Land Use Policy 67 (2017) 340–351

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Development stressors are stronger than protected area management: A case of the Pantanos de Centla Biosphere Reserve, Mexico

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ARTICLE INFO

Keywords:
Land-use change (LUC)
Conservation policy
Protected area management effectiveness assessments (PAME)
Coastal zone management

ABSTRACT

Evaluation of the management effectiveness of protected areas has become a global priority, especially in coastal zones, where essential services are threatened by land use pressures. To assess the effectiveness of a coastal protected area, we estimated the land-use change (LUC) within and outside of the Pantanos de Centla Biosphere Reserve (PCBR) and interviewed key stakeholders to identify the main stressors causing LUC. The native vegetation cover under the PCBR protection decreased by 65% over 24 years; whereas agriculture and livestock lands doubled, even within the core conservation areas of the PCBR. The greatest loss was in the flooded forest (48%), where the reduction was similar in and around the reserve. The effectiveness of reserve management was affected by drivers of land use change, which include agricultural and livestock enterprises that are run by government programs. Effective management of the PCBR has been undermined by poor management practices, limited capacity and resources, and inadequate zoning design. Protected areas and its surrounding landscapes could be considered to be natural experiments for future research, where high value land uses and conservation objectives coincide within coastal areas that will face a predicted sea level rise, more intense floods and higher temperatures.

1. Introduction

Protected areas (PAs) are a main conservation tool for maintaining global biodiversity *in situ* (Chape et al., 2005). The primary goal of PAs is to preserve a network of representative ecosystems globally (Bertzky et al., 2012; Uffe-Bignoli et al., 2014). However, establishing PAs is not enough, and assertive management practices are required to achieve conservation objectives. The global Aichi Biodiversity Target 11 indicates that PAs should be conserved through effective and equitable management by 2020 (UNEP, 2010). As an important step, the performance of Protected Area Management Effectiveness Assessments (PAME) in at least 30% of each participating country's PAs was recommended by 2010 (CBD, 2004). Therefore, assessment of management effectiveness became a priority research and management topic (Knights et al., 2014; Ren et al., 2015; Segi, 2014).

Several issues must be analyzed to determine whether PAs are accomplishing their objective to preserve natural resources and biodiversity (Dudley et al., 2004). Assessing the effectiveness of a PA involves evaluating the adequate allocation of the conservation budget, the designed zoning areas under decree and the long-term population viability of protected species, among other issues (Hockings et al., 2002; Hull et al., 2011). The evaluation mechanisms can favor adaptive management processes that inform decision-making based on experience while also improving transparency and accountability (Bennear and Coglianese, 2005; Hockings et al., 2000). After feedback, management adjustments may involve addressing logistical and budgetary shortcomings and the lack of the incorporation of scientific information and of institutional coordination in decision making (Pomeroy et al.2005).

The PAME of coastal areas is especially important because they contain transitional ecosystems that have high ecological richness (Carr et al., 2003; Stojanovic and Farmer, 2013) whose resources and services are essential for human welfare and development (Glavovic et al., 2015). Efforts to conserve coastal protected areas are threatened by human population growth and accompanying development, such as coastal infrastructure, forestry, extensive livestock farming, agriculture, tourism, the exploration and exploitation of energy resources (oil and gas) and mining (Watson et al., 2014). The ultimate impacts on coastal

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http://dx.doi.org/10.1016/j.landusepol.2017.06.009
Received 9 December 2016; Received in revised form 7 June 2017; Accepted 11 June 2017
Available online 28 June 2017
0264-8377/

PAs can be observed in land use changes (LUCs) (Martínez et al., 2007) and in the speed and effects of transformation, which may alter ecosystem structure, function and services (Andam et al., 2008; Kolb et al., 2013). These adverse processes tend to reduce the carrying capacity of coastal ecosystems and compromise their resilience, a key element in mitigating the expected effects of global warming (Hadley, 2009; Harley et al., 2006). Most studies on LUC in coastal zones have focused on changes in natural vegetation (Lo and Gunasiri, 2014; Ruiz-Luna and Berlanga-Robles, 2003; Soto-Galera et al., 2010); less research has focused on the root causes of coastal transformation due to human development (Olaniyi et al., 2012) and how PAs cope with the drivers of land use and land cover changes (Lambin et al., 2001; Meyfroidt et al., 2013; Veldkamp and Lambin, 2001). More research is needed to understand how productive landscapes and the policy and governance surrounding a PA affect its effectiveness and permanence in the long-term (Symes et al., 2016).

The factors likely involved in LUCs on the Mexican coast must be evaluated, as the enormous diversity of this area sustains an increasing number of economic activities administered by an incipient coastal resources management system (Espinoza-Tenorio et al., 2015). Mexico has the thirteenth longest coastline worldwide (11,122 km), and its four seas, including the highly biodiverse ecoregions of the Gulf of California and the Mesoamerican reef, comprise a large variety of habitats, such as 1,567,000 ha of estuaries and 1350 insular elements (CONABIO et al., 2007). In total, 10% of the Mexican coast is protected by 95 PAs (CONANP, 2015), some of which are catalogued as successful conservation projects (Carabias et al., 2010). However, most of the protected areas were hastily created in the 1990s (Espinoza-Tenorio et al., 2011), and their effectiveness and design have been questioned because they do not account for important ecological features (Bezaury-Creel, 2005; Micheli, 2002; Ortiz-Lozano et al., 2009), limiting their effectiveness in combating increasing human impacts (Camacho-Ibar and Rivera-Monroy, 2014).

The Pantanos de Centla Biosphere Reserve (PCBR), the site of our PA case study, is located on the southern coast of the Gulf of Mexico and protects the most important coastal wetland in Mesoamerica (RAMSAR, 2014) and the main marine freshwater system in the country, the Grijalva–Usumacinta Delta. In the past two decades, increasing anthropogenic activities and natural disturbances, such as hurricanes and floods, have led to the intense deterioration of native vegetation within this reserve (Figueroa and S&nchez-Cordero, 2008; García-Hidalgo, 2014; Guerra-Martínez and Ochoa-Gaona, 2008), making LUC inside and outside of the PA the primary threat (*Pers. Com.*, Director of the PCBR). Because controlling and reversing environmental degradation is a major objective of the PCBR (SEMARNAT, 2000), we aimed to identify the main drivers of land use change from 1992 through 2014 within the PA and a 10-km buffer zone from the reserve establishment.

1.1. Pantanos de centla biosphere reserve

The PCBR protects a vast region of wetlands (Fig. 1); it covers 297,039 ha of mangrove forests, hydrophyte communities and flooded logwood forests. Given its rich biodiversity (Guadarrama and Ortiz, 2000; Macossay-Cortez, 2008; Santiago-Alarcon et al., 2011) as well as its value as a refuge for several threatened species (SEMARNAT, 2000), the PCBR has been recognized in the North American Wetlands Conservation Act, the Ramsar Convention and as an Important Bird and Biodiversity Area.

Historically, the Pantanos de Centla wetlands have been used by the Chontal-Maya culture since pre-Columbian times (Maimone-Celorio et al., 2006), but they have faced accelerated ecosystem transformation from extensive agriculture and livestock activity and illegal exploitation of their endemic forests since the twentieth century (Romero Gil et al., 1993). Furthermore, the PCBR is located in a strategic area of oil and gas fields in which wells, collection stations, discharge lines and pipelines were established in the 1950s. Regional development was accompanied by an increase in human settlements. In 2010, the PCBR population consisted of 21,044 inhabitants, of which 47% were indigenous peoples. Currently, the local economy depends largely on small-scale fisheries and peasant agriculture. In addition to the known stressors within the PCBR, there are many stressors in the surrounding lands, including irrigation systems for agriculture and livestock and dam infrastructure on the Grijalva River, which have modified the wetlands ecosystem.

The National Commission of Protected Natural Areas (CONANP, by its Spanish acronym) is responsible for managing the reserve. The PCBR management program establishes two core zones to preserve the natural capital, including prohibiting any use. Four surrounding buffer areas allow sustainable use of the resources at distinct levels of exploitation: restricted, intensive, special and wildlife use.

2. Materials and methods

Our main approach involved the PA effectiveness evaluation framework suggested by Hockings et al. (2000). This framework comprises an evaluation of three phases of the management cycle (Fig. 2). Our study was designed to retrospectively cover the last two phases related to delivery of the PA objectives. In this regard, we assessed the management effectiveness in terms of avoiding LUCs within the PCBR through the following: 1) a quantitative spatial analysis to assess changes in land use and native vegetation cover in the PCBR and its area of influence; and 2) a qualitative assessment based on interviews with key stakeholders to identify the major stressors and drivers of LUC.

2.1. Analysis of land use change

Landsat images from 1990 and 2014 were used in a diachronic analysis to estimate land cover changes. The two images were geometrically corrected, projected and masked to a polygon of the PCBR using IDRISI Selva software. The area of influence was delimited through a 10-km buffer zone (Figueroa and Sánchez-Cordero, 2008) surrounding the reserve polygon. Because there are no marine habitats in the PCBR, sea zones detected as area of influence were discarded from the analysis to avoid overestimation of waterbodies.

The window images were classified using a standard supervised method suggested by Chuvieco (2008) with the maximum likelihood estimation rule. To classify both images, calibration training sites were obtained with the aid of vegetation and land use maps from published literature regarding the PCBR (Avila et al., 2014; Guerra-Martínez and Ochoa-Gaona, 2008), ground data collected between 2014 and 2015, and knowledge gained from field experience by the researchers. Once the classification was finished, a majority filter (3 × 3 pixels) was applied to reduce the speckled pattern effect of some land cover classes in the classified images (Hirales-Cota et al., 2010).

The accuracy of the 1990 and 2014 final classifications was assessed by an estimate of the kappa coefficient ($\hat{\kappa}$) using the ErrMat command in IDRISI to identify the percentage of pixels correctly classified in each image. Raster classifications were transformed to vector format to estimate the land cover changes and to create vector maps. Finally, the values for net changes (losses and gains) corresponding to each year were obtained using the Land Change Modeler module in IDRISI.

2.2. Assessment of the major stressors and drivers of LUC

2.2.1. Interviews

A semi-structured interview to assess PA effectiveness was designed following Ervin's (2003) criteria: 1) ecological integrity, which is based on threat prevalence, the reach of specific stressors and landscape stability over time; 2) design, related to the size, extent, and location of the protected area, its biological representativeness, and the represented ecosystems; and 3) adoption of management processes at the site level, which are defined by the correlation between threats and the