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Tropical montane cloud forests: Current threats and opportunities for their conservation and sustainable management in Mexico

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ABSTRACT

Tropical montane cloud forests (TMCF) are among the most threatened ecosystems globally in spite of their high strategic value for sustainable development due to the key role played by these forests in hydrological cycle maintenance and as reservoirs of endemic biodiversity. Resources for effective conservation and management programs are rarely sufficient, and criteria must be applied to prioritise TMCF for conservation action. This paper reports a priority analysis of the 13 main regions of TMCF distribution in Mexico, based on four criteria: (1) forest quality, (2) threats to forest permanence, (3) threats to forest integrity, and (4) opportunities for conservation. Due to the diverse socio-environmental conditions of the local communities living in Mexican TMCF regions, their associated social characteristics were also evaluated to provide a background for the planning of conservation actions. A set of indicators was defined for the measurement of each criterion. To assign priority values for subregions within each main region, an international team of 40 participants evaluated all the indicators using multicriteria decision-making analysis. This procedure enabled the identification of 15 subregions of critical priority, 17 of high priority, and 10 of medium priority; three more were not analysed due to lack of information. The evaluation revealed a number of subjects that had hitherto been undetected and that may prove useful for prioritisation efforts in other regions where TMCF is similarly documented and faces equally severe threats. Based on this analysis, key recommendations are outlined to advance conservation objectives in those TMCF areas that are subjected to high pressure on forest resources.
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1. Introduction

Tropical montane cloud forest (TMCF) has long been recognised as one of the most threatened ecosystems globally (Hamilton et al., 1995; Aldrich et al., 1997; Bubb et al., 2004; Scatena et al., 2010). It is characterised by the frequent presence of clouds and mist (Hamilton et al., 1995). According to Bubb et al. (2004), TMCF only accounts for 2.5 percent of the total area of tropical forest worldwide, while Mulligan (2010) estimates forests that feature significant cloud effects to represent about 14% of all tropical forests. Approximately 43% of these TMCF are found in Asia, 41% in North and South America, and 16% in Africa (Scatena et al., 2010). The concept of TMCF embraces a number of communities distributed within tropical mountains, comprising varied structures, floristic affinities, and a very diverse species composition (Scatena et al., 2010). TMCF is widely regarded as a conservation priority worldwide due to its critical role in the maintenance of hydrological and nutrient cycles, and its high biodiversity with exceptional concentrations of endemic species (Hamilton et al., 1995; Bruijnzeel, 2001; Luna et al., 2001). Because of their restricted elevation range, many TMCF plant and animal species may present high risks of extinction under the current predictions of climate change during the next century (Still et al., 1999; Pounds et al., 1999; Bush et al., 2004) and/or because of extreme El Niño–Southern Oscillation (ENSO) events (Anchukaitis and Evans, 2010).

Due to its naturally limited distribution in the cloud belt of tropical mountains, TMCF distribution is often considered

Abbreviations: AHP, analytic hierarchical process; EMU, environmental management unit; FMP, forest management program; NGO, non-governmental organisation; PNA, protected natural areas; NTFP, non-timber forest product; PES, payment for environmental services; TMCF, tropical montane cloud forest.

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analogous to an archipelago, with deforestation enhancing the isolation of remaining TMCF fragments (Hamilton et al., 1995). Elevated human population densities and the consequent demand for forest products and land for alternative uses are the most important pressures for TMCF maintenance (Doumengue et al., 1995). In Mexico, a number of estimates indicate that more than over 50% of the original TMCF area has been replaced by other forms of land use; mainly pasture for cattle grazing, annual crops, and coffee plantations (Challenger, 1998; Cayuela et al., 2006; Muñoz-Villers and López-Blanco, 2008).

An accurate diagnosis of the main threats and opportunities for TMCF conservation and sustainable use can play a central role in its maintenance, and is crucial to the development of ecologically sound public policies. In this paper, we focus on TMCF in Mexico and, while our premise is that all areas of TMCF are equally important, we acknowledge a need to prioritise them due to the variety and complexity of their biophysical and socioeconomic attributes, and the contingent financial and human resources for their conservation. Although methods for biodiversity conservation planning have previously been established (Kuusipalo and Kangas, 1994; Groves et al., 2002; Bonn and Gaston, 2005; Regan et al., 2007), the prioritisation of ecological systems for conservation and management may benefit from considering both the environmental and social conditions for implementation of actions. Such approaches require a practical yet science-based planning framework (Groves et al., 2002). Here, we present a prioritisation analysis of TMCF in Mexico, examining its present condition, the main current threats to its permanence and integrity, the existing opportunities for its maintenance, and the social characteristics of the local human communities in and around TMCF as drivers of either conservation or increased forest loss.

2. Methods

2.1. Study region

TMCF in Mexico ("bosque mesófilo de montaña" *sensu* Rzedowski, 2006) occupies only 0.5–1% of the national territory (~10 000–20,000 km^2; Challenger, 1998), with less than 25% located in currently protected natural areas (Table 1). It is the terrestrial ecosystem with the highest concentration of floral and faunal diversity in the country; it hosts at least 3000 species of vascular plants, ~12% of the country's plant richness. Among the plant species in Mexican TMCF, endemics account for ~30% of the flora (Rzedowski, 1996), but for amphibians and reptiles the endemism may be as high as 33% and 39%, respectively (Flores-Villela and Gerez, 1988). Some of the most emblematic species of these forests include the quetzal (*Pharomachrus mocinno*), horned guan (*Oreophasis derbianus*), and tree ferns (*Alsophila firma*, *Cyathea fulva*, *Dicksonia gigantea*). Most people who inhabit TMCF areas in Mexico live in highly marginalized conditions (CONABIO 2010), with more than 55% of TMCF under communal ownership (Boege, 2008).

Table 1
Extent of tropical montane cloud forest (TMCF) in protected areas in Mexico (CONANP-CONABIO, 2005; Bezaury-Creel et al., 2007).

TMCF	Extent (ha)	Included in protected natural areas (ha)	Proportion included in protected natural areas (%)	No. of protected natural areas
Old-growth	869 419	157 838	18.2	32
Secondary vegetation[a]	955 613	56 233	5.9	24
Total	1 825 032	214 071	24.1	56

[a] Includes other vegetation types commonly associated with TMCF.

In order to conduct the prioritisation analysis, 13 regions of TMCF were identified and within these, subregions were further defined (Fig. 1). TMCF cover was based on the map of land use and vegetation series III (2002–2005), of the National Institute for Statistics, Geography and Informatics (INEGI) and regions were delimited based on physiographic provinces derived from the cartographic information provided by INEGI. Subregions were delimited according to forest cover, geomorphology, isolation, watershed margins, rivers, and presence of indigenous groups.

2.2. Team assessment

Two workshops were organized in 2007 and 2008 by the Mexican Biodiversity Commission (CONABIO) in Mexico City. Forty participants, including researchers, members of non-governmental organisations (NGOs), and government officials dedicated a total of 2000 h to evaluation and analyses. Based on their expertise, groups of 5–7 participants were allocated to the evaluation of each region, and various participants evaluated more than one region. The main areas of expertise represented in this group included TMCF plant ecology and taxonomy, biodiversity conservation, vegetation cartography, forest restoration, community forestry and action research.

2.3. Criteria and indicators

A set of nationally applicable criteria and indicators was constructed in order to prioritise subregions within each region. Each criterion includes a set of indicators used in its measurement or qualitative assessment (Fig. 2) (for criteria and indicator definitions see appendix 1).

2.4. Evaluation of indicators

The analytic hierarchy process (AHP) is a multicriteria decision-making technique (Saaty, 2006), and was the method used for the prioritisation analysis. With AHP, both quantitative and qualitative decision criteria can be analytically managed (Kuusipalo and Kangas, 1994). This technique employs numerical pairwise comparisons of the relative importance (weight) of one indicator over another, and is used to evaluate alternatives (in this case, subregions) with respect to each indicator (Kuusipalo and Kangas, 1994; Regan et al., 2007). The weight and value for each indicator are different aspects of the analysis; the ranking is the result of a combination of the weight and the value assigned to the indicator for a particular subregion. AHP prioritises alternatives according to the pre-weighted criteria. The number of pairwise comparisons depends on the number of elements (subregions) to be compared. The mathematical foundations of AHP can be found in Saaty (2006).

The assessment team defined the weight of each indicator towards the criterion. The weight was defined as the relative contribution of the indicator to the assessment of the corresponding criterion, i.e. the importance of its input to the model. The weights assigned to each indicator were: (0) non-existent or minimal, (1) low, (2) medium, (3) high, and (4) very high. Prioritisation analysis was conducted for each region separately due to the existence of large differences across the country related to biodiversity, forest management history, landscape and socioeconomic features. Thus, the team assigned scores to indicate the value of the indicator for each subregion within the region. The scale used to assign the indicator value for each subregion was the same as that used for the weights. Indicator weight and

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