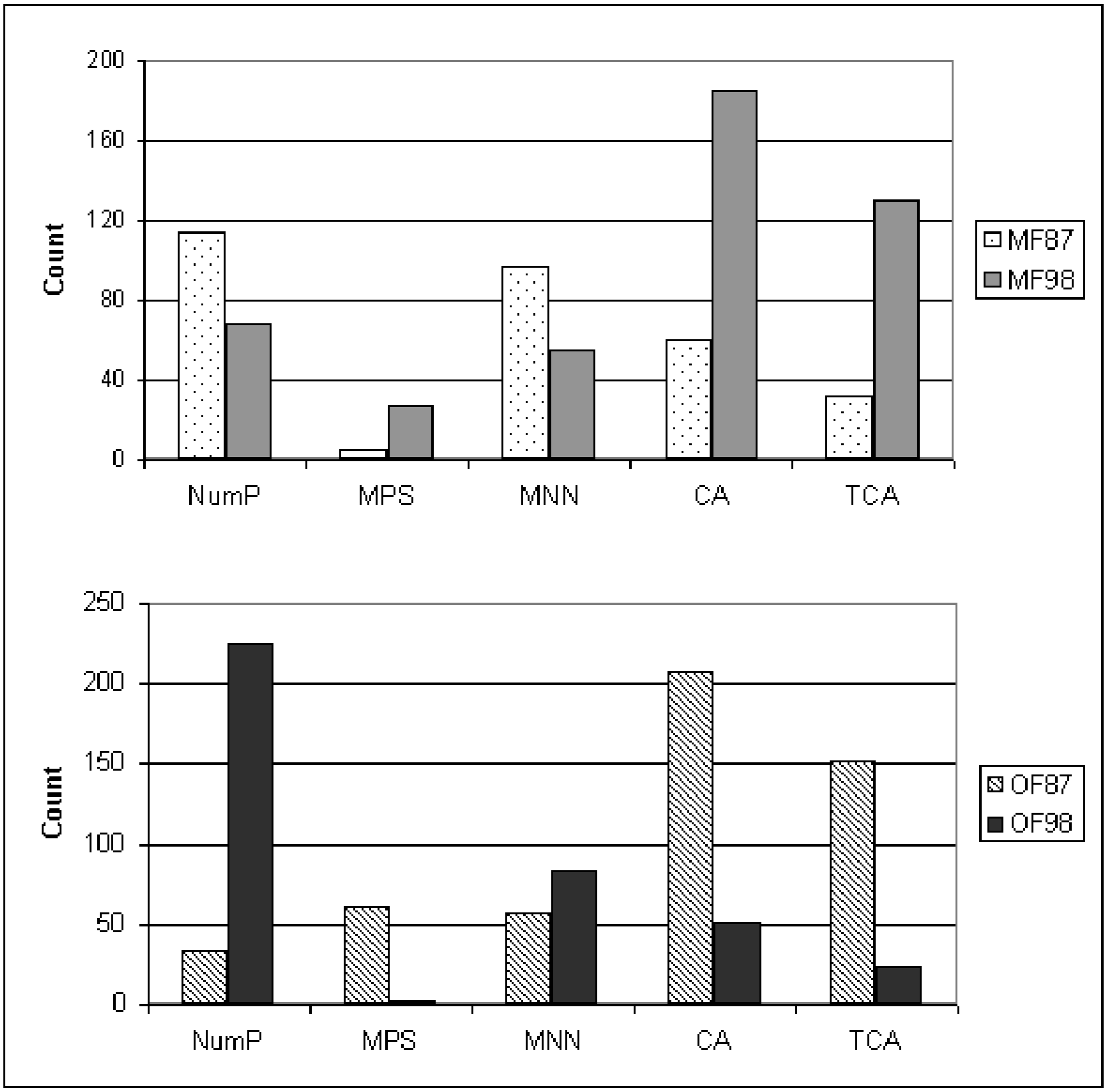


Figure 7: (*continued*).

References

AFE-COHDEFOR, and CONSULT, L. (1999). Informaciones seleccionadas sobre el proyecto "Fomento del Parque Nacional Montaña de Celaque". Proyecto Celaque / GTZ, Tegucigalpa.

Baker, W. (1989). Landscape ecology and nature reserve design in the Boundary Waters Canoe area, Minnesota. *Ecology* **70,** 23-35.

Brown, S., and Lugo, A. E. (1990). Tropical secondary forests. *Journal of Tropical Ecology* **6,** 1-32.

Brown, S., A. E. Lugo, et al. (1992). Processes and Land for Sequestering Carbon in the Tropical Forest Landscape, *Water Air and Soil Pollution* **64**. 139-155.

Chavez, P. S., Jr. (1988). An improved Dark-Object Subtraction technique for atmospheric scattering correction of multispectral data. *Photogrammetric Engineering and Remote Sensing* **24,** 459-479.

CIFOR. (1998). **Annual Report**. Center for International Forestry Research, Jakarta.

Corlett, R. T. (1995). Tropical Secondary Forests. *Progress in Physical Geography* **19,** 159-172.

De Jong, B. H. J., Ochoa-Gaona, S., Castillo-Santiago, M. A., Ramirez-Marcial, N., and Cairns, M. A. (2000). Carbon flux and patterns of land-use/land-cover change in the Selva Lacandona, Mexico. *Ambio* **29,** 504-511.

Fonseca, J. P., Moreno, M. L., and Padgett, G. S. (1999). "Estructura florística, uso de recursos y educación ambiental en el Parque Nacional Montaña de Celaque.", Universidad Nacional Autónoma de Honduras.

Gonzalez-Espinosa, M., Quintana-Ascencio, P. F., Ramirez-Marcial, N., and Gaytan-Guzman, P. (1991). Secondary succession in disturbed Pinus - Quercus forests in the highlands of Chiapas, Mexico. *Journal of Vegetation Science* **2,** 351-360.

Houghton, R. A. (1991). Tropical deforestation and atmospheric carbon dioxide. *Climatic Change* **19,** 99-118.

Janzen, D. H. (1986). "Guanacaste National Park : tropical, ecological and cultural restoration." Editorial Universidad Estatal a Distancia, San José, Costa Rica.

Lamb, D., Parrotta, J., Keenan, R., and Tucker, N. (1997). Rejoining habitat remnants: Restoring degraded rainforest lands. *In* "Tropical Forest Remnants: Ecology, management, and conservation of fragmented communities." (W. F. Laurance, and R. O. Bierregaard, Eds.), pp. 366-385. The University of Chicago Press, Chicago.

Laurance, W. F., Laurance, S. G., and Delamonica, (1998). Tropical forest fragmentation and greenhouse gas emissions. *Forest Ecology and Management* **110,** 173-180.

Laurance, (2000). Do edge effects occur over large spatial scales? *Trends in Ecology & Evolution* **15,** 134-135.

Lugo, A. E. and S. Brown (1992). Tropical Forest as Sinks of Atmospheric Carbon, *Forest Ecology and Management* **54**, 239-255.

Myers, N. (1992). Tropical Forests and Climate.

Neptstad, D. C., Moutinho, P., Uhl, C., Vieira, I., and Silva, J. C. d. (1996). The ecological importance of forest remnants in an eastern Amazonian frontier landscape. *In* "Forest Patches in Tropical Landscapes." (J. S. a. R. Greenberg, Ed.), pp. 133-150. Island Press, Covelo, CA.

Rosenfield, G. H., and Fitzpatrick-Lins, K. (1986). A coefficient of agreement as a measure of thematic classification accuracy. *Photogrammetric Engineering and Remote Sensing* **52,** 223-227.

Rotmans, J., and Swart, R. J. (1991). Modelling tropical deforestation and its consequences for global climate. *Ecological Modelling* **58,** 217-248.

Rudel, T. K., Bates, D., and Machinguiashi, R. (2002). A tropical forest transition? Agricultural change, out-migration, and secondary forests in the Ecuadorian Amazon. *Annals of the Association of American Geographers* **92,** 87-102.

Sarmiento, F. O. (1997). Arrested succession in pastures hinders regeneration of Tropandean forests and shreds mountain landscapes. *Environmental Conservation* **24,** 14-23.

Silver, W. L., Ostertag, R., and Lugo, A. E. (2000). The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands. *Restoration Ecology* **8,** 394-407.

Simberloff, D. (1994). Habitat fragmentation and population extinction of birds. *Ibis* **137,** S105-S111.

Smith, A. P. (1997). Deforestation, fragmentation, and reserve design in western Madagascar. *In* "Tropical Forest Remnants: Ecology, management, and conservation of fragmented communities." (W. F. Laurance, and R. O. Bierregaard, Eds.), pp. 415-441. The University of Chicago Press, Chicago.

Smith, J., and Scherr, S. J. (2002). Forest Carbon and Local Livelihoods : Assessment of Opportunities and Policy Recommendations. Center for International Forestry Research.

Smith, J., van de Kop, P., Reategui, K., Lombardi, I., Sabogal, C., and Diaz, A. (1999). Dynamics of secondary forests in slash-and-burn farming: Interactions among land use types in the Peruvian Amazon. *Agriculture Ecosystems & Environment* **76,** 85-98.

Southworth, J. and Tucker, C. (2001). The Influence of Accessibility, Local Institutions,and Socioeconomic Factors on Forest Cover Change in the Mountains of Western Honduras *Mountain Research and Development* **21**, 276–283.

Walker, R., Salas, W., Urquhart, G., Keller, M., Skole, D., and Pedlowski, M. (1999). Secondary Vegetation: Ecological, Social, and Remote Sensing Issues. NASA's Goddard Space Flight Center / INPE/CPTEC, Greenbelt, MD.

Zúniga-Andrade, E. (1990). “Modalidades de la lluvia en Honduras.” Editorial Guaymuras, Tegucigalpa.