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A spatio-temporal comparison of avian migration phenology using Citizen Science data

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ABSTRACT

The effects of climate change have wide-ranging impacts on wildlife species and recent studies indicate that birds' spring arrival dates are advancing in response to changes in global climates. In this paper, we propose a spatio-temporal approach for comparing avian first arrival data for multiple species. As an example, we analyze spring arrival data for two long-distance migrants (Ruby-throated Hummingbird *Archilochus colubris*; and Purple Martin *Progne subis*) in eastern North America from 2001–2010 using Citizen Science data. The proposed approach provides researchers with a tool to compare mean arrival dates while accounting for spatial and temporal variability. Our results show that on average, Purple Martins arrive 29.95 to 31.84 days earlier than Ruby-throated Hummingbirds, but after accounting for this overall difference, spatial nuances exist whereby martins arrive earlier in the southern United States and migrate northward at a slower rate than hummingbirds. Differences were also noted in how climate and weather variables such as the North Atlantic Oscillation index, winter temperature, winter–spring precipitation, sampling effort, and altitude impacted migration dates. Our method may easily be generalized to analyze a broad range of temporal and spatial Citizen Scientists data to help better understand the ecological impacts of climate change.

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1. Introduction

The effects of climate change are apparent and have wide-ranging impacts on wildlife species (Parmesan and Yohe, 2003). Advancements in spring events, poleward range shifts, and changing interactions among species have been predicted (Matthews et al., 2011) and demonstrated (McKinney et al., 2012). In many cases, birds are sentinels of change and many studies have reported that avian migration dates have advanced in response to changes in global climates (Møller et al., 2010; Knudsen et al., 2011). These advancements have been correlated with changes in temperature (Courter et al., 2013a; Hurlbert and Liang, 2012), precipitation (Studds and Marra, 2011), and large-scale climate indices such as the North Atlantic Oscillation (NAO) index (Gordo et al., 2011).

Not only are the life history characteristics of many birds suitable for detecting potential climate-related impacts (e.g., birds are volant, migratory, and highly responsive to environmental changes), but birds are also popular among naturalists and continental-scale monitoring programs for birds have been in place in North America since the 1880s (Zelt et al., 2012). Today, smartphones and associated web-based platforms make it easier than ever for groups of Citizen Scientists to contribute data to field-based phenology studies (Sullivan et al., 2014). One advantage of assessing changes in avian arrival dates using Citizen Science data is the ability of researchers to understand ecological processes at broader spatial scales (Knudsen et al., 2011). Traditional bird phenology studies have been conducted at broad temporal but narrow spatial scales (Ledneva et al., 2004; Swanson and Palmer, 2009). While there are benefits to site-based approaches (e.g., the ability to reduce observer error, to utilize consistent weather data, etc.), inferences are limited spatially and may not account for the spatial variability of ecological process such as climate change (Primack et al., 2009). Data collected at broad spatial scales are especially important for assessing changes in arrival dates of long-distance migrants that sometimes fly thousands of kilometers between breeding and wintering grounds during their annual cycles (Hostetler et al., 2015).

At a time when long-term migration data and climate data are becoming increasingly available for use by researchers (e.g., through programs such as the North American Bird Phenology Program, eBird, etc.), large-scale comparisons of migratory changes at broad temporal and spatial scales are beginning to emerge (Hurlbert and Liang, 2012), although most studies assess migratory changes for a particular species (e.g., Courter et al., 2013a, Laughlin et al., 2013, Arab and Courter, 2015). Therefore, the objective of our study is to provide a technique for comparing migratory changes among species. As an example, we demonstrate a spatio-temporal comparison of two long-distance migrants in parts of the eastern United States from 2000 to 2010 to elucidate potential differences in the effects of spatial and climate variables on the timing of migration. Our proposed model provides a straightforward exploratory data analysis tool for inferential purposes as well as for predictive modeling.

2. Materials and methods

2.1. Focal species

Ruby-throated Hummingbirds (*Archilochus colubris*) winter in Central America and migrate across the Gulf of Mexico between February and May to their breeding grounds in eastern North America. They feed primarily on nectar and small insects during migration (Robinson et al., 1996). Purple Martins (*Progne subis*) winter in South America and migrate to North America between February and May, with male "scouts" often arriving several weeks before females to look for suitable breeding territories (Tarof and Brown, 2013). Martins are aerial insectivores and arrive in North America approximately one month earlier than hummingbirds (Tarof and Brown, 2013; Courter et al., 2013a). For the purposes of our study, we considered both species to be "long-distance" migrants because they regularly winter outside of the United States (Butler, 2003).

2.2. First arrival and weather data

We use first arrival data for these species from two Citizen Science programs: First arrival dates of Ruby-throated Hummingbirds from 2001 to 2010 were reported by Citizen Science volunteers