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Comparing environmental vulnerability in the montane cloud forest of eastern Mexico: A vulnerability index

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ABSTRACT

The montane cloud forest (MCF) is one of the most threatened ecosystems, in spite of its high strategic value for sustainable development, the role it plays in the hydrological cycle maintenance, and as reservoir of endemic biodiversity. For Mexico, this forest is considered the most threatened terrestrial ecosystem at national level because of land-use changes and the effects of global climate change. To compare and assess the environmental vulnerability in the MCF we measured two physiological traits (stomatal conductance and leaf water potential), four climate variables (air temperature, photosynthetically active radiation, vapor pressure deficit, water availability) and the potential geographic distribution of eleven tree species from this forest. We evaluated stomatal conductance responses using the envelope function method (EFM), and after analyzing these responses we developed a vulnerability index that allowed us to compare the environmental vulnerability among species. We proposed the EFM as a useful tool to assess regional environmental vulnerability by comparing species. Our results showed differential species responses to all the studied variables; however, the vulnerability index allowed us to conclude that the most vulnerable species was *Liquidambar styraciflua*, and the least vulnerable *Persea longipes*. We also found that temperatures above 34 °C, and vapor pressure deficit above 2.9 kPa with relative humidity below 30% jeopardized the stomatal conductance performance of all species. We also found leaf water potential as the most influential variable over the studied species followed by vapor pressure deficit, showing that even in the MCF water is a determinant factor for species' development.

1. Introduction

The montane cloud forest (MCF) posses high strategic value for sustainable development, plays a key role in the hydrological cycle maintenance, and is a reservoir of endemic biodiversity (Toledo-Aceves et al., 2011). For Mexico, this forest is one of the most bio-diverse ecosystem (González-Espinosa et al., 2012); however, it is also considered the most threatened terrestrial ecosystem at national level because of changes in land-use, the effects of global climate change, and local and regional environmental changes (e.g. CONABIO, 2010; Toledo-Aceves et al., 2011; Calderón-Aguilera et al., 2012).

Globally, climate and environmental changes are increasingly recognized as a complex phenomenon involving shifts in many dimensions of Earth's atmospheric functions (Houghton et al., 1995). Three general expectations exist for species' responses to these changes: movement, adaptation (evolutionary change or physiological acclimatization), or extinction (Holt, 1990). If species are sufficiently mobile, they may track the geographic position of their ecological niches; if species are capable of rapid evolutionary change or have a wide range of physiological tolerances, adjustment to changing conditions and landscapes may be possible. Failing mobility and adaptability, extinction is the likely result (Holt, 1990; Melillo et al., 1995). Changes on climate are expected to shift the species' distribution along environmental gradients if their current environmental tolerance is exceeded (Miller and Urban, 1999).

Modeling can be used to predict shifts in vegetation's distribution under climatic change and to simulate vegetation responses (Zolbrod and Peterson, 1999). In theory, species presence/absence and abundance is highest where optimal conditions exist (Gauch et al., 1974). However, global vegetation patterns are already

Abbreviations: g_S, stomatal conductance; T_A, air temperature; PAR, photosynthetically active radiation; VPD, vapor pressure deficit; Ψ, leaf water potential; RH, relative humidity.

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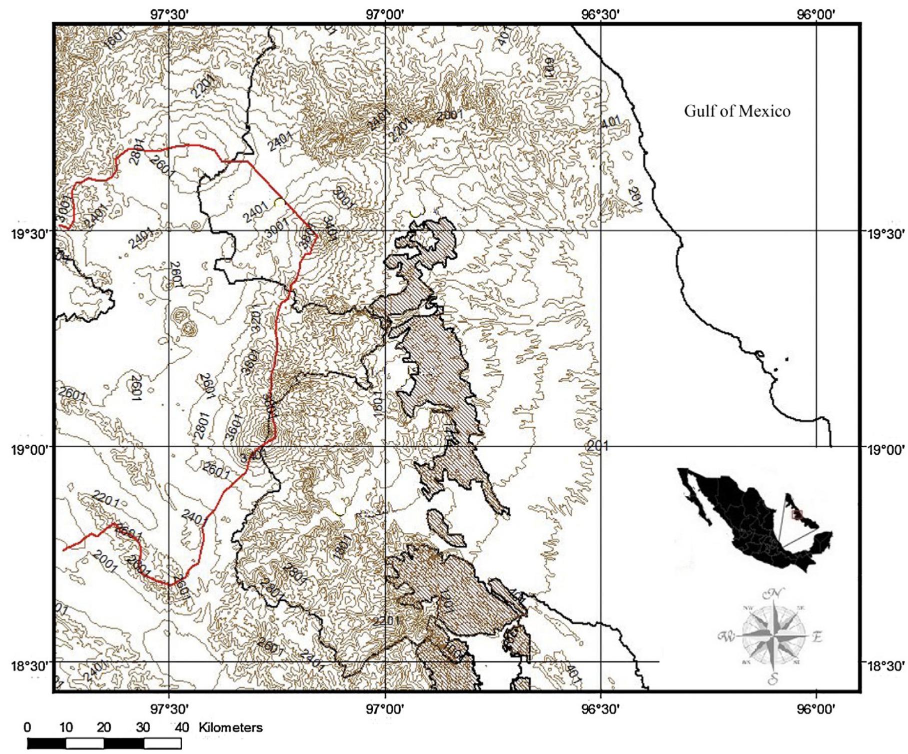

Fig. 1. Location of the study area in the central mountain region of Veracruz, Mexico.

shifting in response to changes in temperature and precipitation (Parmesan, 2006; Allen et al., 2010). Therefore, anticipating potential shifts in local vegetation is critical to develop adaptive strategies. Predicting the vegetation response to climate change requires consideration of interacting physical and biological processes (Halofsky et al., 2013). With climatic conditions predicted to continue changing over the next century (IPCC, 2014), conservationists and environmental managers would like to know where species are likely to remain within, or expand from their current distributions, and conversely, situations where species are likely to become vulnerable (Coops and Waring, 2011).

Vulnerability is defined as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate changes, including climate variability and extreme climate events (IPCC, 2001). Ecophysiological vulnerability is the degree of susceptibility or inability of an organism to adapt their physiological functions to ecological and environmental changes (Esperón-Rodríguez and Barradas, 2014a). Assessment of vulnerability is important, as it enables identification of areas or species at risk, and threats posed by diminution or loss of such resources that will threaten future efforts towards sustainable development.

To determine and compare the environmental vulnerability of eleven tree species from the montane cloud forest of eastern Mexico, we selected stomatal conductance as a vulnerability indicator. We measured four climate variables to assess the species' vulnerability: air temperature, photosynthetically active radiation, vapor pressure deficit and water availability, measured through the physiological trait of leaf water potential, in the field and in the greenhouse. Data from the greenhouse allowed us to observe the species' response in non-natural conditions by increased temperature. We also included the species' potential distribution to our analysis as a vulnerability enhancer. We approached this study with the envelope function method. This method is capable of analyzing variables that directly affect species, providing an effective tool to analyze the diversity of ecophysiological responses (Lambers et al., 1998; Barradas et al., 2010). From the species' physiological responses to different climate and physiological variables, it is explored how species can be affected by the potential vulnerability to changes in these variables. This study presents a first attempt to develop a comparative vulnerability index with ecophysiological implications.

2. Methods

2.1. Study area

The MCF located in the central mountain region of Veracruz in eastern Mexico (19°54′08″N, 96°57′19″W, Fig. 1) forms part of Neovolcanic Ridge and the Sierra Madre Oriental. Abrupt topography is the main characteristic of the region with a pronounced altitudinal gradient, from the sea level up to 5500 m asl at a distance of 100 km (Barradas et al., 2010). Average annual temperatures range between 10 and 29 °C, and annual precipitation ranges from 600 to 1200 mm, with a maximum of 3000 mm in wet regions. Soils in the region are of volcanic origin or Andisols, with physical characteristics that favor good structural stability (Meza and Geissert, 2003). They have low bulk density, high porosity with significant micro-porosity, significant amount of water micro-aggregates, complexation with organic matter, and stable amounts of Fe and Al (Shoji et al., 1993).

2.2. Species selected

Eleven tree species were selected from the MCF: *Carpinus caroliniana* Walter, *Clethra mexicana* DC, *Cornus florida* var. *urbiniana* (Rose) Wangerin, *Liquidambar styracifluaL.*, *Ostrya virginiana* (Mill.) K. Koch, *Persea longipes* Meisn., *Quercus candicans* Née, *Q. germana* Schltdl. & Cham., *Q. xalapensis* Bonpl., *Tapirira mexicana* Marchand, and *Ulmus mexicana* Planch. In Table 1 we present the climate requirements and altitudinal ranges for all the species (González-Espinosa et al., 2011; CONABIO, accessed April, 2014). Percentage of coverage in the MCF for all the species is not available; however, for some species are: *C. caroliniana*, 7.79%; *C. mexicana*, 3.71%; *L.*