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Spatial analysis of endemism to redefine conservation areas in Western Ghats (India)

C. Gaucherel [a,b,*], R. Vezy [a], F. Gontrand [a], D. Bouchet [a], B.R. Ramesh [a]

[a] French Institute of Pondicherry, IFP – CNRS, Pondicherry, India
[b] UMR AMAP – INRA, Montpellier, France

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ABSTRACT

A meaningful effort for the preservation of endemism would require a deep understanding of its related mechanisms and an accurate estimation of its spatial distribution. Here, we applied methods dedicated to species distribution modelling (SDM) to map an integrated index in India's Western Ghats biodiversity hotspot, the endemic tree richness, and to use it for recommendations of protected areas. We then rigorously compared SDM results with spatially explicit and multiscale comparison tools, among them the cutting-edge correlation map and profile (CMP) technique, to finally draw up an endemic richness map with improved accuracy.

The endemic richness showed a sharply increasing southward gradient in the Western Ghats, mainly driven by the seasonality of the temperature and the precipitation's stability. This precise quantification of the tree endemism pattern in peninsular India helped in identifying vulnerable areas in terms of conservation of biodiversity as a whole. The Indian authorities recently used our recommendations to extend protected areas in the southern tip of the Indian peninsula to conserve this endemic richness. We believe that spatial analyses and multiscale comparison tools such as those presented here can help conservationists everywhere to better cope with the difficulties met in identifying zones for protected status.

1. Introduction

Loss of biodiversity often occurs concomitantly with loss of endemic species, the latter being probably equally important, and yet much less studied. A quick search in the Scopus database (in Dec. 2015) highlights 10 568 documents related to the "biodiversity + loss" keywords, and 333 documents for "endemism + loss" keywords. Endemism could be preserved for itself; i.e. for the value endemic species represent; but it could also be preserved as a surrogate of biodiversity quantification (Lamoreux et al., 2005; Orme et al., 2005). However; any such effort should be preceded by an accurate estimation of endemic species distributions and endemism dynamics (Brooks et al., 2006; Hodgson, Thomas, Wintle, & Moilanen, 2009; Sodhi & Ehrlich, 2010). In this study; we intend to compute the distribution of richness of endemic trees in the Western Ghats of India; one of the world's most challenging biodiversity hotspots; by comparing several species distribution models (SDMs) (Elith & Graham, 2009; Gritti, Gaucherel, Crespo-Perez, & Chuine, 2013; Royle, Chandler, Yackulic, & Nichols, 2012) with cutting-edge spatial analyses. The updated endemism pattern will then be used as a surrogate for identifying areas at risk for biodiversity as a whole and thus for identifying priority areas.

Endemism (the ecological state in which species are natural to a specific geographical area only) has been studied for its value, which in a sense represents the highest irreplaceable level of biodiversity (Bossuyt et al., 2004; Jetz, Rahbek, & Colwell, 2004; Kier et al., 2009). In this context, it has been shown that global hotspots of species richness are not congruent with endemism, although protecting endemic hotspots would nevertheless support biological conservation (Lamoreux et al., 2005; Orme et al., 2005). Endemism generally results from a complex association of evolutionary, ecological and social processes at various spatial and temporal scales, whereas human land use changes and activities are known to be the main threats to species and ecosystems (Bose, Munoz, Ramesh, & Pelissier, 2015; Cincotta, Wisnewski, & Engelman, 2000; Dommergues & El Hariri, 2002). In this preliminary study, we did not discriminate between present-day and evolutionary factors and their influence on endemism patterns.

* Corresponding author at: French Institute of Pondicherry (IFP), 11 St Louis Street, 605001, Pondicherry, India.
E-mail address: gaucherel@cirad.fr (C. Gaucherel).

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While there have been some studies on the Western Ghats (WG) region's endemic tree flora (Gimaret-Carpentier, Dray, & Pascal, 2003; Ramesh & Pascal, 1997), the exact nature of its endemic pattern and its origin are still unknown. The diverse bioclimatic conditions encountered along the forest continuum, together with the fact that the evergreen forests of the WG remained isolated from other similar forests in Asia (Bose et al., 2015; Legris & Meher-Homji, 1982), have resulted in a high level of endemism particularly in the evergreen forests. While some scholars have tried to link the WG's high endemism to the repeated disconnections between the continent and the island of Sri Lanka (Bossuyt et al., 2004), it may be that refugee effects, speciation, and/or other historical events on the geological time scale helped shape the endemic species distribution in the WG (Bose et al., 2015; Orme et al., 2005; Van Bocxlaer, Biju, Loader, & Bossuyt, 2009). Any conservation measures that one might propose would therefore be necessarily conditioned by our incomplete knowledge of ecological processes in the region.

Among the powerful and efficient tools now available for the handling of large quantities of occurrence data, species distribution models (SDM) have the advantage of mutual complementarity, and greater accuracy than earlier (Elith & Graham, 2009; Phillips & Dudík, 2008). One notices, however, that SDMs are rarely used to quantify "integrated indices", such as species number and endemism/biodiversity ratios, for the reason that each species' range needs to be computed before combining them into a coarser index (Phillips, Dudík, & Schapire, 2004; Thuiller, 2003). A careful analysis of all the elements involved, such as questions of autocorrelation and sampling biases (Dormann, 2007; Royle et al., 2012), is also necessary.

In this study, we had two closely related objectives. First, we aimed to estimate the existing endemic distribution of tree flora of evergreen and semi-evergreen (EG) forests at its finest level, at each place and at each available scale, and then to identify the environmental factors shaping it. While we knew that the highest endemism was to be found in the southern part of the WG, the exact pattern that could be explicitly used to rationalize the boundaries of the protected areas was not clear (Collins, Sayer, & Whitmore, 1991; Menon & Bawa, 1997). Secondly, we used and compared several SDMs to compute the most accurate endemic distribution of the WG (Phillips & Dudík, 2008; Royle et al., 2012), with the aim of redefining the conservation areas where endemism (i.e. endemic tree richness) is the highest. SDM comparisons usually are carried out on simulated datasets, and often on specific species and scale-dependent data. The cutting-edge multiscale comparison map and profile (CMP) method (Gaucherel, Alleaume, & Hely, 2008; Gritti et al., 2013) helped to finely compare four selected SDMs, and to quantitatively identify where and at which scales they were congruent. We used a dedicated algorithm to propose extensions of existing protected areas on the basis of the updated tree endemic richness distribution map used as a surrogate for biodiversity as a whole.

2. Methods

2.1. Study site and data

The Western Ghats (WG) of India is an interesting case study to investigate regional endemism patterns (Bossuyt et al., 2004; Gimaret-Carpentier et al., 2003; Ramesh & Pascal, 1997). This almost 1600 km-long escarpment parallel to the south-west coast of the Indian peninsula has a high level of heterogeneity in its environmental conditions, resulting from geographical, geological and demographic differences. This biodiversity hotspot has probably one of the world's highest human population density indices (almost 350 individuals/km^2 on average), and has to withstand various anthropogenic pressures (Cincotta et al., 2000; Gimaret-Carpentier et al., 2003; Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000). Today, the interaction of the summer monsoon winds with the WG's relief results in two steep environmental gradients, a west-east decrease in rainfall and a south-north increase in the dry season's duration. The diversity in climatic conditions and topography is expressed in the region's variety of plant formations from evergreen to deciduous and grasslands. Of these forest formations, 4780 known vascular plant species, with 2180 endemic species (45.6%), have been recorded (Nayar, 1996). Because of various land use changes, only 20% of its original forest area is still intact (Gimaret-Carpentier et al., 2003; Ramesh & Pascal, 1997).

In this study, we considered a species as an endemic if it was restricted to the WG boundaries only, those boundaries were defined as approx. 72.66°–78.06° E. 8.07°–21.73° N. The final data include 351 endemic species covering a total of 9762 records of occurrence, based on the extensive records collected from three different sources, namely herbaria, literature, and field inventories (Ramesh & Pascal, 1997). All trees of these standardized plots have been carefully identified by our team and their presence-absence mapped over the whole WG area. Combining these sources helped to reduce potential biases in the sampling efforts (Wintle, Walshe, Parris, & McCarthy, 2012), and further controlled in models with dedicated autocorrelation procedures. However, it became apparent that EG tree endemic species had not been fully inventoried, according to the shape of the species accumulation curve (Fig. A.1a). We modelled the rate of endemic richness in the WG by taking into account the distribution of all arborescent species in the evergreen and semi-evergreen (EG) forests (see Supporting information, Appendix A). In this study, we will handle a "relative endemism rate" (hereafter called "endemism rate") defined as the proportion of the number of endemic species in each pixel out of the total number (351) of endemic species in the WG. In addition, we checked that removal of rare species (those having fewer than 10 occurrences in the WG) did not modify our conclusions.

A set of explicative variables (hereafter called factors) were compiled with a view to predicting (and interpreting) the final endemism pattern. A preliminary statistical analysis (Pearson's correlation and Principal Component Analysis (PCA)) helped to synthesize these variables into five uncorrelated environmental factors (three different PCs, Elevation, and Evergreen forest (EG) density). Bioclimatic variables, based on monthly temperature and rainfall measurements, came from the WorldClim database (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005) and were synthesized into the main components of a PCA (Appendix A). The EG land cover density was computed as the EG forest area in each surrounding pixel, divided by the total surrounding area (at the same scale) with the use of the MHM software (Gaucherel, 2007). No evolutionary factors were included so far, but see the recent and complementary analysis (Bose et al., 2015). All these factors were used to interpret variable influences and to compare the accuracy of the four species distribution models (SDMs) considered in this study (Dormann et al., 2013).

2.2. Models and spatial analyses

A wide range of methods to predict species distributions are available (Appendix B), from statistical models to the more process-based (Gritti et al., 2013; Hartig et al., 2012). A large number of SDMs have been proposed depending on the data quality and modelling purpose (Anderson et al., 2006; Thuiller, 2003). The most commonly used method is the generalized linear model (GLM) (Elith et al., 2011), often applied with simulated pseudo-absence (Chefaoui & Lobo, 2008). Recently, the maximum entropy method (MaxEnt) became more widely used for presence-only datasets