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Birds of a feather: Interpolating distribution patterns of urban birds

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Abstract

Geostatistical methods provide valuable approaches for analyzing spatial patterns of ecological systems. They allow for both the prediction and visualization of ecological phenomena, a combination that is essential for the conceptual development and testing of ecological theory. Yet, many ecologists remain unfamiliar with the application of these techniques. Here, we apply the methodology of geostatistics to an urban avian census in order to investigate and illustrate the utility of these tools. We derive habitat probability maps for three bird species known to differentially occupy the urban to rural gradient within the Phoenix metropolitan area and surrounding desert (Arizona, USA). We aggregated avian censuses conducted seasonally at 40 sites over two years and applied two processes process of interpolation, ordinary Kriging and indicator Kriging, and compared both methods. Ordinary Kriging interpolates values between measurements; however, it requires normally distributed data, which is commonly invalidated in ecological censuses. While indicator Kriging is not able to produce numerical predictions of measurements, it has the advantages of not requiring normally distributed data and requiring fewer statistical decisions. Each of the species exhibited strong deviations from normality due to many observations of zero. Given the skewness of the data, we anticipated that indicator Kriging would be a more appropriate method of interpolation. However, we found that both methods adequately captured spatial distribution of the three species and are sufficient for creating distribution maps of avian species. With additional census monitoring, Kriging can be used to detect long-term changes in population distribution of avian and other wildlife populations.

Keywords: Interpolation; Kriging; Avian; Urban; Home range; Population distribution

1. Introduction

Effective conservation planning requires a comprehensive understanding of the relationships among organisms and their environment (O'Neil & Carey, 1986). In a rapidly urbanizing world, it has become apparent that understanding the ecological effects of this process is a paramount objective. Urbanization is characterized by dramatic land use transformation, typically across expansive extents. This consequently leads to land cover conversion, which can be a dominant process affecting ecological community structure and population dynamics, generating unique assemblages of organisms (Hostetler, 1997). Typically, researchers find that urban areas tend to harbor biotic communities in which only a few species increase in density relative to the surrounding areas, thereby creating distinct differences in community diversity between these two landscapes (Blair, 1996; DeGraaf & Wentworth, 1981; McKinney, 2002). But how does this process affect the spatial distribution of species within this human-dominated system? Understanding the spatial pattern of such relationships is important for both the development of ecological theory and implementation of conservation strategies.

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Maps illustrating home ranges of a particular species have been extremely useful as a heuristic tool for ecologists. Such distributions overlain with land use and/or land cover maps provide an intuitive device for exploring hypothetical relationships of organisms and their environment (e.g. Robertson, 1987). These patterns have also been used to test existing hypotheses in ecology (e.g. Hodgson, Macrae, & Brewer, 2004; Villard & Maurer, 1996). They have also assisted conservation biologists and environmental planners to identify potential conservation areas and monitor conservation efforts (Price, Droege, & Price, 1995; Scott et al., 1993).

Population distribution maps are increasingly based on geostatistical models, largely due to the explosion of technological innovations provided by GIS. This process is largely contingent on model-based estimations of species distributions, which are typically derived in two ways. First, species occurrences can be predicted based on habitat-suitability models (e.g. Hanski & Simberloff, 1997), in which the predictions of animal population abundances are derived through biologically meaningful environmental variables (i.e. forage abundance, habitat type, water availability). This is an effective method for producing population distribution maps; but only if (1) theory exists supporting the incorporation of particular environmental variables into such models and (2) those variables are collected or modeled across the entire region of interest. As a young discipline, urban ecology lacks habitat-suitability models for many species that occupy urban environments. A second commonly-used approach to population distribution mapping in ecology involves interpolation of observed occurrences of particular species (e.g. Jiguet et al., 2002; Pfieffer & Hugh-Jones, 2002; Rempel & Kushneriuk, 2003; Royle, Link, & Sauer, 2002; Villard & Maurer, 1996). This process does not require *a priori* knowledge of habitat relationships; rather, it uses observations of species' abundances via surveys to construct a spatially-explicit distribution model. Surveys conducted at a series of point locations are a common tool for ecological monitoring, particularly for birds (Bibby, Burgess, & Hill, 1992; Toms, Schmiegelow, Hannon, & Villard, 2006). Thus, this approach may be more useful in urban areas or other situations for which habitat suitability models are lacking. Furthermore, the maps derived from the survey data may provide insights into previously unrecognized habitat associations, thereby facilitating the development of new habitat suitability models.

Originally developed for mineral mapping, Kriging is a spatially-based interpolation model which predicts a response at unobserved locations as a linear function of data from the observed locations with the incorporation of a weighting function between points which exponentially decays as the distance between points increases. Other forms of interpolation present specific challenges for ecological analyses. Inverse distance weighting and radial basis functions are largely not used because they are exact, deterministic interpolation techniques, which force the values of the interpolations to be equal to the measured values at those locations, making ecological generalizations difficult. Deterministic, inexact interpolation methods (i.e. global and local polynomial interpolation and splining) allow for enhanced generality; however, they do not provide a mechanism for assessing prediction errors and do not allow for the investigation of autocorrelation. By contrast, Kriging is more flexible than these procedures. The model can be parameterized to be exact or inexact, which can allow for the investigation of spatial autocorrelation, and can produce both probability and prediction standard error maps.

While Kriging is widely used in ecology, the distributions of point count data, such as an avian census, often violate the assumption of normality required by most forms Kriging (Royle et al., 2002). Such data are consistently discrete and positively valued, and consequently, right skewed. This distribution is an especially difficult one to transform to meet the assumptions of normality, making the majority of Kriging techniques (i.e. ordinary, simple, universal) inappropriate. However one form, indicator Kriging, does not assume the data to be interpolated are normally distributed. Given the statistically problematic nature of point count data, we compare advantages and disadvantages of modeling spatial distributions of bird populations of three ecologically distinct species in two disparate land uses via a commonly-employed parametric Kriging technique (ordinary) and a non-parametric Kriging technique (indicator).

The major disadvantage of using indicator over ordinary Kriging is that a prediction map can not be generated. However, prediction maps are logically fallible for point count data, as actual abundance can not predicted because the proportion of the population of the sample is always unknown (Royle et al., 2002). Rather, predictions maps represent an index of relative abundance (Link & Sauer, 1998). Another example of an index of relative abundance, which both Kriging procedures are possible of producing, is a probability map. Such maps estimate the probability that any given point will exceed a pre-defined threshold. While this is not useful in calculating an estimate of what the population count is at a particular site, probability maps using avian census counts estimate the range of a given population, not individuals. If a particular species is dominant across the entire study site, the interpolated probability will be high for all areas. However, if a species differentially utilizes a particular study site, the interpolations will subsequently differentiate, producing a more heterogeneous map of population distribution probabilities. This procedure is particularly useful in study sites with disparate landscape types (i.e. forest vs. grassland, urban vs. rural) in which animals differentially occupy space. By comparing probability maps of ordinary and indicator Kriging, we show that either method can be used effectively in order to interpolate avian distribution patterns of the focal species, and discuss the conditions under which each method will be most useful.