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Forecasting waterfowl population dynamics under climate change — Does the spatial variation of density dependence and environmental effects matter?

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ABSTRACT

Reliable ecological forecasts are essential for conservation decision-making to respond to climate change. It is challenging to forecast the spatial structure of wildlife population dynamics because density dependence and environmental effects vary spatially. We developed models that incorporated density dependence and climatic (precipitation and temperature) effects to explain pond (wetland) dynamics and models that incorporated density dependence and pond effect to explain Mallard (*Anas platyrhynchos*) population dynamics. We trained the models using data from 1974 to 1998 and tested their hindcast performance with data from 1999 to 2010 to examine the scale at which the spatial variation of density dependence and climatic/pond effects should be incorporated to forecast pond and Mallard population dynamics. The pond model that did not allow density dependence and climatic effects to vary spatially (ΔMSE = 0.007–0.018) and the Mallard model that incorporated the spatial variation of density dependence and pond effect at the scale of Bird Conservation Regions (ΔMSE = 0.011–0.012) had the best hindcast performance. Using these models we forecasted the largest decrease (34.7%–43.0%) of Mallard density in the northern Prairie Pothole Region under two climate change scenarios, suggesting that the local Mallard population in this area might be particularly vulnerable to potential future warming. Our results provide insight into the factors that drive the spatial structure of waterfowl population dynamics. Because the spatial variation of density dependence and environmental effects is commonly found in wildlife populations, our framework of modeling and evaluation has wide application for conservation planning in response to climate change.

1. Introduction

Climate change has already caused, and is likely to continue causing, shifts in the distributions, abundance, and dynamics of wildlife populations across a broad range of landscapes and habitats (Parmesan, 2006; Rosenzweig et al., 2008; Thomas et al., 2004; Walther, 2010). These large-scale ecological shifts have altered the effectiveness of current conservation efforts (Hannah et al., 2007; Virkkala et al., 2013). For instance, it has been suggested that fewer than half of the Important Bird Areas in Africa will retain their current conservation value under future climate conditions (Hole et al., 2011). Reliable ecological forecasts of system shifts associated with climate change are therefore needed to support long-term conservation decision-making (Clark et al., 2001).

North American waterfowl populations have been monitored and managed since the 1950s (Smith, 1995; U.S. Fish and Wildlife Service, 2012), but the current monitoring and management framework is challenged to account for large-scale system shifts driven by climate change (Nichols et al., 2011). The Prairie Pothole Region (PPR) is the most important area for waterfowl production in North America (Batt et al., 1989). Climate change in the PPR has not been spatially uniform (Millett et al., 2009). Consequently, wetland availability has decreased in the northern PPR and increased in the south-eastern PPR during the last several decades (Niemuth et al., 2014). Warming is predicted to continue in the PPR in the next century, which may cause further southeast-ward shifts of wetland availability (Johnson et al., 2005; Johnson et al., 2010; Niemuth et al., 2010). Because wetland availability is a key factor that drives waterfowl population dynamics (Batt, 1992; Dzus and Clark, 1998; Johnson and Grier, 1988), studies have recommended shifting conservation efforts from the western and central portion of the PPR to the eastern PPR (Johnson et al., 2010).

However, it is challenging to forecast the spatial structure of waterfowl population dynamics under climate change, due to the fact that waterfowl population dynamics are driven by both density dependence process (Murray et al., 2010; Vickery and Nudds, 1984; Viljugrein et al., 2005) and wetland availability (Batt, 1992; Bethke and Nudds, 1995; Johnson and Grier, 1988; Reynolds et al., 2006), and density dependence and wetland effects vary spatially (Bethke and Nudds, 1995; Sæther et al., 2008). While the spatial variation of density dependence

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and wetland effects has been incorporated in forecast models (Bethke and Nudds, 1995), it remains unclear if such models provide better forecasts than models that do not allow density dependence and wetland effects to vary spatially (Sorenson et al., 1998). Similarly, studies have used models that incorporate density dependence and climatic effects to explain wetland dynamics (Larson, 1995; Niemuth et al., 2014), but did not explicitly consider if incorporating the spatial variation of density dependence and climatic effects improved forecasts of wetland dynamics. Although an increase in model complexity generally improves model fit, more complex models may lead to poorer forecasts due to a reduction in generality.

In this study our goal was to forecast waterfowl population dynamics in response to future climate change. To achieve this goal, first we developed models that incorporated density dependence and climatic (precipitation and temperature) effects to explain pond (i.e. measurement of wetland availability) dynamics and models that incorporated density dependence and pond effect to explain Mallard (*Anas platyrhynchos*) population dynamics. Second, we trained the pond and Mallard models using data of Mallard density, pond density, precipitation, and temperature from 1974 to 1998 and tested the hindcast performance of the pond and Mallard models with data from 1999 to 2010 to examine the scale at which the spatial variation of density dependence and climatic/pond effects should be incorporated to forecast pond and Mallard population dynamics. Third, we fitted the pond and Mallard models that had the best hindcast performance and used the posterior parameter estimates to forecast Mallard population responses to potential future climate change scenarios.

2. Material and methods

2.1. Study area and population/habitat survey

The U.S. Fish and Wildlife Service (USFWS), Canadian Wildlife Service (CWS), and their partners monitor waterfowl abundance and wetland habitat conditions annually in May during the Waterfowl Breeding Population and Habitat Survey (Smith, 1995). This aerial survey extends from the U.S. prairies north through the boreal-taiga habitat and into Alaska. Two-person crews, consisting of a pilot-biologist and an observer, identify all waterfowl to species within a 200 m strip on each side of the aircraft and count the number of individuals encountered. In the PPR and surrounding areas, the observer also counts the number of natural and artificial ponds within the 200 m transect width as a measurement of wetland availability. Potential observation errors of the aerial counts are corrected by ground surveys of waterfowl and ponds, which are conducted concurrently at a subsample of the aerial surveys (Smith, 1995). Our analyses were based on the corrected survey data from the area where both waterfowl and ponds are counted (Fig. 1).

The study area covers three Bird Conservation Regions (BCRs), including the PPR, Badland and Prairie, and the southern portion of Boreal Taiga Plain. BCRs were defined in a holistic and comprehensive manner using hierarchical classifications based on a variety of ecological and biological factors including location, climate, vegetation, hydrology, and terrain (Commission for Environmental Cooperation, 1997). We used BCRs in this study to represent habitat variation at a coarse spatial scale.

The study area also encompasses six administrative regions (i.e. Canadian provinces and U.S. states): Alberta, Saskatchewan, and Manitoba in Canada, and Montana, North Dakota, and South Dakota in the U.S. Anthropogenic activities such as industrial development, agriculture, and other land use are expected to differ among these administrative regions (Bethke and Nudds, 1995; Reynolds et al., 2006; Reynolds et al., 2001). We overlaid the BCRs and administrative regions and considered each unique BCR and administrative region as a modeling unit (Fig. 1).

2.2. Climate data

We obtained temperature and precipitation data from climate data archives of the University of Delaware (Matsuura and Willmott, 2013a, 2013b). The temperature and precipitation data were interpolated

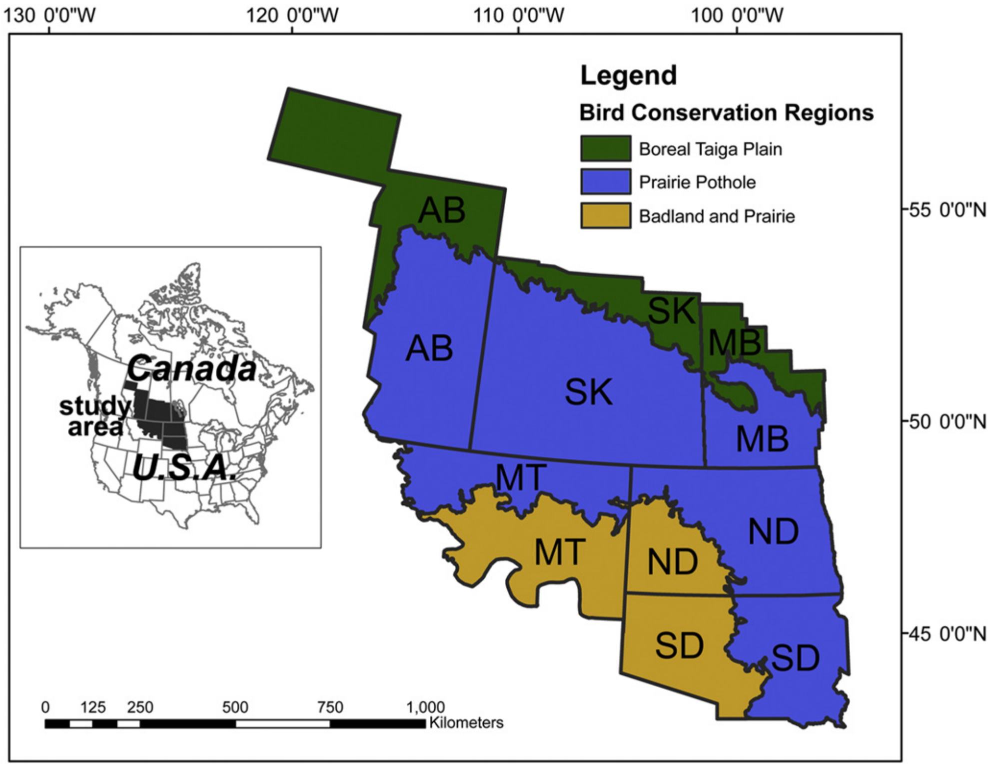

Fig. 1. Study area and the locations of modeling units. Bird Conservation Regions (BCRs) are represented by different colors and BCR names are shown in the legend. The abbreviations of Canadian provinces and U.S. states: AB: Alberta, SK: Saskatchewan, MB: Manitoba, MT: Montana, ND: North Dakota, and SD: South Dakota.