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Tracking population extirpations via melding ecological niche modeling with land-cover information

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ABSTRACT

We explored a new approach to tracking population losses in poorly known species across broad spatial scales, based on integration of tools from ecological niche modeling with data resources derived from remotely sensed land-cover information. Ecological niches were modeled based on known occurrences of species (natural history museum specimen data) and environmental dimensions including topography, climate and original vegetation; these niche models were then projected onto land use/land-cover maps (with classes equivalent to those in the original vegetation dataset) based on air photography and LandSat imagery from 1976, 1993 and 2000, to track loss of potential distributional area over two decades. As an illustration, we analyzed 11 endemic Corvidae (jays) in Mexico; the method is applicable to any species for which distributional information exists and any region for which multi-temporal land-cover information has been developed. We envisage this approach evolving into a "population loss meter", permitting monitoring of losses of species-specific combinations of environmental and landscape features.

1. Introduction

The 'biodiversity crisis' recognized in the past 2–3 decades has as its central concept the idea that increasing human pressure on landscapes and natural habitats is resulting in population extirpation and even species extinction at unprecedented rates (Diamond, 1987; Wilson, 1988; Manne et al., 1999). In spite of intense research in this area, and a great number of investigators focusing on questions of biodiversity conservation, however, surprisingly little advance has been made in characterizing where population loss is occurring and how much has been lost (Herkert, 1996; Sánchez-Cordero et al., 2005).

The problem is clearly one of spatial scale—when an investigator examines a species in sufficient detail to be able to detect population declines, he or she usually loses the range-wide perspective. Quite simply, one rarely can maximize both detail and scope simultaneously. Just as clearly, studying single populations or circumscribed regions is much more feasible in general than broad-scale views of species' population status (Ricklefs and Schluter, 1993).

This paper represents an exploration of a means of deriving a range-wide view of population loss in species. The approach is founded on the ideas of ecological niche modeling—that ecological niches can be inferred from simple occurrence

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information combined with environmental data that characterize an 'ecological landscape' available to the species, and that these niche models have significant predictive power regarding the geographic and ecological potential of the species. The approach consists of modeling ecological niches, and projecting the rule-sets describing the niches onto land-cover information from distinct time periods to detect likely population losses or gains between time periods.

2. Methods

2.1. Input data

The method explored herein requires three distinct data streams: primary species occurrence information (records placing a particular species in a particular location), ecological and environmental data characterizing landscape features and land-cover data sets for multiple time periods. Because of the particular land-cover data sets employed herein, we limit application to species that use primary (not disturbed) habitats principally. The conjunction of these three sets of information permits the novel 'population extirpation tracking' capabilities explored in this paper, which can be applied generally to any taxon and region for which such information is available.

Species occurrence information was drawn from the *Atlas of Mexican Bird Distributions* database, a compendium of bird specimens from Mexico, drawn from data associated with specimens from 57 natural history museum collections worldwide (see Acknowledgments). Although not available for public consultation because of data use agreements with institutions, the dataset is nevertheless a comprehensive (about 450,000 records from 39,000 localities) view of bird distributions in the country (Peterson et al., 1998; Navarro-Sigüenza et al., 2002, 2003). Point occurrence data were georeferenced to the nearest 0.1′ of latitude and longitude based on diverse map series for Mexico. All species' names were modernized to a taxonomic revision of the Mexican avifauna by two of the authors (Navarro-Sigüenza and Peterson, 2004). For the purposes of illustration, we analyze herein the species of the family with the greatest number of endemic species in Mexico—the 13 endemic species of Corvidae; as the method is most applicable to species of primary habitats, we omitted from consideration the two endemic crows of northern Mexico (*Corvus imparatus*, *C. sinaloae*), leaving 11 species for analysis.

Data sets (raster GIS layers) describing the ecological landscape of Mexico were drawn from a variety of sources. For topographic information, we used the Hydro-1K data set,[1] which includes elevation, slope, aspect and an index of tendency to pool water, all at a native resolution of 30 arc seconds (about 1 km). For climatic data, we used data sets describing minimum, mean and maximum annual temperatures; annual mean precipitation and soil humidity, all available from the Comisión Nacional para el Uso y Conocimiento de la Biodiversidad (CONABIO[2]) data facility (vector coverages, 1:1,000,000). All GIS data sets were resampled to a 0.02° grid for analysis using a nearest-neighbor approach.

Data sets summarizing land-cover across Mexico were assembled (Fig. 1), also in the form of raster GIS grids. For a picture of land-cover that coincides temporally with the specimen data used to generate the niche models, we used an 'original vegetation' map originally developed in hard-copy form (Rzedowski, 1978), and now served publicly in electronic format (also on the CONABIO site). This data layer attempts to reconstruct pre-human vegetation type distributions (a very difficult challenge), but quite adequately reflects the vegetation types that would be available to species using primary habitats in the nineteenth and twentieth centuries; this allowed us to key known occurrences of species using primary habitats from the past two centuries to particular land-cover classes. To summarize land-cover shifts over recent decades (Fig. 1), we used the land-cover classifications, which were developed based on aerial photography from 1973 to 1979, and based on LandSat imagery for 1993 and 2000 (Velázquez et al., 2002). These land-cover data sets were then generalized to make them parallel and compatible with the original vegetation map: categories were combined to make the categories in the modern land-cover maps match those in the original vegetation map (Table 1).

2.2. Modeling ecological niches and reconstructing population losses

Species' ecological requirements can be conceptualized via the idea of an ecological niche—among the various definitions of this idea that exist (MacArthur, 1972), the most appropriate to a coarse-scale approach such as this one is that of Grinnell (1917, 1924)—the set of conditions under which a species can maintain populations without immigrational input (Hutchinson, 1957). A series of efforts over the past decade has focused on developing computational approaches to approximating this ecological niche, based on known occurrences of species (Austin et al., 1990)—this work has demonstrated that ecological niches of species as modeled in this framework (1) are highly predictive of distributional phenomena (Peterson, 2001; Peterson et al., 2002a,b), (2) permit visualization of distributions in ecological and geographic dimensions (Austin et al., 1990; Costa et al., 2002; Martínez-Meyer et al., 2004), (3) are highly conserved over ecological and evolutionary time periods (Peterson et al., 1999) and (4) provide a long-term constraint on the geographic potential of species (Peterson, 2003).

Ecological niches were modeled using the Genetic Algorithm for Rule-set Prediction (GARP) (Stockwell and Noble, 1992), now available for public download.[3] This algorithm has seen extensive testing for predictions of species' geographic distributions (Peterson and Cohoon, 1999; Egbert et al., 2002; Stockwell and Peterson, 2002a,b; Anderson et al., 2003; Peterson and Shaw, 2003; Stockwell and Peterson, 2003; Peterson et al., 2004). In GARP, occurrence points are divided evenly into training and testing data sets. GARP works in

1 http://edcdaac.usgs.gov/gtopo30/hydro/index.asp.
2 http://www.conabio.gob.mx/.
3 http://www.lifemapper.org/desktopgarp.