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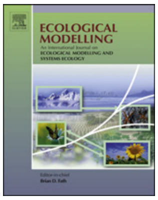

Movement distances enhance validity of predictive models

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ABSTRACT

Including the distance species are able to move in predictive models improves conservation practice. Bird inventory projects carried out from 1993 to 2004 in Taiwan provide an opportunity to investigate the relationships among species distribution, movement distance, and the environment. We compared projected distributions of 17 Taiwanese endemic bird species using what we called the Standard Method (*i.e.* movement distance is zero) and what we called the Buffer Method (*i.e.* movement distance is longer than zero) in three presence-only models (GARP, MAXENT and LIVES). The Standard Method used species original occurrence records directly while the Buffer Method expanded the occurrence of species to areas 1 km^2 around each recorded location. We first tested the efficacy of the Buffer Method using ten common species of the 17, and then applied the method to two rare species of the 17. For both the common and rare species, the distributions predicted by the two methods showed slight but important differences. The Buffer Method for all species had a higher average predictive probability, while the Standard Method had a higher maximum predictive probability. Most of the values for the area under the curve (AUC) were over 0.8 with the exceptions of Taiwan Barbet (*Megalaima nuchalis*) and Taiwan Hwamei (*Garrulax taewanus*), which have recently separated from Indochinese Barbet (*Megalaima annamensis*) and Chinese Hwamei (*Garrulax canorus*), and since 2008 and 2006 have been regarded as species endemic to the study area. Kappa values showed good performance for all species using both methods. The Buffer Method, however, resulted in significantly higher sensitivity and accuracy values for all models of species ($p < 0.05$). We conclude that when modeling species distribution including the area where the species was censused along with areas within the minimum movement areas better defines the surrounding areas that might supplement core habitat requirements. Therefore, using the Buffer Method, species surrounding distribution can be obtained which provides a better understanding of the species distributions. Given that distribution size is a key to the conservation of species, we suggest the Buffer Method can be used in conservation planning.

1. Introduction

Numerous species of animals and plants around the globe are detecting the 0.75 °C of warming over the last century (Root et al., 2005). One way they are responding is by shifting their ranges towards the poles and to higher elevations (Root and Schneider, 2002, 2006; Root et al., 2003; Parmesan and Yohe, 2003). The Intergovernmental Panel on Climate Change (Parry et al., 2007) predicted that the average global temperature will continue to increase by 1.1–6.4 °C above 1990 levels during the 21st century. Such increases will affect the conservation and management of different species in different ways. Projections of future distributions of species by assuming a retaining relationship between each species distribution and environment further indicated that species either with or without dispersal/movement would face a quite extinction risk under climate change (Thomas et al., 2004). However, effect of species movement on modeling is unknown yet. Estimating how species movement affects a predictive model, thus, could certainly aid in addressing the current and future species–environment relationships.

Many predictive models of species distributions have been developed and applied to various landscape scales (Guisan and Zimmermann, 2000; Cushman and McGarigal, 2002; Store and Jokimäki, 2003; Johnson et al., 2004; Guisan and Thuiller, 2005; Elith et al., 2006; Hernandez et al., 2006; De Mas et al., 2009). Additionally, the majority of modeling exercises, species data are transferred to a grid system (Vallecillo et al., 2009; Ko et al., 2009). Modeling methods traditionally have used linear algorithms and emphasized both species presence and absence data (Austin and Meyers, 1996; Jose and Fernando, 1997). Nonlinear

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algorithms and species presence-only models have been recently developed and used widely (Lek et al., 1996; Jose and Fernando, 1997; Aitkenhead et al., 2004; Stockman et al., 2006; Phillips et al., 2006). Results from these latter models have been found to better explain the relationship between species and environmental factors (Manel et al., 1999a,b; Ko et al., 2009). Species absence data are frequently unavailable or inadequate to interpret species distributional ranges/patterns because of uncertainties of those actual or undetectable absences, such as a period of species hibernation as well as inactivity (Gu and Swihart, 2004; Vaclavik and Meentemeyer, 2009). Incorrect absence data even leads to misleading model predictions of species potential distributions (Ko et al., 2009). We thus used the presence-only models in this study which often exhibit good accuracy on predicting species distributions (Elith et al., 2006; Tsoar et al., 2007; McPherson and Jetz, 2007).

Surrounding habitats, as a primary consideration for conservation as species occupancy areas (Saab, 1999), are usually been highly used by bird species as breeding and foraging habitats owing to their high vagility (Ambuel and Temple, 1983; Lees and Peres, 2009). The vagility of different forest birds and waterbirds varies from less than 1 km to more than 200 km (Shirley, 2006; Keller et al., 2009). Spatial-use patterns of species within both the species occupancy and surrounding areas differ greatly at multiple temporal and spatial scales due to varying interactions between landscape structure and species responses to that structure. The structure and pattern of the landscape, natal dispersal, mate selection behaviors, seasonal migration, temperature change, movement potential mortality, and food availability within those areas potentially influence the species' spatial-use patterns, especially movement distances of a species (Desrochers and Hannon, 1997; Norris and Stutchbury, 2001; Cooper et al., 2002). Main factors influencing a species' spatial patterns, however, are often not well understood, but Shirley (2006) found that in general focusing on species moving from one place to another, to engage in particular activities in particular places, provides a rough understanding of how species response to adjacent habitat or forest remnants. The areas where species have been recorded and the areas within the movement distance of the species are the areas most occupied by species. Cooper et al. (2002) used two movement rules to simulate population dynamics in the Brown Treecreeper in Australia, which explained that species' nearest neighbors are important for population and direction of movement affects a species distribution. Therefore, quality of surrounding habitats needs to be addressed, and the species movement patterns, such as movement distance and direction, are valuable inputs when linking species spatial-use patterns and the surrounding habitats together.

Bird surveys in Taiwan have been carried out since 1993 provide an opportunity to estimate the possibility of species movement patterns as an input variable to predictive models of species distributions. The Taiwan Island, an area of about 36,000 km^2, lies in the western Pacific Ocean, less than 161 km from the southeast coast of mainland China, from which it is separated by the Taiwan Strait. Though several survey sites have only been surveyed once over the 17 years, data for at least one year have been recorded over the entire island of Taiwan. Volunteer bird observers trained by Taiwanese organizations have recorded species, heard and seen, along designated transect lines. These data provide information throughout the island on species distributions. Endemic bird species in Taiwan were chosen only as sampling data in this study according to their subjects of concern, especially rare endemic species. Their low population and naturally secretive behaviors, however, increase the difficulty of observation (Ko et al., 2010) as well as predicting their distributions. Fortunately, common species can play as reference when drawing insights into rare species' conservation when they are sympatric related species (Githiru et al., 2007). Finding a method to be used on common species and then applied to rare species will be feasible to understand rare species distributions more. Simultaneously, combining the movement ability of rare endemic species with predictive model will have even greater control and understand their possible distribution.

Using these data from the bird surveys, we addressed two questions in this study: (1) can predictive models using additional species presence based on species vagility (*i.e.* species movement distances) with actual species occurrence records tell us more than using actual species occurrence records alone? and (2) can we enhance the value of predictive models by adding consideration of species' spatial-use patterns (*i.e.* movement patterns)? In general, this study combined predictive models and species minimum movement distances to determine if the predicted distributions were more accurate than those not using species movement information. To do this, we compared traditional methods, which had emphasized species recorded presence only, referred to as the "Standard Method" in our study, with the novel method such as the "Buffer Method", which broadened species recorded presence to neighboring regions, to see how predictive models could become more effective. Three presence-only models, GARP, MAXENT and LIVES, were finally used to predict species potential distributions on the Taiwan whole island.

2. Materials and methods

2.1. Species occurrence data collection

We used two bird inventory projects in Taiwan from 1999 to 2003 (Koh et al., 2006) and 1993 to 2004 (Hsu et al., 2004) in this study. The data included a total of 4082 census locations, which covers around 10% of Taiwan when placed on a 1 km^2 grid system. Each location was censused at least once a year during the breeding season or seasonally during the survey period. Bird-occurrence data were recorded by geographical coordinates and transformed to a square kilometer grid. There are 17 endemic bird species currently in Taiwan and ten of these are common. We used these ten common species and two rare species of the 17 to compare different modeling methods. In addition, the two rare species were used to determine the possible conservation effectiveness of each model (Table 1).

2.2. Modeling methods

Five types of environmental factors were used in the models: topography, climate, vegetation, human disturbance, and ecological regions. The first four types were estimated using ArcGIS and ERDAS and described in detail by Lee et al. (2004) and Ko et al. (2009). We interpolated annual mean temperature and annual total precipitation through 355 stations data including weather stations and auto rain gauges offered from Central Weather Bureau of Taiwan. The last type, ecological regions, included two factors: ecoregions and eastern index. The whole of Taiwan was divided into 41 ecoregions according to township districts, geographical zones and biological boundaries (Su, 1992). The eastern index weighted the three eastern counties more than the other 13 counties. The three counties, Yilan, Hualien, and Taitung, are located on the eastern side of the Central Mountain Range and were assigned an eastern index value of 1 and distinguished from the other counties that were assigned a value of 0. All of environmental variables were estimated by univariate analysis with actual species occurrence records first. We then left the variables which had high relationships ($p < 0.01$) with the species