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Modeling distribution of Amazonian tree species and diversity using remote sensing measurements

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Abstract

The availability of a wide range of satellite measurements of environmental variables at different spatial and temporal resolutions, together with an increasing number of digitized and georeferenced species occurrences, has created the opportunity to model and monitor species geographic distribution and richness at regional to continental scales. In this paper, we examine the application of recently developed global data products from satellite observations in modeling the potential distribution of tree species and diversity in the Amazon basin. We use data from satellite sensors, including MODIS, QSCAT, SRTM, and TRMM, to develop different environmental variables related to vegetation, landscape, and climate. These variables are used in a maximum entropy method (Maxent) to model the geographical distribution of five commercial trees and to classify the patterns of tree alpha-diversity in the Amazon basin. Maxent simulations are analyzed using binomial tests of omission rates and the area under the receiver operating characteristics (ROC) curves to examine the model performance, the accuracy of geographic distributions, and the significance of environmental variables for discriminating suitable habitats. To evaluate the importance of satellite data, we used the Maxent jackknife test to quantify the training gains from data layers and to compare the results with model simulations using climate-only data. For all species and tree alpha-diversity, modeled distributions are in agreement with historical data and field observations. The results compare with climate-derived patterns, but provide better spatial resolution and detailed information on the habitat characteristics. Among satellite data products, QSCAT backscatter, representing canopy moisture and roughness, and MODIS leaf area index (LAI) are the most important variables in almost all cases. Model simulations suggest that climate and remote sensing results are complementary and that the best distribution patterns can be achieved when the two data sets are combined.

Keywords: Species distribution; Remote sensing data; Maxent; Amazon basin; Tree diversity

1. Introduction

Recent efforts to conserve biodiversity are moving beyond preserving only its pattern, such as particular species or populations, to include the many complex processes that produce and maintain biodiversity (Cowling and Pressey, 2001; Crandall et al., 2000). The conservation of regional biodiversity is inextricably linked with the species that occur in a region, the genes they contain, and the other biotic and abiotic features that comprise the ecosystem (Myers et al., 2000). Under pressure to make informed management decisions rapidly, conservation practitioners must increasingly rely on predictive models to provide them with information on species distributions (Ferrier, 2002; Loiselle et al., 2003). In addition, using models to predict species distributions have become key elements in documenting biodiversity on the planet and are critical to understanding the effect of multiple stresses caused by climate and human-induced changes (Fjeldsaå & Lovett, 1997; Pimm, 1991).

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The majority of studies in biogeography use species occurrence or museum collections to map and analyze large-scale patterns of species distribution and richness (Lovett et al., 2000; Rahbek & Graves, 2001). These studies clearly indicate that species differ in the size of their geographic range. Most species, within the same assemblage, tend to have relatively small ranges that reflect how they share space (Brown et al., 1996; Gaston, 1998). Range size may depend on a variety of ecological and evolutionary processes and extrinsic factors of the physical environment such as soils, nutrients, water, and climate (Gentry, 1988; Hunter, 2003; Kreft et al., 2006; Smith et al., 2001). Capturing the interplay of these factors is fundamental to understanding the uneven distribution of diversity on regional and global scales.

In most biogeographic theories, geographic distribution of species and their diversity or richness are conceived in terms of a multidimensional coordinate system, whose axes are various resource gradients (e.g. ecological and environmental variables). This coordinate system defines a hyperspace, and the range of the space that a given species occupies is its niche. The niche is an abstract characterization of the intra-community position of the species that depends on time, space, and differences in resource gradients that cause the species evolution (Whittaker, 1972). Geographic distribution of species and their diversity or richness depends on how well their ecological niche is understood.

It is widely accepted that measurement of environmental requirements to quantify the range size and patterns of species distribution and richness is an important step towards this understanding (Woodward, 1987). This generalization is true at a variety of spatial scales, suggesting the importance of measurements of environmental variables at different scales. For example, climate variables are of increasing importance as the scale increases from regional to continental to global scales. Currently, there is an increasing urgency among conservation biologists to quantify the environmental requirements of particular species at finer spatial scales in order to better prioritize conservation efforts. This has created the need to collect spatial information over large regions using remotely sensed measurements from airborne or satellite sensors (Turner et al., 2003). In addition, the use of remote sensing data by conservation biologists has helped frame new and important research questions. Can remote sensing data identify areas of significance to biodiversity, predict species distributions, and model community responses to environmental and anthropogenic changes? Answering these questions depends on several assumptions: 1) environmental variables, and biophysical properties that characterize species habitat, and drive its distribution are detectable by existing remote sensing sensors, 2) there are sufficient and spatially representative field observations of species presence or absence and habitat characteristics, and 3) there are distribution models capable of extending the field observations to regional and global scales with the aid of environmental variables produced by remote sensing measurements. There has been an increasing interest in studying these assumptions in recent years (Turner et al., 2003; Nagendra, 2001; Guisan & Zimmermann, 2000; Peng, 2000).

This paper examines the potential use of recently developed global datasets from satellite observations for mapping distribution patterns of tree species and diversity in the Amazon basin. Unlike regions with limited species richness and strong gradients of climate variables, the Amazon basin has one of the highest species diversity and richness in the world, but comparatively little variations in climatic variables (temperature and rainfall) (Nelson et al., 1990; De Oliveira and Mori, 1999). These regional characteristics limit the use of climate variables to develop ecological and distribution models. Remote sensing data, on the other hand, provide spatially refined information on landscape and vegetation heterogeneity over the Amazon basin that can be readily incorporated in models to predict species distribution and diversity. These models are either strictly mathematical or based on certain ecological theories. The detailed discussion or review of these models and the ecological theories are beyond the scope of this paper (Elith et al., 2006; Graham & Hijmans, 2006).

Here, we are interested to model the distribution of five widespread commercial trees, and tree alpha-diversity (expressed as Fisher's alpha) over the Amazon basin. We use the maximum entropy method (Maxent) (Phillips et al., 2005) that integrates remote sensing and geographical point locality data of species in order to model distributions and provides a predictive probability to assess the contribution of remote sensing data layers. The paper is organized into three sections: 1) description of species, remote sensing, and climate data, 2) description of the Maxent model and simulations used for testing the application of remote sensing data, 3) assessment of potential range distributions, and 4) discussion on the contribution and significance of remote sensing data for characterizing suitable areas of species habitat.

2. Species data

2.1. Amazonian tree species

Five widespread and well-documented commercial timber trees were selected for distribution modeling. The geographical locations of trees were extracted from the herbarium collection of the New York Botanical Gardens and included data from a variety of forest types and landscape features in northern South America (Fig. 1). The species studied were: *Calophyllum brasiliense* (Clusiaceae), *Carapa guianensis* (Meliaceae), *Hura crepitans* (Euphorbiaceae), *Manilkara bidentata* (Sapotaceae), and *Virola surinamensis* (Myristicaceae). The data set did not include any subspecies with strong distributional or functional characteristics or preferences that might influence the overall distribution.

C. brasiliense (Clusiaceae), known in Brazil by the common name of jacareuba, grows as a canopy tree in a variety of soil, slopes, and elevations (up to 1500 m). The tree can reach 45 m in height with a straight bole without any buttresses or branches for about 2/3 of the height. *C.* (Clusiaceae) is a tropical genus composed of approximately one hundred species. Its natural geographical range extends from southern Mexico throughout Central America to northern parts of South America (Record & Hess, 1943). It is also found in several Caribbean islands