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# Socioeconomic context of land use and land cover change in Mexican biosphere reserves

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## SUMMARY

**Land use/land cover change (LULC) is a major threat to natural protected areas worldwide. This paper explores the relationships between four estimated LULC parameters for 17 Mexican biosphere reserves (BRs) for 1993–2002 on a GIS platform, and ten socioeconomic factors obtained from census data. These relationships were tested through linear correlations and multivariate analysis. BRs showed lower human demographic pressure, but higher population dispersion, social marginality, percentage of rain-fed agriculture area, and dependence upon agriculture and cattle compared to nationwide values. BRs also varied in their indigenous population, and showed cattle overpopulation, and low immigration and road density. Socioeconomic factors explained 87% of LULC variation. High population and road density, cattle overpopulation and low percentage indigenous population were related to percentage of transformed area (2002). Conversely, small population and road density, large proportion of indigenous population and high dependency on agriculture and cattle, were related to the rate of change in transformed area (1993–2002). High human population growth and urban concentration occurred when BRs suffered higher LULC than their corresponding ecoregions. Including socioeconomic conditions prevailing in BRs and their influence on LULC in reserve management and rural development planning will improve strategies for the confluence of conservation and development goals.**

*Keywords*: agriculture, biodiversity conservation, cattle density, conservation effectiveness, deforestation, development, natural protected areas, population, socioeconomic marginality, socioenvironmental analysis

## INTRODUCTION

Natural protected areas (NPAs) currently represent the core of conservation strategies in most nations. Mexico is regarded as a megadiversity country (Sarukhán & Dirzo 1992), containing 171 decreed NPAs covering *c.* 11% nationwide (see URL http://www.conanp.gob.mx). NPAs classified as biosphere reserves (BRs) are particularly important for conservation, as they embody the largest percentage of the federal protected area and allow local communities in their buffer zones to carry out sustainable management of natural resources (INE [Instituto Nacional de Ecología] 1995).

The magnitude of degradation processes in NPAs has raised international concern over their ability to accomplish their expected long-term conservation goals (Hockings 1998, 2003) and spurred the development of methodologies to assess NPAs effectiveness (Ervin 2003*a*). Some assessments have focused on the technical aspects of NPAs malfunction, including inefficient management and insufficient (or total lack of) personnel or financing, together with NPA size and the time since decreed (Bruner *et al.* 2001; Rao *et al.* 2002; Ervin 2003*b*; WWF [Worldwide Fund for Nature] 2004). Other studies have examined the degradation processes in NPAs in the light of their socioeconomic context, including social participation and the development of local institutions for resource use and control (Brooks *et al.* 2006; Hayes 2006; Nepstad *et al.* 2006).

Despite the relevance of NPAs for biological conservation, the impacts of human activities (such as land use/land cover change [LULC], pollution and overexploitation of hydrological resources) may occasionally lead to severe ecosystem transformation (Carey *et al.* 2000). The decrease of vegetation cover is the main cause of degradation processes, including loss of biological diversity (Dale *et al.* 1994; Lidlaw 2000; Kinnard *et al.* 2003), climate change (Houghton *et al.* 1999; Chase *et al.* 2000), land degradation (Riezebos & Loerts 1998; Islam & Weil 2000) and changes in the provision of ecosystem services (Vitousek *et al.* 1997). There is a scarcity of studies examining the effectiveness of Mexican NPAs (but see Mas 2005, Román-Cuesta & Martínez-Vilalta 2006 and Figueroa & Sánchez-Cordero 2008 for significant efforts) and none of these studies has so far investigated the causes of degradation processes such as LULC.

The factors influencing LULC are manifold, displaying complex synergies between them and operating at different spatial and temporal scales (Barbier & Burgess 2001; Geist & Lambin 2002; Perz 2002; Benhin 2006). They include social, economic, political, institutional, cultural and ecological forces

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**Table 1** Area, date of decree and location by state for the 17 selected Mexican biosphere reserves.

| *Biosphere reserve* | *Abbreviation* | *Area (ha)* | *Year of decree* | *State* |
|---|---|---|---|---|
| Calakmul | CK | 719 809.4 | 1989 | Campeche |
| Chamela-Cuixmala | CC | 13 068.5 | 1993 | Jalisco |
| El Pinacate y Gran Desierto de Altar | PDA | 723 884.4 | 1993 | Sonora |
| El Triunfo | ET | 120 186.8 | 1990 | Chiapas |
| El Vizcaíno | EV | 2 474 600.7 | 1988 | Baja California Sur |
| La Encrucijada | LE | 146 157.9 | 1995 | Chiapas |
| La Michilía | LM | 9 325.4 | 1979 | Durango |
| La Sepultura | LS | 168 237.2 | 1995 | Chiapas |
| Lacan Tun | LT | 63 563.6 | 1992 | Chiapas |
| Mariposa Monarca | MM | 55 935.3 | 1986 | Michoacán, México |
| Montes Azules | MA | 329 207.8 | 1978 | Chiapas |
| Pantanos de Centla | PC | 302 106.0 | 1992 | Tabasco |
| Sian Ka'an | SK | 525 129.6 | 1986 | Quintana Roo |
| Sierra de Manantlán | SM | 138 808.7 | 1987 | Jalisco, Colima |
| Sierra del Abra Tanchipa | SAT | 21 260.9 | 1994 | San Luis Potosí |
| Sierra Gorda | SG | 381 188.1 | 1997 | Querétaro |
| Sierra La Laguna | SL | 111 275.2 | 1994 | Baja California Sur |

and conditions (Pebley 1998; Carr *et al*. 2005; de Sherbinin *et al*. 2007). Geist and Lambin (2002) distinguished between underlying and proximate factors, the former affecting the manner in which the latter exert their influence on LULC.

Some of the most widely recognized regional factors, both underlying and proximate, may be broadly classified as: (1) sociodemographic, such as population size/density, migration, population dispersion and social marginality (Pearce 1990; Barbier 1997; de Sherbinin & Freudenberger 1998; Deininger & Minten 2002; Carr 2004*b*; Carr *et al.* 2005), and (2) agroproductive, including production vulnerability, access to markets, dependence upon primary activities and cattle raising expansion (Bilsborrow & Okoth-Ogendo 1992; Barbier & Burgess 2001; Lambin *et al.* 2001; Mäki *et al.* 2001; Benhin 2006). A further relevant, albeit less widely examined sociodemographic factor, is population ethnic composition, considering the implications of indigenous culture-based resource management and social organization (Gómez-Pompa & Kaus 1992; Carr 2004*a*; Leff 2004; Tucker 2004).

Here, we examine the magnitude of LULC processes in a selected set of Mexican biosphere reserves (BRs), along with the role of such prominent socioeconomic factors in driving these processes. Specifically, we address the question of which sociodemographic and agroproductive conditions are linked to BR capacity to deter LULC processes. Systematic knowledge on the socioenvironmental dynamics of BRs in Mexico is of utmost importance, given that Mexico is a megadiverse country with large cultural and social complexity, and a pioneering role in the establishment and international recognition of BRs (Halffter 1984). In Mexico and other countries sharing these conditions, BRs have become a fundamental conservation tool, but their long-term success clearly depends on a continuous examination of the human-environmental interplay developed in them.

## METHODS

We selected 17 terrestrial BRs whose decree predated 1997 from the 39 existing Mexican BRs (Table 1 and Fig. 1; CONANP [Comisión Nacional de Áreas Naturales Protegidas] 2003). We estimated LULC within the selected BRs and in their geographical contexts (the latter being defined as the ecoregion(s) in which each BR occurs, according to INEGI [Instituto Nacional de Estadística, Geografía e Informática], CONABIO [Comisión Nacional para el Conocimiento y Uso de la Biodiversidad] & INE (2007); this was achieved by evaluating, in these two sets of such defined areas, the change in completely transformed areas owing to human activities, between 1993 and 2002. We used 1:250 000 land use/land cover maps produced by INEGI (1993, 2005) for these years and assessed the changes on a GIS platform (ArcView, version 3.2). Transformed areas were defined as those covered by agriculture, man-made pastures, forest plantations and human settlements. We used four LULC indicators, namely (1) percentage of transformed area within each BR (in 2002), (2) absolute extent of change (1993–2002), (3) rate of change (1993–2002) and (4) the difference between the rate of change in BRs and that of their corresponding ecoregion.

We defined LULC rate as the mean annual change rate of transformed area, calculated as a percentage of total assessed area (Figueroa & Sánchez-Cordero 2008):

$$LULC = \frac{(S_2 - S_1)/S_t}{T} \times 100$$

where LULC = land use/land cover change, $S_1$ = initial transformed area, $S_2$ = final transformed area, $S_t$ = total assessed area, and T = time lag in years.

We compared LULC rates in BRs with those calculated for their ecoregions when at least 70% of the BR area

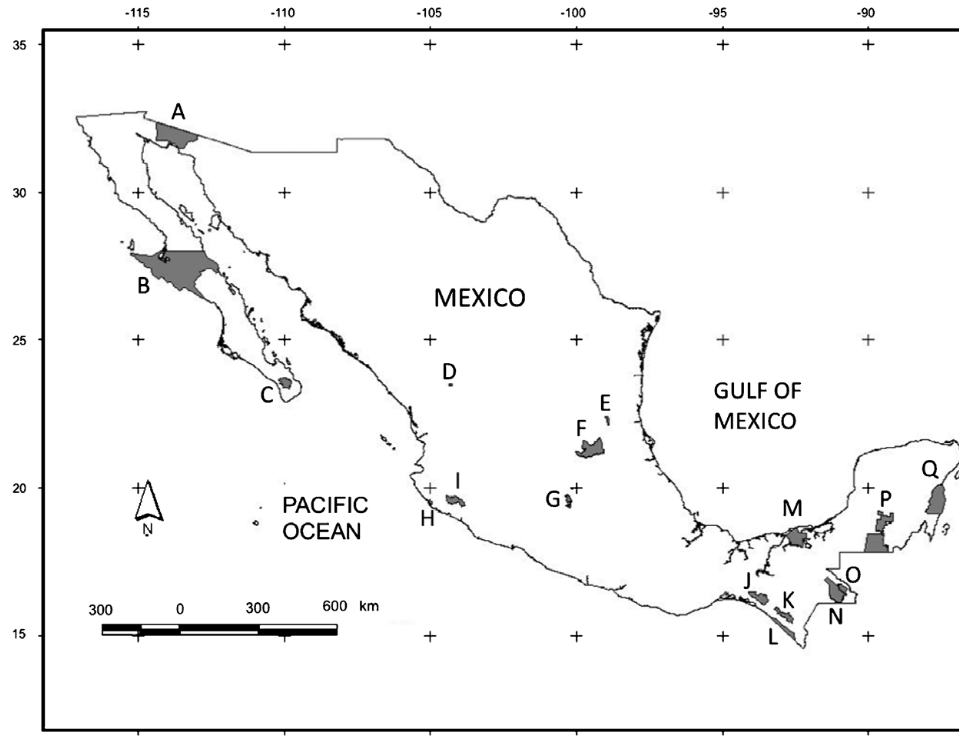


**Figure 1** Location of the 17 selected Mexican biosphere reserves (grey areas). (A) El Pinacate y Gran Desierto de Altar, (B) El Vizcaíno, (C) Sierra La Laguna, (D) La Michilía, (E) Sierra del Abra Tanchipa, (F) Sierra Gorda, (G) Mariposa Monarca, (H) Chamela-Cuixmala, (I) Sierra de Manantlán, (J) La Sepultura, (K) El Triunfo, (L) La Encrucijada, (M) Pantanos de Centla, (N) Montes Azules, (O) Lacan Tun, (P) Calakmul, (Q) Sian Ka'an.

formed part of a single ecoregion. When BR area was distributed more evenly among several ecoregions, a weighted rate was calculated based on the percentage of the BR area corresponding to each of the ecoregions (ecoregions occupying <10% of the BR were excluded).

We selected socioeconomic factors based on their documented relevance and their availability at the *municipio* (county) level. We identified those municipios whose area included part of the selected BRs (INEGI 2001*a*; CONANP 2003; see URL http://www.conanp.gob.mx). For each factor, we selected one indicator corresponding to a date as close as possible to 1993 (Table 2) from the 1990–1991 national official census (CONAPO [Consejo Nacional de Población] 1991; INEGI 1991, 1994). We used global change rates for 1990–2000 when information was available from additional official sources (CONAPO 2001; INEGI 2001*b*).

For Mexico, as for most other Latin American nations, there is ample evidence of the tremendous impact of cattle raising on LULC processes (Toledo 1991; Challenger 1998), which warrants the inclusion of this factor in the analysis. To identify cattle overpopulation (i.e. surpassing the land's cattle carrying capacity), we calculated a cattle overpopulation index by dividing the mean reported carrying capacity (hectares by cattle head) for each vegetation type (COTECOCA [Comisión Técnico Consultiva para la Determinación Regional de los Coeficientes de Agostadero] & SARH [Secretaría de Agricultura y Recursos Hidráulicos] 1988) over the area by cattle head reported in 1991. An index >1 indicates cattle overpopulation. We estimated access to markets by calculating total road density (km $ha^{-1}$) in those municipios whose territories overlap with the selected BRs; considering the differential socioeconomic and environmental impacts that roads may have depending on number of lanes and quality (paved versus non-paved), we weighted their density differentially, based on the official road map of Mexico (INEGI 2000).

We made a general diagnosis of prevailing socioeconomic conditions in the studied BRs and tested correlations between analysed variables through Spearman non-parametric procedures (SPSS [Statistical Package for the Social Sciences] 2004); significance level was adjusted through the Bonferroni method (Gotelli & Ellison 2004). We performed a canonical correspondence analysis (CCA; ter Braak 1996; MVSP [Multivariate Statistical Package] version 3.1) by using socioeconomic factors as independent variables and LULC indicators as response variables. To avoid multicolinearity, we excluded some variables from the CCA on the basis of the linear correlation test results. Percentages of highly marginalized localities and of rain-fed agriculture area were excluded, whilst the percentage of economically active population (EAP) dependent on agriculture and cattle raising was retained, given its strong correlation with these two excluded variables. The change rate of transformed area was also excluded, whereas the absolute extent of change was retained, as these two variables were highly correlated. For large BRs, a small change rate signifies a considerable loss of territory covered by primary or secondary vegetation (see Tables 1 and 3) and these changes may not be observable when comparing rates of change.

**Table 2** Selected sociodemographic and agroproductive factors and indicators for their evaluation. *Constructed parameters; see Methods for details.

| *Factors* | *Indicators* | *Source* |
|---|---|---|
| *Sociodemographic* | | |
| Population pressure | Population size (hab), growth (%), and density (hab/km$^2$) | (INEGI 1991, 2001b) |
| Population dispersion | Population living in settlements <5000 inhabitants (%) | |
| Population concentration | Population living in settlements > 20 000 inhabitants (%) | |
| Immigration | Immigrants established in the last five years (%) | |
| Indigenous population | Speakers of indigenous language (≥ five years old, %) | |
| Marginalization | Localities of high and very high marginality (%) | (CONAPO 1991, 2001; CONABIO 2001) |
| *Agro-productive* | | |
| Dependency upon land | Economically active population (EAP) living on agriculture, cattle raising and forestry (%) | (INEGI 1991, 2001b) |
| Access to markets* | Road density index | (INEGI 2000) |
| Agriculture vulnerability | Rain-fed agriculture area (%) | (INEGI 1994) |
| Cattle overpopulation* | Ratio of observed and adequate livestock density | (COTECOCA & SARH 1988; INEGI 1994) |

**Table 3** Land use/land cover change parameters for the 17 selected Mexican biosphere reserves. *LULC : Land use/land cover change. †BR/ECO = difference between LULC rate of biosphere reserves and their ecoregions.

| *Biosphere reserve* | *Transformed area (%)* | *LULC rate** | *Absolute change (ha)* | *BR/ECO*† |
|---|---|---|---|---|
| Calakmul | 1.38 | 0.08 | 5021.31 | −0.33 |
| Chamela-Cuixmala | 2.75 | 0.00 | 2.61 | −0.83 |
| El Pinacate y Gran Desierto de Altar | 0.02 | 0.00 | −35.01 | −0.15 |
| El Triunfo | 11.01 | −0.14 | −1561.54 | −0.33 |
| El Vizcaíno | 0.68 | 0.02 | 5014.98 | 0.00 |
| La Encrucijada | 30.41 | −0.14 | −1817.77 | −0.14 |
| La Michilía | 0.00 | 0.00 | 0.00 | −0.08 |
| La Sepultura | 12.98 | 0.25 | 3716.02 | 0.13 |
| Lacan Tun | 0.04 | 0.00 | 0.77 | −0.51 |
| Mariposa Monarca | 17.23 | −0.10 | −500.55 | −0.21 |
| Montes Azules | 2.44 | 0.13 | 3980.03 | −0.38 |
| Pantanos de Centla | 12.88 | 0.01 | 324.23 | −0.48 |
| Sian Ka'an | 0.01 | 0.00 | 27.25 | −0.07 |
| Sierra de Manantlán | 15.13 | 0.11 | 1418.81 | 0.02 |
| Sierra del Abra Tanchipa | 3.32 | 0.03 | 47.85 | −0.49 |
| Sierra Gorda | 16.55 | 0.13 | 4371.86 | 0.09 |
| Sierra La Laguna | 0.26 | 0.01 | 53.77 | −0.12 |

## RESULTS

### Processes of land use/land cover change

A large proportion of the selected BRs showed a good capacity to deter LULC processes, as indicated by their low percentages of transformed area in 2002; 60% of selected BRs showed <5% transformed area (Table 3). Some BRs exhibited relatively large rates of change during 1993–2002. Interestingly, the most strongly transformed BRs did not always have the largest LULC rates (Table 3). We observed the largest LULC rates for La Sepultura, Montes Azules, Sierra Gorda and Sierra de Manantlán. Conversely, rates of change were negative in La Encrucijada, El Triunfo, Mariposa Monarca and El Pinacate y Gran Desierto de Altar. BRs with the highest increase in absolute transformed area (>3500 ha) were Calakmul, El Vizcaíno, Sierra Gorda and Montes Azules (Table 3). As expected, we found absolute change of transformed area to be positively and significantly correlated with the rate of change (Fig. 2*a*). For most BRs, we recorded smaller LULC rates than in their respective ecoregions. This asymmetry was higher in Chamela-Cuixmala, Lacan Tun, Sierra del Abra Tanchipa and Pantanos de Centla. Contrastingly, in La Sepultura, Sierra Gorda and to a lesser extent in Sierra de Manantlán, the rate of change exceeded that of their ecoregions (Table 3).

We classified selected BRs into four categories according to LULC indicators. Firstly, BRs with zero or a very low percentage of transformed area in 2002, that did not show LULC processes during the study period (Chamela-Cuixmala, El Pinacate, El Triunfo, La Michilía, Lacan Tun, Pantanos de Centla, Sian Ka'an, Sierra del Abra Tanchipa and Sierra La Laguna). Secondly, BRs with a low percentage of transformed area in 2002, and a low rate of change between 1993 and 2002, but with a marked increase in its absolute extent (not reflected in the rate of change due to a large reserve size); in all these cases, the rate of change was lower than in

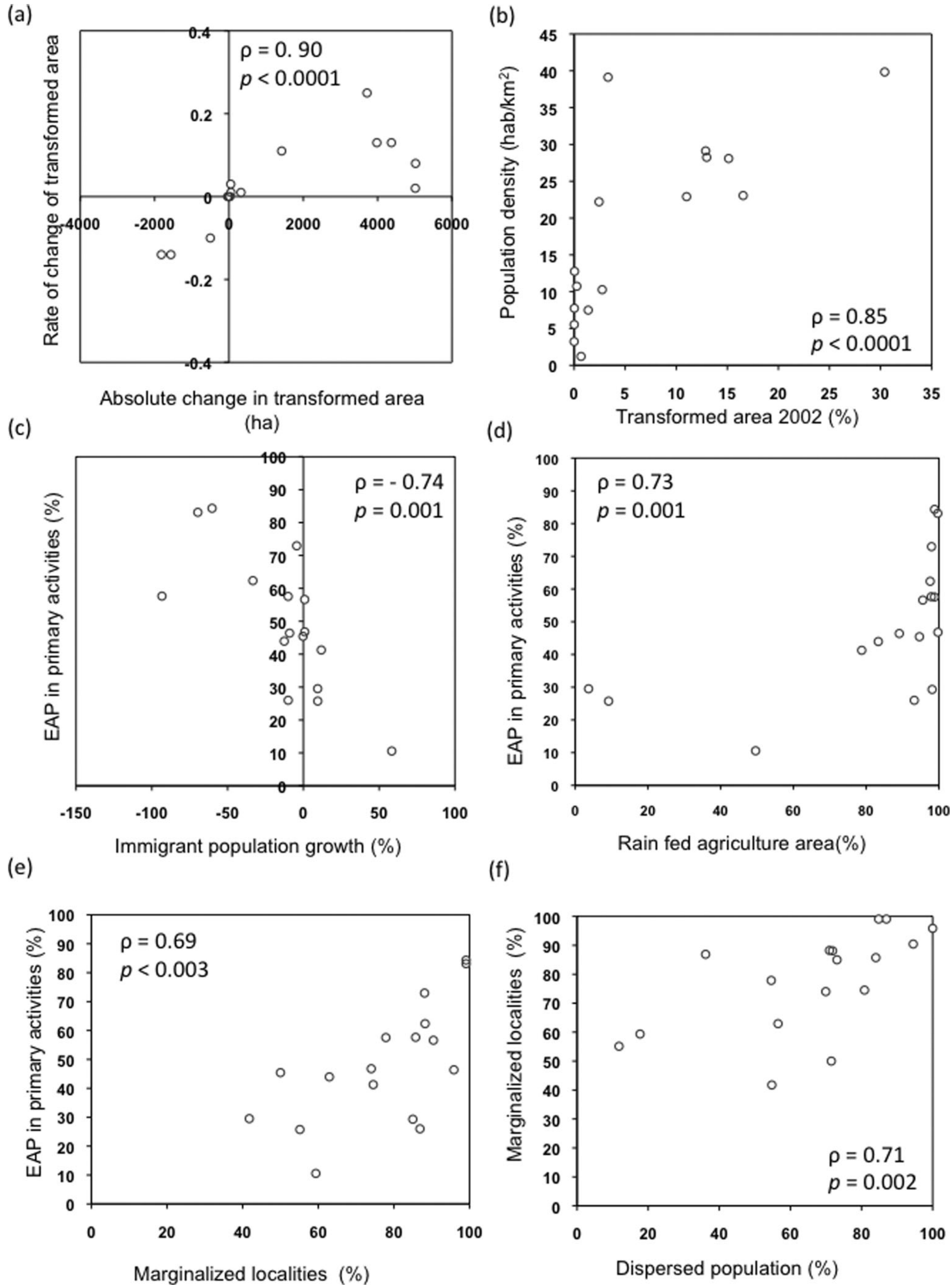


**Figure 2** Scatter-plot and Spearman's *r* correlation coefficient between (*a*) absolute amount of change and rate of change of transformed area (1993–2002); (*b*) percentage of transformed area and population density; (*c*) immigrant population growth and economically active population (EAP, %) dependent on primary activities; (*d*) percentage of rain-fed agriculture area and percentage of EAP devoted to primary activities; (*e*) percentage of localities of high and very high marginalization and percentage of EAP devoted to primary activities; and (*f*) percentage of population living in localities <5000 inhabitants and percentage of localities of high and very high marginalization. These are significant correlations (modified with Bonferroni correction and $p < 0.003$).

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their corresponding ecoregions (Calakmul, El Vizcaíno and Montes Azules). Thirdly, BRs showing a large percentage of transformed area in 2002, but in which this variable became smaller (La Encrucijada and Mariposa Monarca). Finally, the three remaining BRs formed a fourth heterogeneous group as each one displayed a different scenario: Sierra de Manantlán showed *c.* 15% of its area transformed and had a relatively low LULC rate, albeit slightly higher than its respective ecoregion; La Sepultura was also transformed in *c.* 15% of its area, had a very high LULC rate (well above its ecoregion) and a large increase in absolute transformed surface; Sierra Gorda showed the largest values for all three LULC indicators.

### Socioeconomic characteristics of selected biosphere reserves

Population pressure in the selected BRs was low, with a mean population density of 18 habitants km$^{-2}$ (excluding the extreme value for Mariposa Monarca of 130 habitants km$^{-2}$), which is smaller than the mean value reported nationwide (50 habitants km$^{-2}$). However, there was a significant positive correlation between population density and transformed area in 2002 (Fig. 2*b*). Population in BRs grew less than 20% during the 1990s, except in Lacan Tun, Mariposa Monarca, Pantanos de Centla, El Pinacate y Gran Desierto de Altar, Sierra La Laguna and Sian Ka'an; in the last BR population size doubled in the same period.

In 1990, migration to BRs was not an important factor in population growth, except in Sian Ka'an, Sierra La Laguna and La Encrucijada. The proportion of immigrant population had decreased in ten BRs by 2000, but it showed significant increases in La Laguna (58%) and Sian Ka'an (165%). Immigration grew mainly in BRs with low social marginality, low vulnerability of production and dependence on agriculture and cattle raising, all of which was reflected in the significant negative correlation between immigration rate of change and EAP dependent on agriculture and cattle raising, and the positive correlations between EAP dependent on agriculture and cattle raising, the percentage area of rain-fed agriculture and the proportion of localities with high marginality (Fig. 2*c*–*e*).

There was large population dispersion in the selected BRs. The mean proportion of population living in small localities (66%) was larger than nationwide (31%). Conversely, the mean proportion of population concentrated in medium-sized and large cities (10.6%) was smaller than the nationwide value (60%). BRs with a greater population dispersion showed higher marginality (Fig. 2*f*). Marginality was also higher in BRs than nationally, as most localities were classified as having high or very high marginality in 1990 (CONAPO 1991). In 12 BRs, the proportion of such localities exceeded the estimated value of 74% for the entire country. The proportion of indigenous population was greater than nationally only in Lacan Tun, Montes Azules, Sian Ka'an, La Michilía, Calakmul, Mariposa Monarca and Sierra del Abra Tanchipa.

The proportion of land devoted to rain-fed agriculture was >80% of total agricultural area, suggesting a high vulnerability for agriculture for most BRs. EAP was highly dependent on agriculture and cattle raising, exceeding national levels; EAP dependency on agriculture and cattle was positively correlated with the proportion of land area devoted to rain-fed agriculture and with socioeconomic marginality (Fig. 2*d*, *e*). Virtually all BRs suffered from cattle overpopulation, especially Mariposa Monarca, Sierra La Laguna, Pantanos de Centla and Sierra del Abra Tanchipa. All BRs had limited access to markets owing to their relative isolation, very low road density and a prevalence of dirt roads and two-lane highways.

### Socioeconomic context and land use and vegetation change in biosphere reserves

Spearman correlations allowed us to distinguish two broad BR profiles. The first group comprised BRs characterized by relatively large population size, density and growth (with this population concentrated in medium-sized and large cities), higher immigration, road density and cattle overpopulation, together with relatively lower socioeconomic marginality, dependence on agriculture and cattle raising, vulnerability of agricultural production and percentage of indigenous population (but large growth in this population sector). In these BRs, which may be considered as 'more developed', a larger percentage of transformed area was generally observed for 2002. The second group may be considered as 'less developed', and included those BRs displaying the exact opposite trends and a lower percentage of transformed area for 2002.

The analysed socioeconomic factors explained 86.9% of LULC indicators variance (Axis 1, 63.4%; Axis 2, 23.4%). The factors with the largest loadings on Axis 1 were population density (positive correlation) and the 1990 percentage of indigenous population (negative correlation; Table 4). The largest loadings for Axis 2 were population growth and increase in percentage of immigrant population (both positively correlated). In the case of Axis 1, population density was positively correlated with population size and density, road density and cattle overpopulation, and negatively correlated with percentage of indigenous population (Fig. 3*a*). Axis 2 was positively correlated to percentage of EAP dependent on agriculture and cattle raising, and negatively to population growth, indigenous population growth and population concentration (Fig. 3*a*).

The distribution of LULC indicators on the ordination space showed correlation trends with the ordination axes, and ultimately with the examined variables (Fig. 3*b*). Percentage of transformed area in 2002 corresponded to positive values on Axis 1 and, less strongly, on Axis 2. Therefore, those variables determining most strongly the existence of a large percentage of transformed area were population and road density, cattle overpopulation and, less importantly, population dispersion and EAP dependent on agriculture and cattle raising. This sector of the ordination space included BRs with the largest

**Table 4** Intraset correlation coefficients in the canonical correspondence analysis relating socioeconomic factors and land use/land cover change in 17 selected Mexican biosphere reserves.

| *Factor* | *Correlation coefficient* | |
|---|---|---|
| | *Axis 1* | *Axis 2* |
| Population size | 0.380 | 0.136 |
| Population growth | −0.008 | −0.594 |
| Population density | 0.598 | 0.166 |
| Dispersed population (%) | 0.203 | 0.365 |
| Concentrated population (%) | 0.028 | −0.34 |
| Immigrant settlers (%) | 0.276 | −0.195 |
| Immigration growth | −0.244 | −0.523 |
| Indigenous population growth | 0.012 | −0.481 |
| Indigenous population (%) | −0.451 | −0.113 |
| Economically active population dependent on agriculture, cattle and forestry (%) | 0.046 | 0.516 |
| Cattle overpopulation index | 0.341 | 0.002 |
| Road density index | 0.356 | 0.081 |

percentage of transformed area, such as La Encrucijada and Mariposa Monarca (Fig. 3*a*).

Absolute change in transformed area was associated with negative scores on Axis 1, and less strongly with positive scores of Axis 2; such change is therefore influenced by higher percentage of indigenous population, EAP dependent on agriculture and cattle raising, marginality and area of rain-fed agriculture. This section of the ordination space included BRs in which absolute transformed area increased considerably during 1993–2002, such as Calakmul, Montes Azules and El Vizcaíno.

The difference between the rate of change in BRs and their ecoregions (which is larger when the rate of change within the BRs exceeds that of its respective ecoregion), is mostly associated with negative scores on Axis 2 (Fig. 3*b*), i.e. with factors such as both overall and indigenous population growth, and population concentration in cities. However, those BRs having larger rates of change than their corresponding ecoregions were centrally located on the ordination space, probably because they had large values of percentage of, and absolute change in transformed area.

BRs with low percentage of transformed area and few internal changes (Sierra La Laguna, El Pinacate, Sian Ka'an and La Michilía) had negative scores on both axes, and were associated with high percentages of indigenous population and, less strongly, to increases in population growth and immigration (Fig. 3*a*).

## DISCUSSION

The conservation of biological diversity is an international priority, especially for megadiverse countries. LULC processes may threaten conservation efforts in NPAs, as they undermine the structure and function of their ecosystems by triggering and intensifying other degradation processes (Dale *et al.* 1994; Vitousek *et al.* 1997; Houghton *et al.* 1999; Islam and Weil 2000; Sánchez-Cordero *et al.* 2005). Success in attaining conservation goals in NPAs depends mainly on maintaining native vegetation cover.

The majority of our selected BRs were capable of containing LULC processes during the 1990s, confirming their relevance for vegetation conservation (Figueroa & Sánchez-Cordero 2008). Nevertheless, some BRs require urgent attention if they are to reverse current LULC trends; Sierra Gorda and La Sepultura were both highly transformed and had suffered large changes in vegetation cover, outstripping their corresponding ecoregions. This disparate ability of BRs to conserve biodiversity calls for an urgent assessment of the underlying socioeconomic and political processes, together with a critical appraisal of management and development plans.

### Socioeconomic conditions of biosphere reserves

Each BR has a unique historical, socioeconomic and political context, nevertheless all of them represent land subjected to particular environmental policies that promote the conservation of biological diversity and permit (ideally) sustainable development of local communities in buffer zones. Although this approach enables the coexistence of conservation and development goals, there are enormous challenges given the inadequate socioeconomic conditions prevailing in most BRs.

Demographic pressure in Mexican BRs is low, but population is highly dispersed throughout their territories. Unlike findings from other countries, where immigration is a relevant threat to BRs (de Sherbinin & Freudenberger 1998; Mwamfupe 1998; Carr 2004*a*, 2006, 2009; Stocks *et al.* 2007), in Mexican BRs immigrant population has been declining. This result is unsurprising, as international migration to the USA has reduced rural population substantially in many Mexican regions. During 1995–2000, 1 470 000 people, mainly of rural origins, migrated to the USA, rendering Mexico the third country worldwide regarding population withdrawal, after China and the Democratic Republic of Congo; by 2003 *c*. 27 million Mexicans lived in the USA and remittances from migrant residents in the USA (US$ 25.1 billion in 2008) constitute the second largest revenue source for Mexico, after oil (Tuirán 2004; Durand 2007; Roberts & Hamilton 2007; see URL http://www.conapo.gob.mx).

Population is attracted to less isolated and marginalized BRs, with higher urban development. Higher waged labour availability may be a strong incentive for immigration, as waged labour income represents more than half of total income for rural households (de Janvry & Sadoulet 2001). High social marginalization is also common (see Nadal 2003). The percentage of indigenous population, although variable, was high in some BRs, reflecting the geographic coincidence of cultural and biological diversity (Toledo *et al.* 2002).

Despite the apparently low demographic pressure in BRs, survival of people living inside them depends directly upon local land and resources. In most Mexican NPAs conditions for agriculture are inadequate (Brandon *et al.* 2005; Mas 2005),

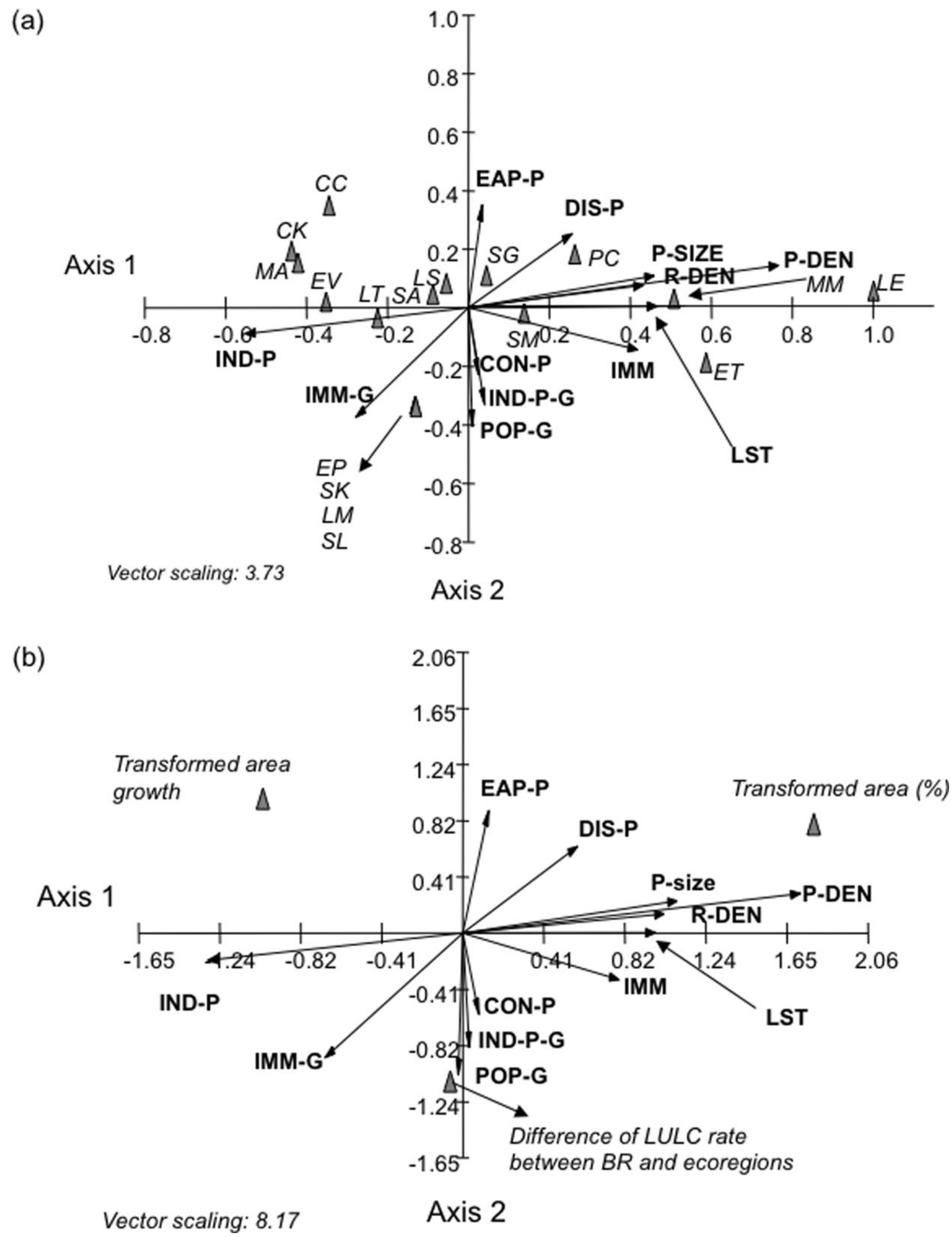


**Figure 3** Ordination of (*a*) biosphere reserves and (*b*) LULC parameters (triangles) in a canonical correspondence analysis (CCA), relating land use/land cover change parameters and socioeconomic factors. Abbreviations for biosphere reserves are in Table 1. EAP-P = percentage of economically active population devoted to primary activities; DIS-P = percentage of population living in localities <5000 inhabitants; P-SIZE = population size; R-DEN = road density index; P-DEN = population density; LST = cattle overpopulation index; IMM = percentage of immigrant population; CON-P = percentage of population living in localities > 20 000 inhabitants; IND-PG = indigenous population growth; P-G = population growth; IMM-G = immigrant population growth; IND-P = percentage of indigenous population.

yet BR residents are dependent on agriculture and cattle raising in rain-fed land with high productive vulnerability and weak links to regional and national markets. To make this scenario worst, we also documented cattle overpopulation in most BRs.

## Socioeconomic conditions and land use/land cover change

A complex interplay of factors affect LULC processes, which operate at different spatial and temporal scales and are highly context-dependent (Angelsen & Kaimowitz 1999; de Sherbinin *et al.* 2007). At the local level, some factors depend on household decision-making, and others are part of socioeconomic and political structures (Chowdury & Turner 2006). Critical local-scale factors include community institutions regulating natural resource use (Asbjornsen & Ashton 2002; Velázquez *et al.* 2003; Merino-Pérez & Bray 2004; Antinori & Bray 2005), social costs of conservation policies and level of social participation (Little 1994; Chapela & Barkin 1995; Ghimire & Pimbert 1997; Haenn 2000). Among regional factors are specific environmental conditions (Pressey *et al.* 2002; Mas 2005), the history of territorial occupation and use of natural resources, the type and intensity of economic activities, and development policies (Geist & Lambin 2002; Chowdhury & Turner 2006). Our results confirm some regional sociodemographic and agroproductive factors affect LULC processes in BRs. These factors were better able to explain long-term processes (percentage of transformed area in 2002) than short-term ones (rate of change 1993–2002). We did not investigate rural development policies (Chowdhury & Turner 2006) and local social conflicts (Ghimire & Pimbert 1997), which may trigger short-term processes.

The BRs showing the highest long-term LULC shared traits that allowed us to regard them as more developed, in terms of an economic model that favours infrastructure development, population concentration and cattle expansion. There is ample evidence for the influence of population pressure, cattle expansion and market demand of natural resources on deforestation processes (Toledo 1991; Lambin *et al.* 2001; Carr *et al.* 2005). Although population pressure is not particularly high in BRs relative to national values, it undoubtedly contributes to LULC under these socioeconomic conditions. Public development policies underlie all these factors and their effect on resource use, and are thus critical drivers of LULC processes.

The largest short-term LULC processes were recorded in BRs with variable socioeconomic conditions, but higher rates of change were observed mostly where population, albeit present at low densities, was highly dependent upon agriculture and cattle raising. These BRs shared high proportions of indigenous population, predominance of rain-fed agriculture and high social marginalization, along with less cattle overpopulation. The complex interaction of poverty, productive vulnerability and direct dependence on land, may induce short-term LULC processes (although see Carr 2006 for different scenarios regarding the relationship of indigenous population, poverty and LULC in Guatemala). The interplay of socioeconomic variables characterizing these BRs conceals the role of indigenous population, although in areas of strong indigenous presence large long-term LULC processes were less important. This may be partly owing to adequate natural resource management and the social organization of indigenous communities (Gómez-Pompa & Kaus 1992; Bray *et al.* 2003; Tucker 2004; Alarcón-Chaires 2006; Carr 2006; Stocks *et al.* 2007), although in some cases, productive practices may depend more upon site socioeconomical and agroecological characteristics than upon population ethnicity (Carr 2004*a*). Future studies should address this question.

Our results apply within the spatial and temporal scale of the analysis. This mesoscale study was designed to detect the influences of factors acting (and measurable) at this specific space and timespan, and changing the scale of analysis might alter the observed importance of the analysed factors (de Sherbinin *et al.* 2007). For example, it would not be possible to evaluate the importance of household dynamics on LULC at this scale, a relationship only measurable at the local scale.

### Rural development and conservation

Is it possible to improve rural livelihoods in BRs and their surrounding areas without inducing large-scale LULC? To address this question, the concurrence of multidisciplinary approaches is obviously required. In short-term LULC, population pressure may not be as important as inadequate production conditions, poverty and high dependency on agriculture and cattle raising. The existence of viable and profitable economic opportunities may buffer the strong pressures on natural vegetation currently observed (Lambin *et al.* 2001).

Rural development policies have been shown to exert a strong influence on LULC (Angelsen & Kaimowitz 1999; Geist & Lambin 2002; Chowdhury & Turner 2006). Since the 1980s, several policy changes have occurred in Mexico, diminishing peasants' capacity to accumulate capital through primary economic activities (Calva 1993). These changes have also had strong negative environmental consequences (Barbier 2000); in areas of high socioeconomic vulnerability, negative environmental impacts may increase as peasants face the need to produce under adverse circumstances, consequently becoming more impoverished. Some current policies promote large monocultures, along with intensive use of chemical inputs, with a strong emphasis towards a market-based production, a situation that is well documented in Calakmul (Reyes-Hernández *et al.* 2003; Chowdhury & Turner 2006).

If conservation is to coexist with rural development, a careful design of specific policies should be undertaken in order to induce forms of production consistent with conservation (Harvey *et al.* 2008). An example of such strategies is the hampering of cattle expansion with simultaneous linking of production to fair-trade markets, and encouragement of lower impact agricultural practices. This is true not only for BR communities, but also for the remainder of rural Mexico, to avoid only preserving relatively well conserved isolated reserves within a completely transformed landscape (Vandermeer & Perfecto 2007). Viable alternative strategies must be at least equally, but preferably more profitable than current ones (Barbier & Burgess 2001).

## CONCLUSIONS

The concurrence of conservation and development, particularly in less developed countries, is an overwhelmingly complex issue. Despite obvious inherent limitations of the available data, our study highlights some of the challenges faced by the conservation-development binomial, given the prevailing socioeconomic conditions in BRs and their links to vegetation cover decline.

Successful conservation and development demands the simultaneous participation of different stakeholders, such as professionals from a range of disciplinary fields, governmental institutions, non-governmental organizations and local communities, among others. It also requires that decision-making processes regarding national public policies, especially related to rural development, acknowledge the relevant role of environmental concerns. A central implication of our results is that we must address the question of what kind of development should we seek in BRs. From our perspective, policies should focus on modifying socioeconomic structural factors if more environmentally friendly and economically viable production is to be promoted, including agricultural and cattle intensification, green markets and fair trade, diversified and organic production, and ecological restoration. BRs are one viable option for pursuing conservation and development in megadiversity nations worldwide, but important challenges still need to be addressed.

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