Environmental Monitoring and Assessment (2005) **105:** 69–80
DOI: 10.1007/s10661-005-3156-5

ASSESSING PROTECTED AREA EFFECTIVENESS USING SURROUNDING (BUFFER) AREAS ENVIRONMENTALLY SIMILAR TO THE TARGET AREA

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(Received 1 July 2003; accepted 30 June 2004)

Abstract. Many studies are based on the assumption that an area and its surrounding (buffer) area present similar environmental conditions and can be compared. For example, in order to assess the effectiveness of a protected area, the land use/cover changes are compared inside the park with its surroundings. However, the heterogeneity in spatial variables can bias this assessment: we have shown that most of the protected areas in Mexico present significant environmental differences between their interior and their surroundings. Therefore, a comparison that aims at assessing the effectiveness of conservation strategies, must be cautioned. In this paper, a simple method which allows the generation of a buffer area that presents similar conditions with respect to a set of environmental variables is presented. The method was used in order to assess the effectiveness of the Calakmul Biosphere Reserve, a protected area located in the south-eastern part of Mexico. The annual rate of deforestation inside the protected area, the standard buffer area (based upon distance from the protected area only) and the *similar buffer area* (taking into account distance along with some environmental variables) were 0.3, 1.3 and 0.6%, respectively. These results showed that the protected area was effective in preventing land clearing, but that the comparison with the standard buffer area gave an over-optimistic vision of its effectiveness.

Keywords: buffer areas, change assessment, GIS, Mexico, protected area effectiveness, spatial heterogeneity

1. Introduction

Spatial information technology is used increasingly for the evaluation of governmental programs and policies (East and Wood, 1998; Loomis and Echohawk, 1999; El-Raey *et al*., 2000; Ozcan *et al*., 2003). Many GIS-based studies involve the use of buffer areas in order to generate a surrounding zone for comparative purposes with the target area (Sánchez-Azofeifa *et al*., 1999, 2003; Bruner *et al.*, 2001; Caro, 2001, 2003; Liu *et al.*, 2001; Samways and Kreuzinger, 2001). The assumption that an area and its surrounding (buffer) area present similar environmental conditions is done, although not always explicitly. Nevertheless, the heterogeneity in spatial variables can violate this assumption and bias the assessment. For example, in order to assess the effectiveness of protected areas, Bruner *et al*. (2001) compared land clearing within the park boundaries and a belt (buffer) surrounding the parks. They found that land clearing is lower inside the parks and attributed it to the effectiveness of the parks. However, these differences may be the effect of other factors such as the differences between the environmental characteristics of the two compared areas (Vanclay, 2001).

The aims of this study are to evaluate how heterogeneous spatially-explicit environmental variables influence change assessment and to develop a method to deal with this heterogeneity when generating buffer areas. This article presents (a) an evaluation of the assumption of the comparability between the protected areas and their surroundings, (b) a simple method aimed at generating a buffer area similar to the target area with regard to several spatial variables and, (c) an application in order to asses a tropical protected area.

2. Study Area

Mexico encompasses a continental territory of near two million square kilometres and is one of the five biologically richest countries, therefore considered as megadiverse (Groombridge and Jenkings, 2000). However, it has been undergoing rapid processes of land use/cover changes with an average rate of deforestation of 0.5% per year during the last 25 yr (Mas *et al.*, 2004). During the past 40 yr, Mexico has moved actively to identify lands to include in a system of protected areas. Nowadays, Mexico has 148 protected areas, including national parks, biosphere reserves, sanctuaries and marine parks, which cover 7% of the territory and 17% of the territorial sea (CONANP, 2003).

In order to illustrate this method, the deforestation was analyzed in a region in the south-eastern part of Mexico where an important reserve, the Calakmul park, is located. This protected area, which extends over 722 000 ha of lowland tropical forests, was declared in 1989 and accepted as a UN Biosphere Reserve in 1993 (Figure 1). It protects many endangered species, provides an important refuge for migratory birds and forms a biological corridor to reserves in Belize, Guatemala and Mexico. Nevertheless, expansion of shifting agriculture and logging in and around the Reserve are threatening the conservation of the forest ecosystems (Wood *et al.*, 2000).

3. Materials and Methods

In order to assess land use/cover changes, a multidate digital GIS database was used. This database was obtained by the integration of land use/cover maps of 1976, 1993 and 2000 at the scale of 1:250 000 (Mas *et al.*, 2004). A digital elevation model along with soil, road network, settlements digital maps with a scale of 1:250 000, was obtained from the National Institute of Geography, Statistics and Informatics (INEGI). The digital elevation model was used to create a slope map. Digital maps

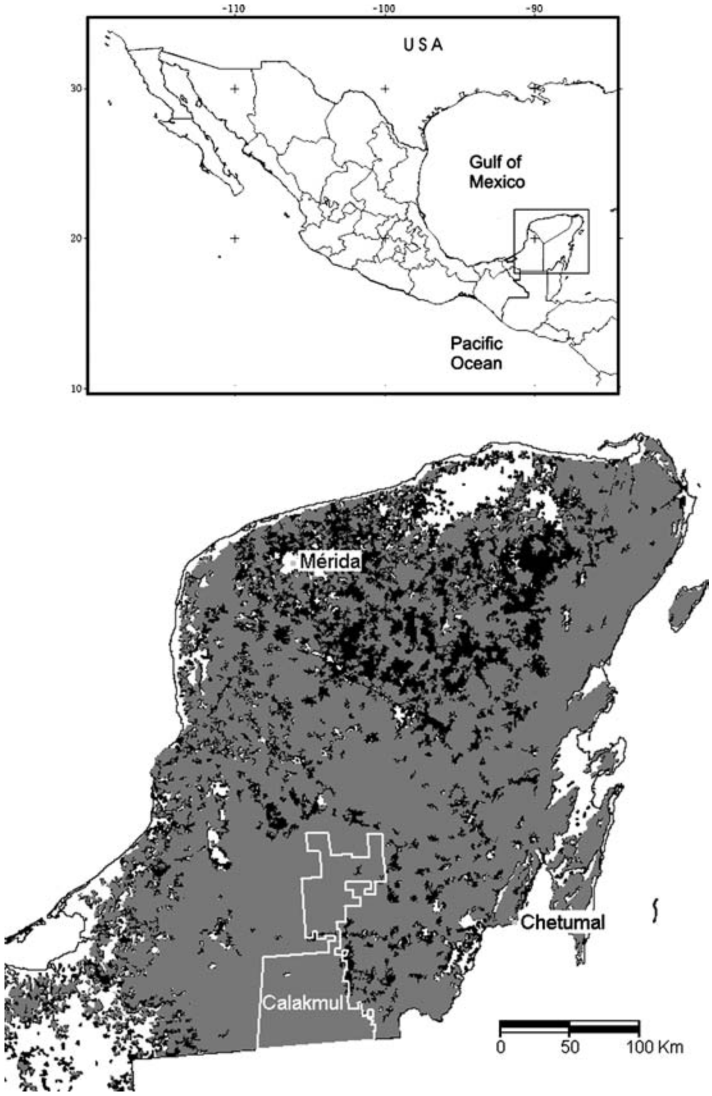

Figure 1. Location of the Calakmul Biosphere Reserve. Forest areas and deforested areas between 1993 and 2000 are respectively grey and black shaded.

of the shortest distance to the nearest road and to the nearest settlement were also produced. A digital map of protected areas was obtained from the National Institute of Ecology (INE). The softwares Arc/info and Access were used respectively to manage GIS and tabular databases.

As a first step, we compared some environmental characteristics of the protected areas in Mexico with their surroundings (buffer of 10 km around the areas). The distance of ten kilometres was chosen because (a) it creates buffer area large enough to obtain reliable statistics on land cover change based upon the multidate GIS database and, (b) it allows the obtaining of results comparable with Bruner *et al.* (2001), Sánchez-Azofeifa *et al.* (2003) and Kinnaird *et al.* (2003). We discarded protected areas with continental buffer area less than 250 ha (small protected areas located on an island or along the coast) because of the limitations of the dataset at scale 1:250 000. The five environmental variables used here were elevation, slope, soils, distance from roads, and distance from settlements. Slope categories were defined according to their suitability for irrigated agriculture (0–3°), rain-fed agriculture (3–8°) and forest conservation (slope >30°) (Lugo Hubp, 1988). These variables were chosen, because many studies have shown their relationship with land use/cover changes (Sader and Joyce, 1988; Apan and Peterson, 1998; Ochoa-Gaona and González-Espinosa, 2000; Mas and Puig, 2001; Soares-Filho *et al.*, 2001). The comparison was based upon a Chi-Square test. This test procedure tabulates a variable into categories and compares the observed and expected frequencies in each category to test that all categories contain the same proportion of values. In this case, the test responded to the question "Are the environmental conditions significantly different inside the protected area when compared to their surroundings?"

As a follow-up step, a method aimed at generating a buffer area environmentally similar to the target area was developed and applied to assess the effectiveness of the Calakmul Biosphere Reserve. This method was designed for raster maps and was based upon the search of pixels surrounding the target area, which would constitute a buffer area that presents the same proportion of some categorical variables. Hereafter, such buffer area will be referred to as *similar buffer area* in contrast with the standard buffer area based only upon the distance from the target. First, the spatial variables that are important with regard to the topic of the study must be identified. For example, in the case of land clearing, the impact of factors such as the slope, the type of soil, the distance from road must be evaluated in order to select a subset of the more important variables. The selection of non-correlated variables is recommended in order to select variables, which better explain the variance of the dependent variable (land clearing). The identification of such variables can be done by means of graphics or through statistical approaches such as correlation, linear regression or logistic regression (Apan and Peterson, 1998; Ochoa-Gaona and González-Espinosa, 2000; Mas and Puig, 2001; Soares-Filho *et al.*, 2001). In the case study of Calakmul, the relationships between the deforestation and five spatial variables (the type of soils, the elevation, the slope, the distance from human settlements and from roads) were assessed using a chi-square test and a logistic regression in order to select the more important variables influencing the deforestation process in the region. Cramer's V allowed the assessment of the strength of the association between the deforestation and the spatial variables. It ranges between 0 (no relation between factors) and 1 (perfect relations between the two factors). A backward logistic regression was used to describe the relationship of the environmental independent variables to the dichotomous dependent variable (deforestation/no-deforestation). In order to assess the relative importance of the independent variables, we interpreted the partial difference of log-likelihood (-2 Log LR) for the model with a given variable dropped from the equation.

Continuous variables were recoded into ranks in order to simplify the procedure. The target area is characterized by calculating the proportion of area, or the number of pixels, belonging to each combination of the categories of each variable. These proportions concerning the target area constitute the requirements that the algorithm will use when exploring the surroundings of the target area. The number of variables and the number of ranks used for each variable must be low, because the number of combinations increases exponentially with the number of variables and the number of categories for each variable. A maximum search distance is set, based upon expert's knowledge, to delineate a surrounding zone, which contains the candidate pixels that constitute the buffer area. These candidate pixels are ranked using the distance from the boundary of the target area and compared with the statistics of the target area. If the pixel fulfils the statistical requirements (e.g., presents a combination of variables which exists in the target area), it is selected, if not, it is discarded. This iterative process is carried out until the buffer area is totally constituted or the pool of candidate pixels is finished.

The variables are not considered independently because many processes such as erosion, landslide or forest clearing are dependant upon the interaction (combination) of various variables. For example, different rates of deforestation can be expected in an area covered by fertile and non-fertile soils, or located near or far away from a road. Nevertheless, an area with very low accessibility will present a low rate of deforestation that is independent from the fertility of the soil.

The standard buffer area and the *similar buffer area* were generated around the Calakmul Biosphere Reserve using, respectively, only the distance from the protected area boundaries and, this distance along with the selected environmental variables. The rates of deforestation were assessed inside the protected areas and the two buffer areas.

4. Results

The comparison of environmental characteristics inside the protected areas and in their surroundings was carried out over 118 protected areas. More than 60% of the protected areas have significant differences amongst the five environmental conditions included in this study (Table I). Table II shows the number of protected areas, which present differences concerning each of the environmental variables.

In Figures 2–6 a comparison is made between the protected and surrounding areas with reference to the five environmental variables. Protected areas are located in remote places, are less represented above 500 m altitude (where over 60% of crop and pasture lands and 71% of the population are found in Mexico), and comprise

TABLE I
Number of environmental variables which present significant difference inside the protected areas and their surroundings ($p = 0.05$)

Numbers of variables	Number of protected areas	%
5	74	62.7
4	16	13.6
3	15	12.7
2	12	10.2
1	1	0.8

TABLE II
Number of protected areas which present different environmental conditions with regards to 5 variables ($p = 0.05$)

Variables	Number of protected areas	%
Distance from roads	113	95.8
Soil type	108	91.5
Distance from settlements	105	89.0
Elevation	90	76.3
Slope	88	74.6

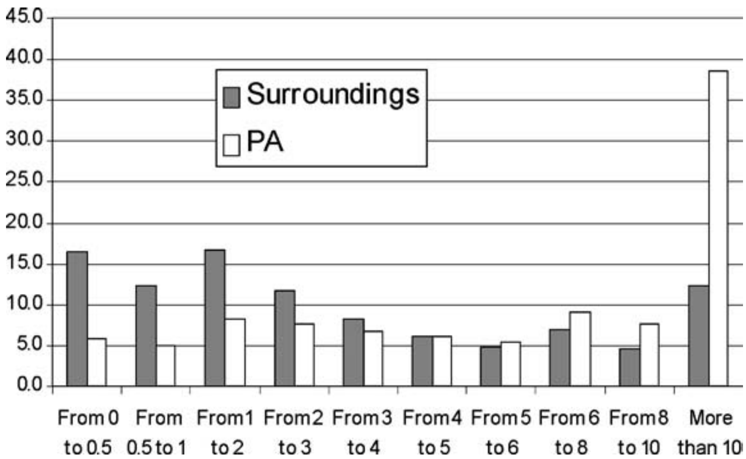

Figure 2. Comparison between protected areas and their surroundings with regard to accessibility (Distance from roads). The graph expresses the proportion (%) of land in the different ranks of distance buffer zones from roads (kilometres).

more unsuitable soils for agriculture and livestock production, such as regosol, lithosol, gleysol and solonchak. No significant difference with regard to slope was found. However, a more detailed analysis shows that gentle slopes are well represented in protected areas located in arid regions and wetlands meanly. This

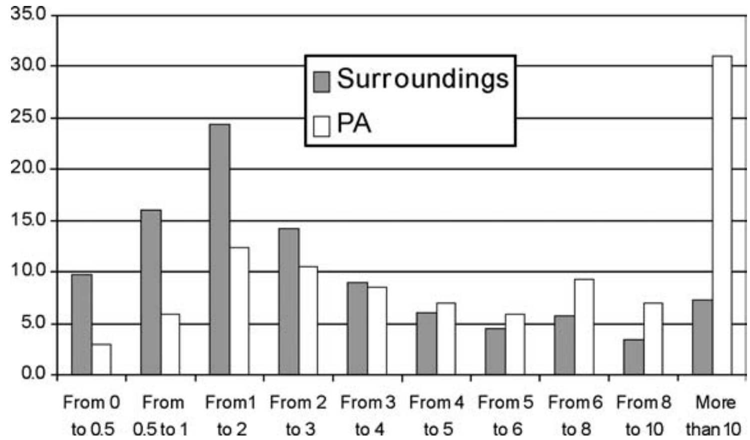

Figure 3. Comparison between protected areas and their surroundings with regard to accessibility (Distance from settlements). The graph expresses the proportion (%) of land in the different ranks of distance buffer zones from settlements (kilometres).

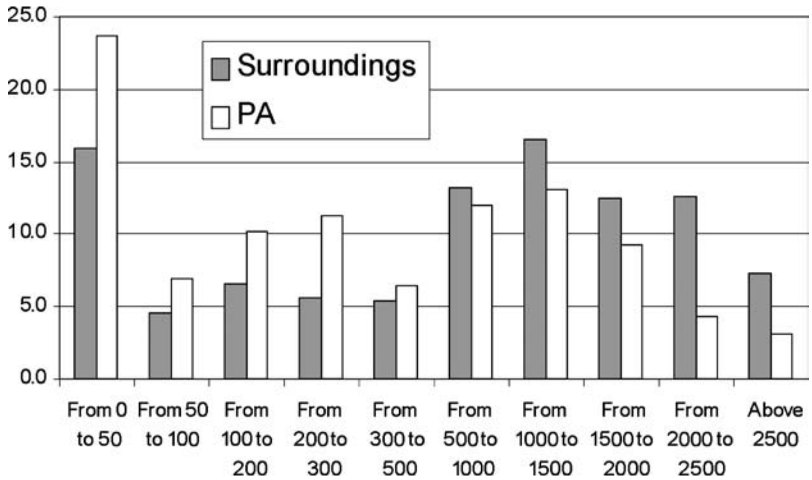

Figure 4. Comparison between protected areas and their surroundings with regard to the relief (Elevation). The graph expresses the proportion (%) of land in the different elevation zones (meters above sea level).

bias of protected areas towards remote places with least potential for commercial or subsistence use has been documented elsewhere (Margules and Pressey, 2000; Pressey *et al.*, 2002). The large environmental differences between the interior and the surrounding of the protected areas are understandable because the areas declared as protected areas generally present a higher grade of conservation, due to their inaccessibility and unsuitability for agricultural development. Therefore, comparisons between a protected area and its surrounding aimed at assessing its effectiveness must be cautioned.

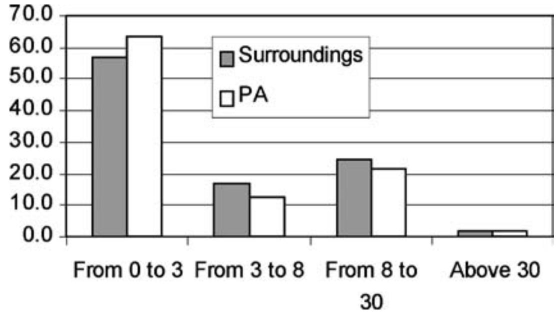

Figure 5. Comparison between protected areas and their surroundings with regard to the relief (Slope). The graph expresses the proportion (%) of land in the different slope angle classes (degree).

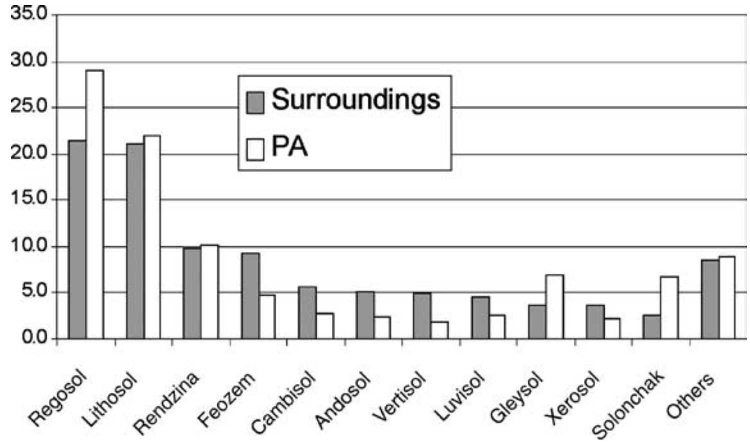

Figure 6. Comparison between protected areas and their surroundings with regard to the soil. The graph expresses the proportion (%) of land in the different type of soils.

In the Calakmul region, it was found that the main factors controlling deforestation were the type of soil and the distance from settlements and from roads (Tables III and IV). A *similar buffer area* around the protected area was generated based upon these three variables. A standard buffer area (based upon distance from the target area only) was also generated (Figure 7).

Inside the protected area, the rate of deforestation was low (0.3%/yr). This rate was higher within the standard buffer area (1.3%/yr), which could be interpreted as an effective impact of the protected area. However, when taking into account the soil and the distance from settlements and from roads (that is comparing with the *similar buffer area*) the difference of the deforestation rate between protected area and surrounding area is lower. This indicates that the status of protection plays a certain role (the deforestation rate in the *similar buffer area* is twice the rate inside the protected area), but that the comparison with the standard buffer area gave an over-optimistic vision of the effectiveness of the protected area (Table V). Another way

TABLE III
Results of Pearson chi-square test and Cramer's V calculations between land clearing and environmental variables ($N = 439871$)

Land clearing X	χ^2	*df*	Significance	Cramer's V
Distance from roads	36385.7	9	0.0000	0.288
Distance from settlements	36073.4	9	0.0000	0.286
Soil type	17238.4	15	0.0000	0.198
Elevation	12468.1	5	0.0000	0.168
Slope	307.5	3	0.0000	0.026

TABLE IV
Summary of bivariate logistic regression statistics

	Model if term removed			
Term removed	Log likelihood	−2 log LR	*df*	Significance of log LR
Distance from settlements	−33126.4	2177.082	1	0.0000
Distance from roads	−32767.9	1459.973	1	0.0000
Soil type	−32657.6	1239.501	13	0.0000
Slope	−32123.9	172.051	1	0.0000
Elevation	−32042.5	9.326	1	0.0023

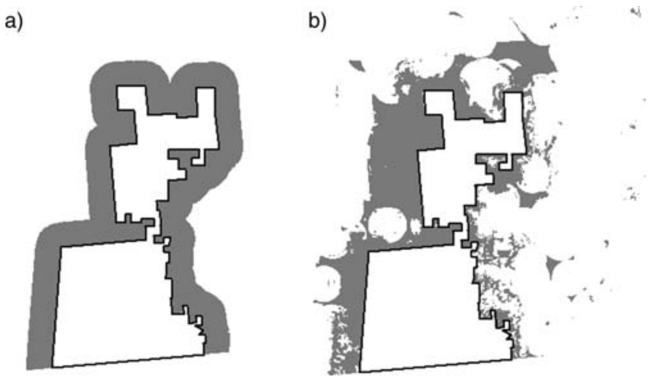

Figure 7. Standard and "similar" buffer areas of the Reserve of Calakmul. Note that the *similar buffer area* is generally non-continuous.

to show the reduced, but significant, role played by the protected area in preventing land clearing is by introducing the status of protection (protected/no protected) as an independent variable into the logistic model. As showed in Table VI, this status is related significantly (and negatively) with deforestation, but the other environmental variables (Distance from settlements, distance from roads, soil type and slope), except the elevation, are more important.

TABLE V
Rates of deforestation inside the protected areas and the two buffer areas (1993–2000)

	Target area (protected area)	Standard buffer area	"Similar" buffer area
Deforested area as a proportion of forested area in 1993	1.9	8.7	4.4
Rate of deforestation (%/yr)	0.3	1.3	0.6

TABLE VI
Summary of bivariate logistic regression statistics with the status of protection as an independent variable ($N = 116383$)

	Model if term removed			
Term removed	Log likelihood	−2 log LR	*df*	Significance of log LR
Distance from settlements	−32963.13	1936.437	1	0.0000
Distance from roads	−32692.12	1394.416	1	0.0000
Soil type	−32611.3	1232.775	13	0.0000
Slope	−32088.76	187.688	1	0.0000
Protection status	−32037.87	85.901	1	0.0000
Elevation	−32006.95	24.075	1	0.0000

5. Conclusion

In many studies, the assumption that the buffer area can be compared with the target area is made regardless of their respective characteristics. However, as shown in the illustration given above, this assumption is often erroneous and misleading conclusions can be obtained. The use of statistical tests to ensure the comparability between the target and the buffer area is recommended and, in case that the standard buffer area shows significant differences from the target area, an approach as the *similar buffer area* should be carried out.

In tropical countries such as Mexico, one of the problems faced in the studies aimed at assessing protected areas effectiveness is the lack of hard data on biodiversity. Land cover changes, which can be monitored easily by remote sensing, have direct impacts on biodiversity levels and therefore provide a useful proxy for biodiversity loss. In the case of Mexico, multidate remotely-sensed imagery such as Landsat, SPOT or MODIS, could be used in order to assess land cover changes inside and in the surrounding of the protected areas (Ibáñez *et al.*, 2002). The comparison of the rate of both land clearing and recovering between each protected area and its *similar buffer area* could be a way to carry out a rapid, cost-effective and homogeneous assessment of the effectiveness of the protected areas. Based upon this assessment, poorly effective protected areas could be identified and submitted to deeper analyses.

Finally, the approach of the *similar buffer area* can be applied as a tool for the selection of additional reserves (Margules and Pressey, 2000). It can allow the location of enlarged protected area or new, separate ones, taking into account a set of spatial variables such as land cover, tenure or acquisition costs, allowing the analysis of various policy options and providing the basis for refinement of the conservation plan by local experts.

Acknowledgements

The programs for *similar buffer area* generation have been developed by C. Alcántara-Concepción and R. Castro-Miguel at the Institute of Geography-Unidad Foránea Morelia at the National University of Mexico (UNAM). Useful comments about the algorithm elaboration were done by F. Valois (ESRI, Québec, Canada). The multidate spatial database was elaborated under the project *Regionalización ecológica a nivel regional: Análisis del cambio de uso del suelo* under contract by the Institute Nacional de Ecología (INE). Comments from two anonymous referees helped considerably to refine the final manuscript.

References

Apan, A. A. and Peterson, J. A.: 1998, 'Probing tropical deforestation', *Appl. Geogr.* **18**(2), 137–152.

Bruner, A. G., Gullison, R. E., Rice, R. E. and da Fonseca, G. A. B.: 2001, 'Effectiveness of parks in protecting tropical biodiversity', *Science* **291**, 125–128.

Caro, T. M.: 2001, 'Species richness and abundance of small mammals inside and outside an African national park', *Biol. Conserv.* **98**(3), 251–257.

Caro, T. M.: 2003, 'Umbrella species: Critique and lessons from East Africa', *Animal Conserv.* **6**(2), 171–181.

CONANP (Comisión Nacional de Áreas Naturales Protegidas): 2003, Retrieved from http://conanp.gob.mx.

East, J. and Wood, M.: 1998, 'Landcare GIS: Evaluating land management programs in Australia', *Environ. Monit. Assess.* **50**(3), 201–216.

E1-Raey, M., Fouda, Y. and Gal, P.: 2000, 'GIS for environmental assessment of the impacts of urban encroachment on rosetta region, Egypt', *Environ. Monit. Assess.* **60**(2), 217–233.

Groombridge, B. and Jenkins, M. D.: 2000, *Global Biodiversity: Earth's Living Resources in the 21st Century*, United Nations Environment Programme (ed.), 246 p.

Ibáñez, R., Condit, R., Angehr, G., Aguilar, S., García, T., Martínez, R., Sanjur, A., Stallard, R., Wright, S. J., Rand, A. S. and Heckadon, S.: 2002, 'An ecosystem report on the Panama Canal: Monitoring the status of the forest communities and the watershed', *Environ. Monit. Assess.* **80**(1), 65–95.

Kinnaird, M. F., Sanderson, E. W., O'Brien, T. G., Wibisono, H. T. and Woolmer, G.: 2003, 'Deforestation trends in a tropical landscape and implications for endangered large mammals', *Conserv. Biol.* **17**(1), 245–257.

Liu, J., Linderman, M., Ouyang, Z., An, L., Yang, J. and Zhang, H.: 2001, 'Ecological degradation in protected areas: The case of Wolong nature reserve for giant pandas', *Science* **292**, 98–101.

Loomis, J. and Echohawk, J. C.: 1999, 'Using GIS to identify under-represented ecosystems in the National Wilderness Preservation System in the U.S.A. *Environ. Conserv.* **26**, 53–58.

Lugo Hubp, J. I.: 1988, Elementos de Geomorfología Aplicada (Métodos cartográficos), Instituto de Geografía, Universidad Nacional Autónoma de México, México, 128 p.

Margules, C.-R. and Pressey, R.-L.: 2000, 'Systematic conservation planning', *Nature* **405**, 243–253.

Mas, J. F. and Puig, H.: 2001, 'Modalités de la déforestation dans le Sud-ouest de l'Etat du Campeche, Mexique', *Can. J. Forest Res.* **31**(7), 1280–1288.

Mas, J. F., Velázquez, A., Díaz-Gallegos, J.-R., Mayorga-Saucedo, R., Alcántara, C., Bocco, G., Castro, R., Fernández, T., and Pérez-Vega, A.: 2004, 'Assessing land use/cover changes: A nationwide multidate spatial database for Mexico', *Int. J. Appl. Earth Observ. Geoinform.* **5**(4), 249–261.

Ochoa-Gaona, S. and González-Espinosa, M.: 2000, 'Land use and deforestation in the highlands of Chiapas, Mexico', *Appl. Geog.* **20**, 17–42.

Ozcan, H., Cetin, M. and Diker, K.: 2003, 'Monitoring and assessment of land use status by GIS', *Environ. Monit. Assess.* **87**(1), 33–45.

Pressey, R. L., Whish, G. L., Barret, T. W. and Watts, M. E.: 2002, 'Effectiveness of protected areas in north-eastern New South Wales: Recent trends in six measures', *Biol. Conserv.* **106**, 57–169.

Sader, S. A. and Joyce, A. T.: 1988, 'Deforestation rates and trends in Costa Rica, 1940 to 1983', *Biotropica* **20**(1), 11–19.

Samways, M. J. and Kreuzinger, K.: 2001, 'Vegetation, ungulate and grasshopper interactions inside vs. outside an African savanna game park', *Biodivers. Conserv.* **10**(11), 1963–1981.

Sánchez-Azofeifa, G. A., Quesada-Mateo, C., Gonzalez-Quesada, P., Dayanandan, S. and Kamaljit S. B.: 1999, 'Protected areas and conservation of biodiversity in the tropics', *Conserv. Biol.* **13**(2), 407–411.

Sánchez-Azofeifaa, G. A., Dailyb, G. C., Pfaffc, A. S. P. and Buschd, C. C.: 2003, 'Integrity and isolation of Costa Rica's national parks and biological reserves: Examining the dynamics of land-cover change', *Biol. Conserv.* **109**(1), 123–l35.

Soares-Filho, B., Assunção, R. M. and Pantuzzo, A. E.: 2001, 'Modeling the spatial transition probabilities of landscape dynamics in an Amazonian colonization frontier', *BioScience* **51**(12), 1059–1066.

Vanclay, J. R.: 2001, 'The effectiveness of parks', *Science* **293**, 1007a.

Wood, A., Stedman-Edwards, P. and Mang, J.: 2000, *The Root Causes of Biodiversity Loss*, Earthscan Publications Ltd., U.K., 399 p.