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Effectiveness of natural protected areas to prevent land use and land cover change in Mexico

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Abstract This study evaluated the extent to which natural protected areas (NPAs) in Mexico have been effective for preventing land use/land cover change, considered as a major cause of other degradation processes. We developed an effectiveness index including NPA percentage of transformed areas (agriculture, induced vegetation, forestry plantations, and human settlements) in 2002, the rate and absolute extent of change in these areas (1993–2002), the comparison between rates of change observed inside the NPA and in an equivalent surrounding area, and between the NPA and the state(s) in which it is located. We chose 69 terrestrial federal NPAs, decreed before 1997, that were larger than 1,000 ha, not urban/reforested with non-native vegetation, not islands and not coastal strips, and estimated the extent of transformed areas using 1993 and 2002 land use/land cover maps. Over 54% of NPAs were effective, and were heterogeneously distributed by management categories: 65% of Biosphere Reserves, 53% of Flora and Fauna Protection Areas, and 45% of National Parks. 23% of NPAs were regarded as weakly effective, and the remaining 23% as non-effective. We recognize the importance of NPAs as a relevant conservation instrument, as half of NPAs analyzed (particularly biosphere reserves) prevented natural vegetation loss compared with their geographic context. Our results suggest that conservation based on NPAs in Mexico still faces significant challenges. Our approach can be expanded for evaluating the effectiveness of NPA in other regions, as land use/land cover maps are now available almost worldwide.

Keywords Conservation · Deforestation · Ecological integrity · Evaluation · Land cover change · Land use change · Natural protected areas · Parks

Introduction

Natural protected areas (NPAs) are a cornerstone for conservation strategies worldwide, as their role is to protect biological diversity, and to maintain the ecological integrity of

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ecosystems, which provide a wide array of environmental services, livelihoods and sustenance to local communities (Ervin 2003a; IUCN 2005). International forums have proposed that the global network of NPAs should reach 10% of the global surface (IUCN 1993), a goal currently exceeded with nearly 12% of the terrestrial surface under protection (IUCN 2005). Still, a target based exclusively on protected area does not necessarily ensure the maintenance of global biodiversity, because the global network of NPAs provide an inadequate representation of biodiversity components (i.e. ecosystems, vegetation types, species; Margules and Pressey 2000; Pressey et al. 2002; Rodrigues et al. 2004; Chape et al. 2005), and because of the limited capacity of many NPAs to ensure the long-term persistence of these components, necessary for preserving the structure and functions of ecosystems (Hockings 1998; Margules and Pressey 2000; Ervin 2003a; Hockings 2003).

NPAs face several threats such as deforestation and habitat fragmentation, encroachment, pollution, invasion of alien species, wild fires, logging and hunting (Ervin 2003b; Carey et al. 2000). The impact of these threats on NPAs depend on multiple factors, mainly management effectiveness (Ervin 2003b), the socioeconomic and political context (Little 1994; Ghimire and Pimbert 1997b), environmental factors (as vegetation type or altitudinal range), conservation status, and accessibility of resources (Pressey et al. 2002; Mas 2005), among others.

There is a growing interest in evaluating NPAs to ensure an adequate representation of biodiversity and a strong capacity for long-term conservation in systematic conservation planning (Margules and Pressey 2000). These evaluations are also part of the Programme of Work on Protected Areas, and the Programme of Forest Biodiversity, of the Convention on Biological Diversity (http://www.cbd.int/default.shtml). Governmental and non-governmental agencies and organizations have been particularly active in developing systematic guidelines for this purpose (Brandon et al. 1998; IUCN 1999; Ervin 2003a, b; Hockings 2003; Chape et al. 2005). Three main strands of effectiveness evaluations have been developed (Ervin 2003a): (1) design assessment, which examines the representation of biodiversity components in NPA networks; (2) evaluation of management processes, focused on the detection of management challenges and weaknesses regarding staff, financing, planning and activities developed; and (3) evaluation of ecological integrity, which focuses on traits such as intactness, ecological processes and functioning, species viability, and the magnitude of threats and pressures over protected areas. Biodiversity representation and conservation have received particular attention for evaluating effectiveness, while the role of NPAs maintaining ecological integrity has often been neglected (Ervin 2003a).

Mexico holds an exceptionally rich biodiversity ranking among the megadiverse countries of the world (Sarukhán and Dirzo 1992; CONABIO 1998; Mittermeier et al. 1998; Toledo and Ordóñez 1998). Conservation strategies in Mexico rely heavily on NPAs; in 2007, there were 161 federal decreed NPAs, varying in size and management category, covering 11.54% nationwide (22.71 million ha; CONANP 2007). Recent studies provide site-focused quantitative evaluations of the effectiveness of Mexican NPAs in preventing particular threats, such as land use and land cover change (LUCC) processes and wild fires (e.g. Mas 2005; Román-Cuesta and Martínez-Vilalta 2006); but a systematic nationwide quantitative assessment for NPAs in Mexico is still lacking.

Here, we evaluated the effectiveness of a large number of NPAs in preventing LUCC in Mexico, both quantitatively and systematically. Our aim was to assess the extent to which NPAs are an effective conservation instrument for reducing LUCC. There is evidence of the impact that LUCC has on other degradation processes, such as biodiversity loss (Dale et al. 1994; Lidlaw 2000; Sala et al. 2000; Kinnard et al. 2003; Sánchez-Cordero et al. 2005), land degradation (Riezebos and Loerts 1998; Islam and Weil 2000), local and regional climate change (Chase et al. 2000), global climate change (Houghton et al. 1999), and loss of ecosystem services (Vitousek et al. 1997). As LUCC and these associated degradation processes may compromise the structure and function of ecosystems, our approach can be regarded as an indirect evaluation of NPAs capacity for maintaining ecological integrity (*sensu* Ervin 2003a), using LUCC as a surrogate variable.

Methods

We assessed the effectiveness of NPAs to prevent LUCC processes by quantifying (1) the rate of change and (2) the total extent of change, between 1993 and 2002, as well as (3) the percentage, in 2002, of areas transformed by human use; transformed areas included agriculture, cultivated and induced pastures, human settlements, and forestry plantations. The rate of change of transformed areas inside each NPA was also compared with that estimated for an equivalent area surrounding the NPA, and for the state(s) in which it is located (Fig. 1).

We selected 69 federal decreed NPAs (out of 160 NPAs decreed in Mexico; 43%) which (1) were 1000 ha or larger, as this is the minimum area for conserving ecosystems according to The World Conservation Union (Ordóñez and Flores-Villela 1995), and for the scale of the land use/land cover maps; (2) were decreed before 1997, since the most recent land use/land

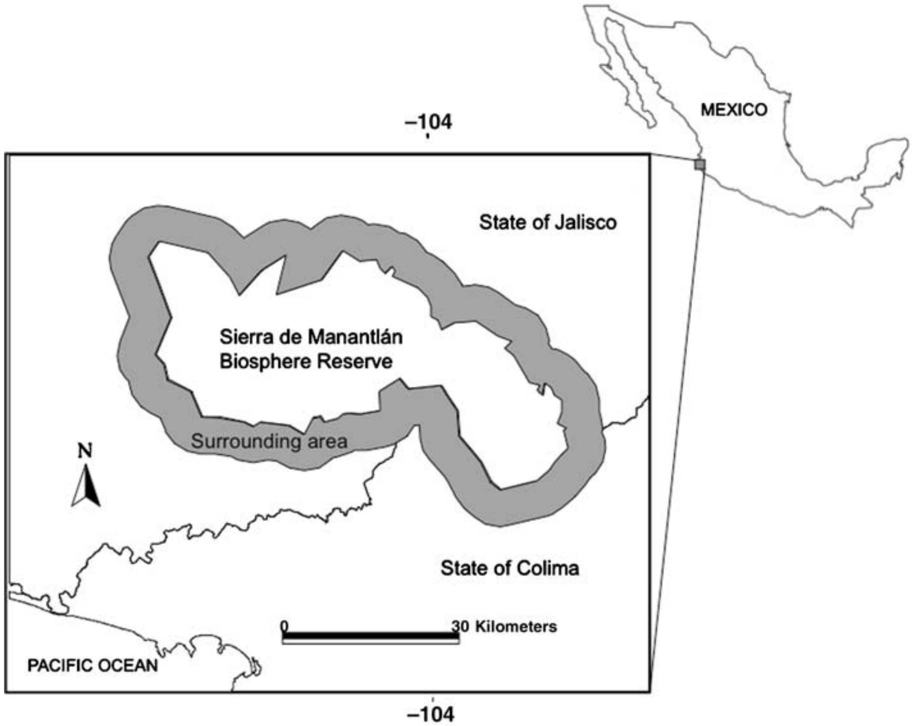

Fig. 1 Example depicting areas used for the comparison of land use/land cover rates of change, included in the effectiveness evaluation: the Sierra de Manantlán Biosphere Reserve, its surrounding area, and part of the states of Colima and Jalisco, where it is located

cover map used dated from 2002, assuming 5 years as sufficient for detecting NPAs effect on LUCC changes; (3) did not comprise islands, given the absence of a surrounding area for LUCC comparisons; (4) were not strictly coastal zones, as the scale of land use/land cover maps were inadequate considering their small size and shape; and (5) were not urban, nor reforested with non-native vegetation. The areas selected belong to different management categories: 29 National Parks, 19 Flora and Fauna Protection Areas, 17 Biosphere Reserves, 3 Natural Monuments, and 1 Natural Resources Protection Area (Table 1).

For each NPA, we constructed a surrounding area of equivalent size (± 100 ha), using the 2003 Natural Protected Area Map for Mexico (CONANP 2003; www.conanp.gob.mx) on a GIS platform (ArcView GIS v. 3.2; Fig. 1). From all surrounding areas, we excluded surfaces covered by sea, overlapping NPAs, and other countries' territories. In four cases (El Pinacate y Gran Desierto de Altar and El Vizcaíno Biosphere Reserves, Lagunas de Zempoala National Park, and Valle de los Cirios Flora and Fauna Protection Area), surrounding areas were less than 50% of NPA surface. We obtained transformed areas for selected NPAs, surrounding areas, and the state(s) of location, using the 1993 and 2002 land use/land cover maps 1:250,000, produced by the Instituto Nacional de Estadística, Geografía e Informática (INEGI 1993, 2005; www.inegi.gob.mx). These maps are the best available considering this scale of analysis. Further, data comparisons between these dates are reliable as both maps were constructed using the same methodological framework: satellite images (Landsat), vegetation classification, and extensive field validation. Transformed areas excluded primary and secondary vegetation, and areas with no apparent vegetation cover. We did not include areas without vegetation cover in transformed areas, as it is difficult to distinguish denuded areas occurring naturally (i.e. sand dunes, mountain tops), from areas produced by LUCC at this scale. We estimated LUCC rate as the annual percentage of change of transformed areas relative to the total evaluated area, as follows:

$$\mathrm{LUCCR} = \frac{(S_2 - S_1)/S_t}{N} \times 100$$

where LUCCR = Rate of change, S_1 = Initial transformed area, S_2 = Final transformed area, S_t = Total evaluated area, and N = Time lag in years.

If an NPA occurred in the boundaries of two or more states, we estimated the states' weighed LUCC rate, with the percentage of the NPA area corresponding to each state, as weighting values. We chose the rate of change in the state of location as a reference value for comparison, as each state has a particular socioeconomic dynamic, influenced by specific governmental policies of rural development, affecting regional LUCC processes.

We constructed an effectiveness index as the sum of five parameters, with data standardized as values from 0 to 1, including: (1) NPA percentage of transformed areas in 2002; (2) the rate, and (3) absolute extent of change in these areas (1993–2002); (4) the comparison between the rates of change observed in the NPA and in an equivalent surrounding area; and (5) between the NPA and the state(s) in which it is located. We considered the latter two parameters as highly relevant, assuming that effective NPAs should show reduced LUCC processes compared to their own geographic contexts. For these comparisons, we arbitrarily assigned a value of zero for NPAs showing a higher LUCC rate than that observed in their equivalent surrounding areas or states of location, and a value of one, for NPAs showing a lower LUCC rate than their equivalent surrounding areas and states of location. In no case were these paired rates equal. Finally, we described the distribution of effectiveness values through official Mexican management categories, and to their corresponding IUCN management categories (IUCN 1994).

Table 1 Land use/land cover rates of change (1993–2000), and general descriptions of 69 Mexican natural protected areas (NPAs) included in the study

Natural protected area	Management category	Area (ha)	TS[a] 2002 (%)	Absolute change in TS (ha)	LUCC[b] rate (%)	Date of decree	State of location
Bonampak	NM[c]	4,243.8	0.0	0.0	0.00	1992	Chiapas
Bosencheve	NP[d]	10,963.8	70.6	258.8	0.26	1940	México, Michoacán
Calakmul	BR[e]	719,809.3	1.4	5,021.3	0.08	1989	Campeche
Campo Verde	FFPA[f]	108,137.2	0.6	−0.1	0.00	1938	Chihuahua
Cañón de Santa Elena	FFPA	278,993.1	1.6	−423.9	−0.02	1994	Chihuahua
Cañón del Río Blanco	NP	48,594.1	50.7	1,557.0	0.36	1938	Veracruz
Cañón del Sumidero	NP	23,321.7	30.0	3,661.4	1.74	1980	Chiapas
Cascada de Agua Azul	FFPA	2,319.8	24.4	−72.5	−0.35	1980	Chiapas
Cascada de Bassaseachic	NP	5,878.7	1.8	0.0	0.00	1981	Chihuahua
Cerro de La Silla	NM	5,983.5	0.2	6.5	0.01	1991	Nuevo León
Chamela-Cuixmala	BR	13,068.5	2.8	2.6	0.00	1993	Jalisco
Chan-Kin	FFPA	12,211.5	0.7	−0.3	0.00	1992	Chiapas
Cofre de Perote	NP	11,479.1	40.3	1,661.2	1.61	1937	Veracruz
Constitución de 1857	NP	5,011.2	1.0	48.4	0.11	1962	Baja California
Corredor Biológico Ajusco—Chichinautzin (Fracción I)	FFPA	19,544.8	29.1	−24.9	−0.01	1988	México, Morelos, D. F.
Corredor Biológico Ajusco—Chichinautzin (Fracción II)	FFPA	16,678.5	42.5	165.4	0.11	1988	México, Morelos, D. F.
Cuatrociénegas	FFPA	83,496.9	4.0	161.5	0.02	1994	Coahuila
Cuenca Hidrográfica del Río Necaxa	NRPA[g]	41,404.8	60.9	628.2	0.17	1938	Puebla
Cumbres de Majalca	NP	4,790.4	9.3	−0.4	0.00	1939	Chihuahua
Cumbres de Monterrey	NP	175,717.5	3.0	−153.8	−0.01	1939	Nuevo León
Desierto de Los Leones	NP	1,952.0	3.0	−14.1	−0.08	1917	D. F.
El Chico	NP	2,710.9	2.7	−61.7	−0.25	1982	Hidalgo
El Cimatario	NP	2,489.0	14.5	−52.0	−0.23	1982	Querétaro

Table 1 continued

Natural protected area	Management category	Area (ha)	TS[a] 2002 (%)	Absolute change in TS (ha)	LUCC[b] rate (%)	Date of decree	State of location
El Jabalí	FFPA	5,016.0	44.6	223.3	0.49	1981	Colima
El Pinacate y Gran Desierto de Altar	BR	723,884.4	0.0	−35.0	0.00	1993	Sonora
El Potosí	NP	2,150.1	0.0	0.0	0.00	1936	San Luis Potosí
El Tepozteco	NP	23,167.9	31.1	396.7	0.19	1937	Morelos, D. F.
El Triunfo	BR	120,186.8	11.0	−1,561.5	−0.14	1990	Chiapas
El Veladero	NP	3,627.5	9.9	122.0	0.37	1980	Guerrero
El Vizcaíno	BR	2,474,600.7	0.7	5,015.0	0.02	1988	Baja California Sur
Gogorrón	NP	36,590.3	34.6	626.2	0.19	1936	San Luis Potosí
Grutas de Cacahuamilpa	NP	1,619.1	29.2	−89.9	−0.62	1936	Guerrero
Insurgente José María Morelos	NP	4,539.1	3.3	−149.0	−0.36	1939	Michoacán
Insurgente Miguel Hidalgo y Costilla	NP	1,911.3	33.9	1.1	0.01	1936	México, D. F.
Iztaccíhuatl-Popocatépetl	NP	89,872.1	5.8	−166.7	−0.02	1935	México, Puebla, Morelos
La Encrucijada	BR	146,157.9	30.4	−1,817.8	−0.14	1995	Chiapas
La Michilía	BR	9,325.4	0.0	0.0	0.00	1979	Durango
La Primavera	FFPA	30,412.4	7.0	−14.4	−0.01	1980	Jalisco
La Sepultura	BR	168,237.2	13.0	3,716.0	0.25	1995	Chiapas
Lacan-Tun	BR	63,563.6	0.0	0.8	0.00	1992	Chiapas
Lagunas de Chacahua	NP	15,012.2	15.3	628.2	0.46	1937	Oaxaca
Lagunas de Montebello	NP	6,433.4	11.1	−17.1	−0.03	1959	Chiapas
Lagunas de Zempoala	NP	4,536.9	2.5	−89.0	−0.22	1936	México, Morelos
Maderas Del Carmen	FFPA	207,269.1	0.0	0.0	0.00	1994	Coahuila
Malinche o Metlalcuéyatl	NP	45,276.7	60.6	939.5	0.23	1938	Tlaxcala, Puebla
Mariposa Monarca	BR	55,935.3	17.2	−500.6	−0.10	1986	Michoacán, México
Montes Azules	BR	329,207.8	2.4	3,980.0	0.13	1978	Chiapas
Nevado de Colima	NP	9,782.8	0.0	0.0	0.00	1936	Jalisco, Colima

Table 1 continued

Natural protected area	Management category	Area (ha)	TS[a] 2002 (%)	Absolute change in TS (ha)	LUCC[b] rate (%)	Date of decree	State of location
Nevado de Toluca	NP	53,744.8	33.7	−293.5	−0.06	1936	México
Palenque	NP	1,717.6	72.2	−2.7	−0.02	1981	Chiapas
Pantanos de Centla	BR	302,106.0	12.9	324.2	0.01	1992	Tabasco
Papigochic	FFPA	242,413.4	16.8	9,236.7	0.42	1939	Chihuahua
Pico de Orizaba	NP	19,506.3	10.8	43.1	0.02	1937	Veracruz, Puebla
Pico de Tancítaro	NP	23,283.5	30.8	−515.2	−0.25	1940	Michoacán
Sian Ka'an	BR	525,129.6	0.0	27.3	0.00	1986	Quintana Roo
Sierra de Álamos-Río Cuchujaqui	FFPA	92,186.6	10.2	3,593.3	0.43	1996	Sonora
Sierra de Álvarez	FFPA	13,621.4	19.0	3.3	0.00	1981	San Luis Potosí
Sierra de Manantlán	BR	138,808.6	15.1	1,418.8	0.11	1987	Jalisco, Colima
Sierra de Quila	FFPA	13,502.7	1.8	7.1	0.01	1982	Jalisco
Sierra de San Pedro Mártir	NP	73,350.7	2.5	511.6	0.08	1947	Baja California
Sierra del Abra Tanchipa	BR	21,260.9	3.3	47.9	0.03	1994	San Luis Potosí
Sierra Gorda	BR	381,188.1	16.6	4,371.9	0.13	1997	Querétaro
Sierra La Laguna	BR	111,275.2	0.3	53.8	0.01	1994	Baja California Sur
Sierra La Mojonera	FFPA	9,278.7	0.0	0.0	0.00	1981	San Luis Potosí
Tutuacá	FFPA	361,799.2	4.1	48.2	0.00	1937	Chihuahua
Uaymil	FFPA	88,722.3	0.0	0.0	0.00	1994	Quintana Roo
Valle de Los Cirios	FFPA	2,520,094.9	0.3	1,072.8	0.00	1980	Baja California
Yaxchilán	NM	2,637.8	0.0	0.0	0.00	1992	Chiapas
Yum Balam	FFPA	152,588.6	1.6	1,573.7	0.11	1994	Quintana Roo

[a] TS—Transformed areas; [b] LUCC—Land use/land cover change; [c] NM—Natural Monument; [d] NP—National Park; [e] BR—Biosphere Reserve; [f] FFPA—Flora and Fauna Protection Area; [g] NRPA—Natural Resources Protection Area

Results

In 2002, transformed areas (including exclusively agricultural areas, induced and cultivated pastures, forestry plantations and human settlements, and excluding primary and secondary vegetation, and areas with no apparent vegetation cover) comprised 26% nationwide and 5% of selected NPAs; these values were highly variable, ranging from zero (e.g. Yaxchilán or La Michilía), to 72% (Palenque). Most NPAs (96%) showed LUCC processes: 54% showed an increase, and 46% a decrease in transformed areas (Table 1). We assigned three different NPAs effectiveness categories: (1) effective, with index values between four and five (37 NPAs, 54%), (2) weakly-effective, with index values between three and four (16, 23%), and (3) non-effective, with index values between zero and two (16, 23%; Table 2). We reassigned La Michilía Biosphere Reserve and Sierra La Mojonera Flora and Fauna Protection Area from non-effective to effective, as they lacked transformed areas; this resulted from no change in land cover, although their surrounding areas showed a slight decrease in transformed areas. This situation is best described by classifying them as effective NPAs.

When excluding Natural Monuments and Natural Resources Protection Areas (with three and one NPAs, respectively), Biosphere Reserves showed the highest proportion of effective areas (65%), followed by Flora and Fauna Protection Areas (53%), and National Parks (45%). In addition, Flora and Fauna Protection Areas showed the highest proportion of weakly-effective areas (26%), and National Parks of non-effective areas (31%; Table 3).

Effective NPAs displayed lower LUCC rates than their surrounding areas and states of location (except Sierra La Mojonera Flora and Fauna Protection Area and La Michilía Biosphere Reserve), low proportions of transformed areas by 2002, and low absolute increases in transformed areas (except Calakmul Biosphere Reserve). Some of these NPAs even showed an absolute decrease in transformed areas (Tables 1 and 2).

Conversely, weakly effective NPAs showed higher LUCC rates than their equivalent surrounding areas, but lower than their states of location, except for the Palenque National Park. In this case, the rate of change inside this NPA was lower than that observed in its surrounding area. It was assigned to this category based on the value of its effectiveness index, since it showed 72% of its area already transformed by 2002; a low LUCC rate likely resulted from the fact that this NPA was almost completely transformed since 1993. Most of the remaining weakly effective NPAs had relatively low percentages of transformed areas by 2002, with low LUCC rates, and relatively low absolute extent of change in transformed surfaces (1993–2002), with the exception of El Vizcaíno Biosphere Reserve, where the absolute extent of change in transformed areas reached 5,015 ha.

Non-effective areas showed mixed scenarios: (1) five NPAs with lower LUCC rates than their surrounding areas, but higher than their state of location, suggesting high regional pressures for land conversion to transformed areas. They showed either an increase in the absolute extent of transformed areas (1993–2002), or a high percentage of transformed areas in 2002 (Tables 1 and 2); (2) three NPAs with higher LUCC rates than their surrounding areas, but lower than their state of location, suggesting high local pressure for land conversion to transformed areas. They also showed either, a high percentage of transformed areas in 2002, or a high absolute increase in them between 1993 and 2002 (Tables 1 and 2); (3) Eight NPAs had higher LUCC rates than their surrounding areas and states of location, suggesting high regional and local pressure for land conversion to transformed areas. Some of them showed a high percentage of transformed areas (2002), a high rate of change in transformed areas, or an increase in the absolute extent of transformed areas, between 1993 and 2002.

Table 2 Effectiveness parameters, index values, and categories for the selected 69 Mexican natural protected areas

Natural protected area	Effectiveness parameters[a]					EI[b]	EC[c]
	1	2	3	4	5		
Cañón del Sumidero	0.58	0.50	0.00	0	0	1.09	Non-effective
Cofre de Perote	0.44	0.69	0.06	0	0	1.18	Non-effective
Malinche or Matlalcuéyatl	0.16	0.75	0.64	0	0	1.55	Non-effective
El Jabalí	0.38	0.82	0.53	0	0	1.73	Non-effective
Sierra Gorda	0.77	0.44	0.68	0	0	1.90	Non-effective
El Tepozteco	0.57	0.80	0.66	0	0	2.03	Non-effective
Lagunas de Chacahua	0.79	0.78	0.54	0	0	2.11	Non-effective
Papigochic	0.77	0.00	0.56	1	0	2.33	Non-effective
Bosencheve	0.02	0.81	0.63	1	0	2.46	Non-effective
Constitución de 1857	0.99	0.83	0.69	0	0	2.51	Non-effective
Cañón del Río Blanco	0.30	0.69	0.59	0	1	2.58	Non-effective
Cuenca Hidrográfica del Río Necaxa	0.16	0.78	0.67	0	1	2.60	Non-effective
Sierra de Álamos-Río Cuchujaqui	0.86	0.51	0.55	1	0	2.92	Non-effective
Corredor Biológico Ajusco-Chichinautzin (Fracción II)	0.41	0.82	0.69	1	0	2.92	Non-effective
La Sepultura	0.82	0.50	0.63	0	1	2.95	Non-effective
Gogorrón	0.52	0.78	0.66	1	0	2.96	Non-effective
El Vizcaíno	0.99	0.38	0.73	0	1	3.10	Weakly-effective
Insurgente Miguel Hidalgo y Costilla	0.53	0.84	0.74	0	1	3.10	Weakly-effective
Sierra de Álvarez	0.74	0.84	0.74	0	1	3.31	Weakly-effective
Pantanos de Centla	0.82	0.81	0.73	0	1	3.36	Weakly-effective
Cascada de Agua Azul	0.66	0.84	0.89	0	1	3.39	Weakly-effective
Lagunas de Montebello	0.85	0.84	0.75	0	1	3.43	Weakly-effective
Sierra de San Pedro Mártir	0.96	0.79	0.71	0	1	3.46	Weakly-effective
Cuatrociénegas	0.94	0.82	0.73	0	1	3.49	Weakly-effective
Sierra de Quila	0.97	0.83	0.74	0	1	3.55	Weakly-effective
Cascada de Bassaseachic	0.97	0.84	0.74	0	1	3.55	Weakly-effective
Cumbres de Monterrey	0.96	0.85	0.74	0	1	3.55	Weakly-effective
Campo Verde	0.99	0.84	0.74	0	1	3.57	Weakly-effective
Desierto de Los Leones	0.96	0.84	0.77	0	1	3.57	Weakly-effective
Lacan-Tun	0.99	0.84	0.74	0	1	3.57	Weakly-effective
Palenque	0.00	0.84	0.75	1	1	3.58	Weakly-effective
El Triunfo	0.85	0.98	0.80	0	1	3.62	Weakly-effective
La Michilía[d]	1.00	0.84	0.74	0	0	2.57	Effective
Sierra La Mojonera[d]	1.00	0.84	0.74	0	1	3.57	Effective
Calakmul	0.98	0.38	0.71	1	1	4.07	Effective
Montes Azules	0.97	0.48	0.68	1	1	4.12	Effective
Nevado de Toluca	0.53	0.86	0.76	1	1	4.16	Effective
Corredor Biológico Ajusco-Chichinautzin (Fracción I)	0.60	0.87	0.74	1	1	4.18	Effective
Sierra de Manantlán	0.79	0.71	0.69	1	1	4.18	Effective

Table 2 continued

Natural protected area	Effectiveness parameters[a]					EI[b]	EC[c]
	1	2	3	4	5		
El Veladero	0.86	0.82	0.58	1	1	4.27	Effective
Pico de Tancítaro	0.57	0.88	0.84	1	1	4.30	Effective
Yum Balam	0.98	0.69	0.69	1	1	4.36	Effective
La Encrucijada	0.58	1.00	0.80	1	1	4.38	Effective
Pico de Orizaba	0.85	0.83	0.73	1	1	4.41	Effective
Mariposa Monarca	0.76	0.88	0.78	1	1	4.42	Effective
Grutas de Cacahuamilpa	0.60	0.84	1.00	1	1	4.44	Effective
Cumbres de Majalca	0.87	0.84	0.74	1	1	4.45	Effective
Valle de Los Cirios	1.00	0.74	0.74	1	1	4.47	Effective
El Cimatario	0.80	0.84	0.84	1	1	4.48	Effective
La Primavera	0.90	0.84	0.74	1	1	4.48	Effective
Tutuacá	0.94	0.83	0.74	1	1	4.51	Effective
Sierra del Abra Tanchipa	0.95	0.83	0.73	1	1	4.51	Effective
Iztaccíhuatl-Popocatépetl	0.92	0.85	0.75	1	1	4.52	Effective
Chamela-Cuixmala	0.96	0.84	0.74	1	1	4.53	Effective
Sierra La Laguna	1.00	0.83	0.74	1	1	4.56	Effective
Chan-Kin	1.00	0.84	0.74	1	1	4.56	Effective
Cerro de La Silla	1.00	0.83	0.74	1	1	4.57	Effective
Sian Ka'an	1.00	0.83	0.74	1	1	4.57	Effective
Maderas del Carmen	1.00	0.84	0.74	1	1	4.57	Effective
Bonampak	1.00	0.84	0.74	1	1	4.57	Effective
El Potosí	1.00	0.84	0.74	1	1	4.57	Effective
Nevado de Colima	1.00	0.84	0.74	1	1	4.57	Effective
Uaymil	1.00	0.84	0.74	1	1	4.57	Effective
Yaxchilán	1.00	0.84	0.74	1	1	4.57	Effective
El Pinacate y Gran Desierto de Altar	1.00	0.84	0.74	1	1	4.58	Effective
Cañón de Santa Elena	0.98	0.87	0.75	1	1	4.60	Effective
Lagunas de Zempoala	0.96	0.84	0.83	1	1	4.64	Effective
El Chico	0.96	0.84	0.85	1	1	4.65	Effective
Insurgente José María Morelos	0.95	0.85	0.89	1	1	4.70	Effective

[a] Effectiveness parameters: 1. Percentage of transformed areas in NPAs (2002), 2. Absolute extent of change in transformed areas (1993–2002), 3. Rate of change of transformed areas in NPA (1993–2002), 4. Comparison between the rate of change of transformed areas in NPA and in surrounding area, 5. Comparison between the rate of change of transformed areas in NPA and in its state of location; [b] EI—Effectiveness index. [c] EC—Effectiveness category. [d] La Michilía Biosphere Reserve and Sierra La Mojonera Flora and Fauna Protection Area were removed form non-effective and weakly effective categories, respectively (see "Results")

IUCN NPAs management categories do not directly correspond in all cases to the official Mexican management categories of federal decreed NPAs (CONANP 2003). In our selection, 16 NPAs, mostly Biosphere Reserves, are regionalized in a core zone, corresponding to IUCN category IA, and a buffer zone corresponding to IUCN category VI. Most National Parks in our study (27) are included in IUCN category II; three Natural Monuments and one National Park in IUCN category III, 17 Flora and Fauna Protection

Table 3 Effectiveness of 69 Mexican natural protected areas according to management category, as defined by the Comisión Nacional de Áreas Naturales Protegidas (CONANP)

Management category	NPAs[a] in Effectiveness categories (%, *n*)			Total
	Non-effective	Weakly-effective	Effective	
Flora and Fauna Protection Area	21.1 (4)	26.3 (5)	52.6 (10)	100 (19)
Natural Resources Protection Area	100.0 (1)	0.0 (0)	0.0 (0)	100 (1)
Natural Monument	0.0 (0)	0.0 (0)	100.0 (3)	100 (3)
National Park	31.0 (9)	24.1 (7)	44.8 (13)	100 (29)
Biosphere Reserve	11.8 (2)	23.5 (4)	64.7 (11)	100 (17)
Total	23.2 (16)	23.2 (16)	53.6 (37)	100 (69)

[a] NPAs—Natural protected areas

Table 4 Distribution of Mexican natural protected areas (*n*, %) selected for this study in management categories defined by The World Conservation Union (IUCN 1994), and effectiveness categories as determined by this study

IUCN management categories	NPAs[a] according to official management categories	NPAs[a] in Effectiveness categories (*n*, %)			Total (*n*, %)
		Effective	Weakly-effective	Non-effective	
IA–VI[b]	14 Biosphere Reserves	10 (62.5)	3 (18.8)	3 (18.8)	16 (100)
	2 Flora and Fauna Protection Areas				
II	27 National Parks	12 (44.4)	6 (22.2)	9 (33.3)	27 (100)
III	3 National Monuments	3 (75.0)	1 (25.0)	0 (0.0)	4 (100)
	1 National Park				
VI	17 Flora and Fauna Protection Areas	11 (52.4)	6 (28.6)	4 (19)	21 (100)
	1 Natural Resources Protection Area				
	3 Biosphere Reserves				
None	1 National Park	100 (1)	0 (0)	0 (0)	1 (100)

[a] Natural protected areas; [b] IA–VI refers to areas with a core zone belonging to IUCN category IA, and a buffer zone, to category VI

Areas, one Natural Resources Protection Area and three Biosphere Reserves in IUCN category VI. El Cimatario National Park is not referred to any IUCN management category (Table 4). Of the NPAs corresponding to both IUCN management categories IA (core area) and VI (buffer area), 63% (10 NPAs) were effective; 52% (11 NPAs) belonging only to category VI were effective. Category III included few NPAs (3), where two out of three were effective, and 44% (12 NPAs) in category II were effective (Table 4).

Discussion

As NPAs gain importance for conservation, it becomes relevant to critically evaluate their effectiveness in preventing LUCC, as this process compromises the structure and function of ecosystems (Vitousek et al. 1997; Riezebos and Loerts 1998; Houghton et al. 1999;

Chase et al. 2000; Islam and Weil 2000; Sala et al. 2000; Kinnard et al. 2003), and thus, ecological integrity (Turner et al. 2007). Our analyses comprised nearly half of the existing decreed federal NPAs in Mexico, and most were effective for preventing LUCC between 1993 and 2002. Still, a significant proportion of NPAs were weakly effective or non-effective, suggesting that conservation goals may face stronger challenges than previously assumed.

Three effective NPAs (Bonampak and Yaxchilán Natural Monuments, and Nevado de Colima National Park) did not show transformed areas inside or in the surrounding areas. In these particular cases, the absence of LUCC processes may be the consequence of factors other than the presence of the NPA, such as geographical isolation or adequate management by local communities suggested by the absence of detectable change in the surrounding areas at the scale of analysis.

Weakly effective NPAs comprised most protected areas where LUCC rates were higher than in their surrounding areas. Although this trait points to non-effectiveness, most of these NPAs showed reduced LUCC rates (Tables 1 and 2). Nonetheless, they require attention, as most of them appear to be incapable of preventing LUCC relative to the non-protected surrounding areas. A critical revision of design and management of non-effective NPAs under threat, showing higher LUCC rates than their surrounding areas and states of location, should lead to effective conservation actions. Specifically, identifying risk factors leading to area transformation due to current management strategies, socioeconomic dynamics of communities living in and around NPAs, non-local stakeholder's impacts, as those derived from regional and national policies of rural development, and a lack of participation of local communities, are urgently needed.

Biosphere reserves cover most of the decreed protected area and have received high financial support (CONABIO 1998). Our results show that this management category included the highest percentage of effective NPAs, suggesting that this conservation strategy might be particularly adequate for conservation in Mexico. Most Mexican NPAs were decreed in areas with previous land rights, mainly communal property, where the livelihoods of communities directly depend on their natural resources (INE 1995; Melo 2002). Biosphere reserves allow local communities to make a sustainable use and management in their buffer zones (LGEEPA 1988). These NPAs correspond to IUCN category VI, the only present in Mexico including the provision of natural resources and services to meet community needs in its objectives (IUCN 1994).

The capacity of NPAs to accomplish the objectives of biodiversity conservation has been evaluated mainly from two standpoints: management effectiveness and ecological integrity. Studies evaluating ecological integrity include a wide variety of approaches, scales and methods (Ervin 2003a), such as prevalence and ranking of threats (Brandon et al. 1998; Singh 1999; Rao et al. 2002; Ervin 2003b; Goodman 2003; WWF 2004), intactness measured through land cover changes (Sánchez-Azofeifa et al. 1999; Liu et al. 2001; Mas 2005), species viability or persistence (Woodroffe and Ginsberg 1998; Lidlaw 2000; Caro 2001; Fabricious et al. 2003; Parrish et al. 2003; Bhagwat et al. 2005), ecological processes and functioning (Parrish et al. 2003), and landscape stability (Friedman and Zube 1992).

Previous studies have measured effectiveness by comparing trait values between NPAs and unprotected areas in the same geographic location. Caro (2001) and Bhagwat et al. (2005) used field collection sites inside and outside NPAs in South Africa and India, respectively, to evaluate effectiveness regarding species' persistence, measured through richness and abundances. Sánchez-Azofeifa et al. (1999) observed lower deforestation and habitat fragmentation inside NPAs than in unprotected areas in the Sarapiquí region in

Costa Rica. Liu et al. (2001) found that the Wolong Reserve in China showed an increase in deforestation and habitat fragmentation similar to an unprotected surrounding area. Román-Cuesta and Martínez-Vilalta (2006) evaluated NPAs effectiveness for arresting wild fires in Chiapas, Mexico, by comparing their incidence inside NPAs, with that found in surrounding areas. Differences in methods and scales used in these studies preclude formal attempts to compare results.

Mas (2005) criticized methods for assessing NPAs by comparing their LUCC rates with those of 'buffer-like' surrounding areas, which is how we approached this study. He found that 60% of Mexican NPAs showed differences in soil type, slope, and distance to roads and settlements with the 10 km 'buffer-like' surrounding areas, and argued that NPAs are more isolated and less suitable for economic production, as was found previously in New South Wales, Australia (Pressey et al. 2002). These authors found that most NPAs in New South Wales were characterized by unsuitable conditions for commercial logging, and discuss that NPAs selection intends to minimize impacts on economic activities creating a bias towards areas of less economic value. Thus, Mass (2005) argues that since NPAs tend to show less suitability for economic activities than other non-protected areas, the direct comparison of NPAs with 'buffer-like' areas tends to overestimate effectiveness, since lower LUCC may result from differences in land suitability for production, rather than NPA effectiveness per se. For the Calakmul Biosphere Reserve, he found that differences in LUCC between this NPA and a surrounding area of 10 km wide were lower when comparing the reserve only with adjacent areas showing similar environmental conditions (Mas 2005).

We argue that the conclusions of Pressey et al. (2002) are not directly applicable to Mexico, as assumed by Mas (2005) given that: (1) reserves in New South Wales were created from public lands, and the authors focus mainly in the suitability of land for commercial logging, whereas in Mexico, most NPAs derive mainly from communal property (absent in the New South Wales case), and were never expropriated. Many 'ejidos' and communities still live and depend on NPAs, for example, in 2000, there were 4,485 localities and 1,404,516 inhabitants inside NPAs (CONANP 2003); (2) Mexican NPAs show less suitable conditions for agricultural production (Brandon et al. 2005), since most suitable areas have been under use for centuries and NPAs have been decreed in more conserved areas; notwithstanding, poor rural settlements may transform their NPAs habitats even in remote areas showing steep and low fertility lands, which are also susceptible to human-induced transformation (Challenger 1998); (3) we believe that Mas's (2005) approach underestimates the economic importance of NPAs, both to local peoples' livelihoods and sustenance (as land for agriculture and cattle farming, timber, firewood, game species, medicinal plants), and to non-local social actors (as timber, game species, species for trade, places of high scenic value for tourism, mining, and potential pharmaceutical resources; INE 1995); and (4) even conceding that our method overestimates effectiveness, our results for weakly-effective and non-effective NPAs still stand.

We recognize that our approach has at least six potential shortcomings. First, if vegetation types differ between NPAs and their surrounding areas, LUCC rates may not be directly comparable, since vegetation type influences forms and rates of resource use, and ecosystem vulnerability (Challenger 1998). On the other hand, the limits of access to natural resources imposed by NPAs on local communities may increase the pressure on the surrounding areas, and resulting higher LUCC rates outside may be the consequence of NPAs' presence, and not a proof of its effectiveness (Bhagwat et al. 2001). Furthermore, NPAs tend to be located in better conserved areas, and the current difference between an NPA and its surrounding area may reflect merely a condition that pertained prior to that

NPAs' decree. In our study, the limitations derived from directly comparing NPAs and their surrounding areas are partially reduced by including other parameters to evaluate effectiveness, as percentage of transformed areas inside NPAs, and rate and absolute extent of change in these areas.

Second, our results are heavily dependent on LUCC present in the specific geographical context of each NPA. LUCC rates are quite heterogeneous nationwide, deriving from each region's particular historical and current socio-environmental dynamic, and a direct comparison of LUCC rates between NPAs would lead to a distorted ranking of their effectiveness.

Third, our approach resulted in only a partial evaluation of ecological integrity, as the spatial scale of analysis precluded important aspects. The evaluation of ecological integrity requires examining the extent and prevalence of critical threats (LUCC rates in our study), and of certain local attributes of the ecological system as indicators of its structure and function; for example, variation in key ecological attributes of certain conservation targets (Parrish et al. 2003), the presence of healthy and viable populations of species that perform key ecological functions, or that are particularly vulnerable to perturbations, measurable only at the local scale. Furthermore, the evaluation of effectiveness through LUCC at this scale excludes the possibility of incorporating other threats to NPAs, such as poaching, invasive exotic species, and overgrazing, among others. For example, an effective area from the perspective of this study could be facing the 'empty forest syndrome' due to heavy hunting (Redford 1992). Notwithstanding, we used LUCC processes only as an indicator, and not as a direct measure of ecological integrity, given the strong influence that this process may have on ecosystems structure and function.

Fourth, LUCC may not be an adequate indicator of the maintenance of particular conservation targets in certain NPAs, as for example, the uniqueness of endemic aquatic species present in Cuatrociénegas Flora and Fauna Protection Area. However, land cover change will affect other features crucial to overall ecological integrity and environmental quality.

Fifth, our evaluation is partial in the sense that it precludes the examination of socio-economic and political processes associated to LUCC and conservation. Locally, the LUCC rate of an NPA can be related to factors as the social organization of local communities (Ghimire and Pimbert 1997a; Agarwal and Gibson 1999), local institutional governance regulating access to, and control of resources (Bray et al. 2003; Tucker 2004), the social participation and involvement of local people in decision-making processes (Pimbert and Pretty 1997), and the political interplay of numerous stakeholders (Blaikie and Jeanrenaud 1997; Wilshusen et al. 2002). In Mexico, conservation of forest cover can be highly influenced by the management strategies in community forestry, as nearly 8,000 'ejidos' and 'comunidades agrarias' (the forms of common property in Mexico) own 80% of the remaining forests (Bray et al. 2005); many of these are community forest enterprises, that have developed participatory management approaches with positive socioeconomic and environmental outcomes (Bray 1991; Asbjornsen and Ashton 2002; Velázquez et al. 2003; Merino-Pérez and Bray 2004; Anitnori and Bray 2005). The development of sustainable forest management by rural communities can be a factor for conservation of natural vegetation by reducing LUCC processes inside NPAs and their surrounding areas. A future evaluation of NPAs effectiveness should also include the social costs for local communities derived from conservation actions. This inclusion is necessary if conservation through NPAs is intended to be a socially just and viable land use strategy (Ghimire and Pimbert 1997a). The scale of analysis in our study precludes the inclusion of these crucial factors.

Lastly, for the spatial scale of analysis used in our study, we employed the most recent and reliable official sources of information available (INEGI 1993, 2005). These land use/land cover maps are comparable in the sense that both were based on Landsat images, and constructed using the same methodology and vegetation classification system (www.inegi.gob.mx) However, a direct comparison of both maps is not error free, since the interpretation of land use/land cover maps performed by different personnel may lead to occasional misclassification of polygons. Using change in transformed surfaces as a surrogate of LUCC reduces errors derived from the misclassification of primary and secondary vegetation in the original maps; and yet, these are the best possible sources of information for recent LUCC estimates.

Despite these limitations, our results provide a solid preliminary diagnosis of the effectiveness of Mexican NPAs to prevent LUCC, constitute a first nationwide quantitative and systematic assessment of the real conservation performance of the Mexican protected area system, and identify NPAs requiring immediate conservation actions. Our approach is likely to be applicable to other regions and countries as land use/land cover maps are becoming readily available virtually worldwide. Further studies should focus on the urgent need for complementary qualitative systematic assessments, based on social perceptions of different stakeholders, that should be supplemented with quantitative data about the results of management actions and environmental policies.

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