AVIAN PHENOLOGY, CLIMATE, AND LAND-USE CONSERVATION ASSESSED AT BROAD SPATIAL AND TEMPORAL SCALES USING INTERDISCIPLINARY APPROACHES AND CITIZEN SCIENCE

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Doctor of Philosophy
Wildlife and Fisheries Biology

by
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ABSTRACT

Current natural resource challenges include global alteration of land cover, loss of biodiversity, impacts from increasing demands for agricultural products, and climate change. Birds are often used to assess the effects of ecological stressors because they are sensitive to environmental changes, ubiquitous and charismatic, and long-term monitoring programs have been in place for more than a century. I demonstrate the effects of climate change on avian migration and nesting dates and the potential value of using interdisciplinary approaches and citizen science to address contemporary ecological challenges. I examine Ruby-throated Hummingbird (*Archilochus colubris*) migration in the eastern United States from 1880-2010 and demonstrate a migratory advancement of approximately two weeks that varies by latitude. Extended migratory stopovers in mid-latitudes during warmer winters may affect synchrony between birds and their breeding habitats and impede some pollination and pest suppression services birds provide. Possible sources of bias in data collected by amateur naturalists, particularly the tendency for avian “first” arrivals to be reported on weekends, is decreasing over time in North America, is less than reported in Europe, and can be overcome by accounting for “day of week” in models that assess phenology. Incorporating these findings will make conclusions more robust in studies that use first arrival dates to assess the effects of climate change. Growing degree-days provide a tool to predict nesting dates of common bird species in the eastern United States and to assess the effects of temperature across trophic levels in agroecosystems. This information could facilitate communication between farmers and ecologists and promote biological pest control and bird conservation.
on farms. Cooperation among governmental agencies, university scientists, and the
general public has helped revive a legacy dataset that chronicles bird migration for more
than 800 species in North America during the past century. I demonstrate how these data
could be used to understand the effects of climate change on bird migration and propose
possible research questions that could be addressed from these data. I describe how
graduate students are well-positioned to bridge the information gap that exists between
research scientists and field practitioners. I provide suggestions to advisors and university
administrators on how to best support this process and argue that being exposed early to
the broader issues of research and implementation may enhance the graduate research
experience and improve conservation outcomes. Land-use models demonstrate effects of
urbanization on important bird and amphibian species in South Carolina and identify
biologically important areas most at-risk from human development. These findings could
inform management and land-use decisions at various spatial scales. Taken together, my
work demonstrates impacts of climate change and urbanization on avian species, provides
creative solutions to conservation challenges within interdisciplinary frameworks, bridges
gaps between researchers and field practitioners, and overcomes barriers to using citizen
science data in research. Although the ecological challenges facing humanity are well-
documented, science and technology are also advancing. Implementation of innovative
and interdisciplinary conservation strategies, such as those presented here, will provide
guidance for positive conservation outcomes.
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CHAPTER ONE
INTRODUCTION

My initial appointment at Clemson University was to study the effects of habitat fragmentation and patch configuration on avian diversity in agroecosystems and contribute to the development of a Healthy Farm Index, a project initiated by Dr. Ron Johnson and others at the University of Nebraska-Lincoln. During my first two months at Clemson I was given considerable freedom to explore the field of agroecology. I read hundreds of scientific papers and participated in the 94th Annual Ecological Society of America meeting in Albuquerque, New Mexico. Because my previous scientific training was focused primarily on animal behavior and science education, much of what I learned was new and I became intrigued by the global conservation challenges that were repeatedly identified, such as climate change and biodiversity loss. As my dissertation research unfolded in the following months, a number of interesting opportunities arose for me to examine changes in bird phenology and effects of other broad-scale ecological stressors, but in ways that differed from the originally expected focus. One particular opportunity of note was an invitation from Patuxent Wildlife Research Center to access, and analyze for the first time, nearly six million hand-written first arrival cards that chronicled bird migration in North America during the past century.

Globally, the earth faces ecological stress that many believe marks the beginning of a new epoch, the Anthropocene, in which earth’s ecosystems are being drastically altered by humans (Rockström et al. 2009). Three of the greatest challenges humankindfaces are climate change, biodiversity loss, and mediating the impacts of agriculture on
ecosystems (Vitousek 1997, Rockström et al. 2009, Foley et al. 2011). According to the Intergovernmental Panel on Climate Change (IPCC 2007), mean global air temperatures have increased 0.74° C since 1900 and the rate of warming in the past 50 years has been greater than during any other time in the last 1,000 years. Global emissions of greenhouse gases such as carbon dioxide have increased over 30% since preindustrial times (i.e., 280 to >370 parts per billion; Karl and Trenberth 2003), trapping solar radiation and warming the planet.

Exacerbated by climate change is the drastic loss of worldwide biodiversity (Thomas et al. 2004, Loarie et al. 2009). It marks the sixth major extinction event in the history of life on Earth (Chapin et al. 2000) and is the first to be driven by human-impact (Rockström et al. 2009). It is estimated that the extinction rate today is 100-1000x the rate of “background” (i.e., natural) levels of extinction (Chapin et al. 2000). Currently, approximately 12% of birds, 20% of mammals, and nearly 10% of plants are threatened with extinction (Chapin et al. 2000), a major problem given the growing consensus that biodiversity is critically important to proper ecosystem functioning (Hooper et al. 2005, MEA 2005).

Causing many species declines are the growing demands on earth’s agricultural lands to provide food and fiber for over seven billion people (Foley et al. 2005). Recent conversion of forests to agricultural lands is a major driver behind loss of ecosystem functioning and services (Matson et al. 1997). Modern forms of agriculture often degrade water quality through fertilizer inputs, increase soil erosion, and damage habitat for native biodiversity (Foley et al. 2005). Currently 12% of global land is cultivated in crops
(Rockström et al. 2009) and additional agricultural lands will be needed to meet the needs of a human population that could exceed 9 billion people in next 50 years (McCarthy 2009).

Tradeoffs dominate human decision making, and decisions on how to allocate funds to combat environmental problems are often made by people of various personal, family, religious, political, economic, and scientific perspectives (Davis and Slobodkin 2004). Now more than ever, cooperation and collaborative thinking are needed to understand complex ecological problems; in many cases, synthesizing information from disparate disciplines (e.g., climatology, phenology, ecology, sociology) allows ecologists to work toward innovative conservation solutions (Carpenter and Folke 2006). Therefore, the overarching themes of my dissertation are:

1. Provide innovative solutions to broad-scale ecological problems
2. Bridge gaps between disparate disciplines to improve conservation outcomes
3. Demonstrate how citizens can contribute to an understanding of ecological processes

While most of my work occurs in avian systems, I strive to frame my research questions and findings in their broader ecological contexts. Addressing questions within this framework has required significant and unique collaboration with scientists and citizen scientists at a variety of institutions including Patuxent Wildlife Research Center, NASA, Georgetown University, the High Plains Regional Climate Center, the Cornell Lab of Ornithology, the USA National Phenology Network, Journey North, hummingbirds.net, and the Purple Martin Conservation Association. Here I describe six projects – each a
chapter of my dissertation – which I have exclusively or collectively envisioned, conceived, and seen to completion while at Clemson University. Based on my committee’s recommendation, many of the findings I present have been published, or are currently being considered for publication.

My dissertation begins with a chapter entitled “Assessing Migration of Ruby-throated Hummingbirds at Broad Spatial and Temporal Scales.” I used information from the North American Bird Phenology Program and recent citizen science databases to assess changes in hummingbird migration in North America from 1880-2010. I then matched weather records to observations and reconstructed historical hummingbird migration patterns using ArcGIS (ESRI 2011). We report a dramatic change in the timing of hummingbird migration over time that varies by latitude, particularly during warmer winters, a finding that may inform land managers and farmers when and where ecosystem services provided by birds (e.g., pollination and pest suppression) could be impeded. This paper has been submitted for publication and we are awaiting reviewer feedback. I include it with permission from my co-authors R.J. Johnson, W.C. Bridges, and K.G. Hubbard.

“Weekend Bias in Citizen Data Reporting: Implications for Phenology Studies” was a project I initiated and developed with students over the course of three semesters as part of Clemson University’s Creative Inquiry Program. We used >80,000 migration records reported by citizen volunteers in North America from 1880-2010 to assess the likelihood that “first” arrivals were disproportionately reported on weekends. We examined this bias over time, between continents, and among species. We noted a bias
toward weekend reporting and discuss ways to correct for this bias in studies that use avian phenology to assess the effects of climate change on wildlife species. This paper has been submitted for publication and we are awaiting reviewer feedback. I include it with permission from co-authors R.J. Johnson, C.A. Stuyck, B.A. Lang, and E.W. Kaiser.

My fourth chapter assesses the usefulness of growing degree-days, a concept familiar to most farmers, to predict nesting dates of common bird species in the northeastern United States. To our knowledge, this is the first time growing degree-days have been used in this capacity. We are preparing this manuscript for publication and are optimistic this technique will improve communication between researchers and farmers regarding the importance of bird function on sustainable farms. It also may provide a yardstick to assess the effects of temperature changes across trophic levels in agroecosystems. I include it with permission from co-authors R.J. Johnson, W.C. Bridges, and K.G. Hubbard.

A version of my fifth chapter, "Reviving a Legacy Citizen Science Project to Illuminate Shifts in Bird Phenology," was recently published in the International Journal of Zoology (Zelt et al. 2012) and its purpose is to demonstrate how data collected through the North American Bird Phenology Program (1880-1970) can help in understanding phenology. I was invited by collaborators at Patuxent Wildlife Research Center to envision the concept for this paper, transcribe all data for analysis (with help from my creative inquiry students), interpret biological findings, significantly edit all content, and conduct the analyses for Case Study #1. I appear as second author on the published
manuscript and include it in my dissertation with permission from my co-authors J. Zelt, A. Arab, R.J. Johnson, and S. Droge.

My final two chapters focus on bridging gaps between various disciplines to improve conservation outcomes. “Graduate Students in Conservation Biology: Bridging the Research-Implementation Gap” was an idea that emerged from discussions in a weekly ecology reading group and was formalized in an assignment for Dr. Robert Baldwin’s Conservation GIS class. I begin by reviewing four common recommendations for bridging the Research-Implementation Gap that has been identified in conservation biology and explain how graduate students are well-positioned to contribute in this endeavor; I conclude by explaining five ways research institutions and professionals can encourage graduate student participation in this process. A form of this chapter has been published in the Journal for Nature Conservation (Courter 2012). My final chapter, “Use of Threat Analysis to Assess the Effects of Land Development on Biodiversity in a Blue Ridge-Piedmont Landscape” also originated from a class project in Dr. Robert Baldwin’s Conservation GIS class. Together, my co-authors and I developed models to project the effects of urbanization on important bird and amphibian species in South Carolina and conducted threat analyses to identify biologically important areas that were most at-risk from human development. I contributed extensively to all aspects of this project, developed the habitat reduction model, and wrote the majority of the manuscript with co-author Thilina Surasinghe. Because of our equal contributions, we decided I would be first author on a presentation given at the 3rd Annual Emerging Issues Along Urban-Rural Interfaces Conference in Atlanta, GA (Courter et al. 2010), and he would be first author.
in the written version recently published in the *Journal of Conservation Planning* (Surasinghe et al. 2012). I include it in my dissertation with permission from co-authors T.D. Surasinghe, R.F. Baldwin, and R.J. Johnson.

References


CHAPTER TWO

ASSESSING MIGRATION OF RUBY-THROATED HUMMINGBIRDS AT BROAD SPATIAL AND TEMPORAL SCALES

Abstract

Phenological patterns in birds appear in part to be temperature-dependent, and temperatures are changing in some places. Most bird phenology studies are conducted at broad temporal scales but local spatial scales, making it difficult to assess the effects of temperature changes that vary widely across landscapes. Recently, networks of ‘citizen science’ volunteers have emerged and their collective efforts may improve phenology studies if biases associated with such efforts are recognized and addressed. Here, we compared mean Ruby-throated Hummingbird (*Archilochus colubris*) first arrival dates from Journey North (2001-2010) with data from the North American Bird Phenology Program (1880-1969). Hummingbirds arrived earlier in the more recent time period throughout the eastern United States; these advances, however, varied by latitude from 11.4–18.2 days, with less pronounced changes above 41°N. Warmer winter and spring temperatures in North American breeding grounds were correlated with earlier arrivals at lower latitudes in our recent time period. Surprisingly, hummingbirds arrived later at high latitudes (42-43°N) during warmer winters and later at both mid- and high latitudes (38-39, 41-44°N) during warmer springs, perhaps indicating extended migratory stopovers below 40°N during these years. Overall, climate variables predicted arrival dates better in our recent time period. Our results document spatial variability in how warming temperatures affect hummingbird arrivals and add credence to the hypothesis that spatial...
differences in arrival patterns at high versus low latitudes could exacerbate asynchrony between some birds and their food resources and modify associated ecosystem services such as pollination and insect pest suppression.

Introduction

Birds are often used to assess the effects of climate change on wildlife species because they respond quickly to temperature changes, are charismatic and easy to identify, and monitoring programs have been in place for more than a century (Crick 2004, Wilson 2007, Newson et al. 2009, Knudsen et al. 2011). Recent studies suggest that many species are returning earlier than in previous time periods in large part because of climate-related changes (Cotton 2003, Møller et al. 2004, Miller-Rushing et al. 2008a, Møller et al. 2010), such as changes in mean annual temperature (Ledneva et al. 2004), winter temperature (Cotton 2003, Swanson and Palmer 2009, Hurlbert and Liang 2012), spring temperature (Murphy-Klasson et al. 2005), and large-scale climate indices, such as the North Atlantic Oscillation Index (NAO; Hüppop and Hüppop 2003, Vähätalo et al. 2004). Changing arrival dates have also been correlated to non-climate factors, such as an increase in popularity of backyard bird-feeding (Robb et al. 2008), changing sizes of bird populations (Miller-Rushing et al. 2008a), and land cover changes in wintering grounds, breeding grounds, and/or migratory pathways (Moore et al. 1995, Parrish 2000).

In addition to serving as sentinels of climate change, birds provide important ecosystem services to farmers and the general public (Sekercioglu 2006, Whelan et al. 2008, Wenny et al. 2011). Birds function as insect predators (Mols and Visser 2002),
pollinators (Clout and Hay 1989), scavengers (Seckercioglu et al. 2004), seed dispersers (Levey et al. 2005), seed predators (Holmes and Froud-Williams 2005), and ecosystem engineers (Valdivia-Hoeflich et al. 2005). Recent evidence suggests that changing temperatures and other factors are disrupting food webs by causing birds to arrive either too early or too late compared with food resources (Marra et al. 2005, Visser and Both 2005, Saino et al. 2011). Møller et al. (2008) reported that the abundance of European migratory bird species that were unable to adjust their spring migrations to use peak food resources declined between 1990-2000. This potential asynchrony could be detrimental to bird populations and potentially to the biological pest suppression that birds provide, leading to increased pest outbreaks (Price 2002). Predicting where potential asynchronies may be most severe and how climate change may alter migration patterns remains difficult, however, given the spatial variability of changing temperatures (Stenseth et al. 2002, Stokke et al. 2005, Visser and Both 2005). The effects of climate change often vary regionally and are most pronounced in northern latitudes and at higher elevations, especially in North America (Easterling et al. 1997), making it difficult for birds that pass through multiple climate regions during migration (Strode 2005, Newton 2008).

Most bird phenology studies have been conducted at broad temporal, but narrow spatial scales (Bradley et al. 1999, Cotton 2003, Ledneva et al. 2004, Murphy-Klassen et al. 2005, Swanson and Palmer 2009). Benefits of site-based migration studies include the ability for multiple species to be compared simultaneously, observer error to be reduced, and available weather data to be collected and correlated consistently over multiple years. Inferences, however, can be limited spatially, making it difficult to assess the effects of
temperature changes that vary widely across landscapes (Primack et al. 2009, Knudsen et al. 2011).

Fewer studies have used multiple observations along migratory routes to examine migration timing (Knudsen et al. 2011). For example, Marra et al. (2005) compared the interval between banding dates of long-distance migrants in Louisiana from 1961-2001 with two stations approximately 2,500 km farther north, and found that mean passage time (22 days) was inversely related to temperature, with birds arriving 0.8 days earlier per 1°C increase in temperature. Miller-Rushing et al. (2008b) found variable responses of migratory birds to spring temperatures at banding stations separated by hundreds of kilometers and also among locations within Massachusetts, suggesting that factors such as temperature variability, migratory cohorts, and site conditions may influence migratory arrival patterns. In Europe, Hüppop and Winkel (2006) used first arrival dates of Pied flycatchers (*Ficedula hypoleuca*) at six sites along a migratory pathway to show that migration is strongly influenced by temperatures *en route*. Saino and Ambrosini (2008) compiled mean first arrival dates from five previous studies conducted in different locations to conclude that meteorological conditions during breeding in Europe covaried with conditions during late winter in sub-Saharan Africa, perhaps allowing birds to predict future conditions and optimize migration timing. Even fewer studies have assessed changes in phenology over an entire region or continent. One of the broadest-scale studies, to date, used observations from an extensive network of volunteer observers at >1,300 sites around Spain from 1944-2004 (Gordo and Sanz 2006). They used location (latitude and longitude) and climate variables to predict changes in arrival dates for
common migratory species. Such studies are difficult because of the enormous network of observers required to pinpoint annual ‘first-events’ that often span thousands of kilometers.

A counterpart to assess historical, broad-scale changes in migration in North America had been largely unavailable until a recent effort from the United States Geological Survey (USGS) revitalized the North American Bird Phenology Program (NABPP). From 1880-1970, the NABPP coordinated efforts of hundreds of naturalist volunteers to report annual first bird sightings in North America using standardized observation protocols to better understand migration patterns and bird distributions (Merriam 1885, Jessica Zelt, person. comm). Efforts are currently underway to scan and digitize this largely unanalyzed (except Droege et al. 2003) database and make records available to the public through the United States of America National Phenology Network (USA-NPN; http://www.usanpn.org, Dickinson et al. 2010). At the same time, ‘citizen scientists’ are reporting a variety of spring events such as bird arrivals, insect emergence, and plant flowering dates. Wilson (2007), for example, compiled more than 32,000 first arrival observations from nearly 200 birders in Maine from 1994-2005 and correlated arrival dates with climate variables. Howard and Davis (2009) used three years of migration data from the online citizen science database Journey North (http://www.learner.org/jnorth/) to describe two continent-wide flyways of monarch butterflies during fall migration in North America. Such data could improve phenology studies if biases associated with citizen data collection techniques are recognized and addressed (Miller-Rushing et al. 2008a, Dickinson et al. 2010).
Hummingbirds are charismatic, abundant, neotropical migrants that have fascinated naturalists for centuries (Robinson et al. 1996); and detailed observations of the Ruby-throated Hummingbird (*Archilochus colubris*) have been made in both recent and historical time periods. Hummingbirds are easily identified, and given that they are the only regularly occurring hummingbird in eastern North America, they are suitable subjects for long-term monitoring programs. Ruby-throats regularly winter in Central America between northern Panama and southern Mexico and most migrate across the Gulf of Mexico, arriving at their breeding grounds in eastern North America between February-May (Robinson et al. 1996). During migration hummingbirds feed primarily on nectar and small insects (Robinson et al. 1996) and occasionally tree sap associated with wells of Yellow-bellied sapsuckers (*Sphyrapicus varius*; Miller and Nero 1983). In addition, hummingbirds help pollinate at least 31 plant species in North America, 19 of which rely on hummingbirds as their primary pollinators (Austin 1975). Recent studies indicate that hummingbirds are arriving earlier to their breeding grounds than in previous time periods in Maine (Wilson et al. 2000), Massachusetts (Butler 2003, Ledneva et al. 2004), South Dakota (Swanson and Palmer 2009), and New York (Butler 2003).

Given the recent trend for earlier hummingbird arrivals, the extensive geographic database of observations now available, and a general understanding that climate influences bird migration at multiple scales, we assessed spatial differences in arrival dates of Ruby-throated Hummingbirds from 1880-2010 in eastern North America in relation to climate variables. We also assessed potential mechanisms for the observed changes in relation to the long-distance migration pattern and foraging habits of
hummingbirds, and spatial variation of climate effects from wintering grounds to their more northerly breeding areas.

Methods

Arrival data

Historical hummingbird migration data (1880-1969) provided by the North American Bird Phenology Program (NABPP; http://www.pwrc.usgs.gov/bpp/), were transcribed from handwritten arrival cards to Microsoft Excel spreadsheets by the senior author and student volunteers. Each arrival record appearing in our database was then rechecked for accuracy to ensure that a mistake was not made during the transcription process. Recent hummingbird data (2001-2010), reported by citizen science volunteers through hummingbirds.net and Journey North (www.journynorth.org), were accessed from the Journey North online database. First arrivals from both time periods reported between February 1 – May 31 were converted to ‘day of year’ (e.g., April 10 = day 100), accounting for leap years. Arrival locations were assigned a location (i.e., latitude, longitude, and altitude) based on the centroid of the reported arrival city and zip code using the ESRI Arc 10 Geocoder and the GPS Visualizer geocoding service (www.gpsvisualizer.com).

Arrivals from historical (1880-1969) and recent (2001-2010) time periods were then divided into 1° latitudinal bands (~111 km each; Fig. 2.1) from 33-44.99°N to encompass the northward pattern of hummingbird migration in the eastern United States. For example, all arrival records between 35-35.99°N were grouped into the 35°N band.
Arrival data north of 45°N and south of 33°N did not meet our minimum sample size requirement (≥75 observations per time period) and were omitted from analyses.

Longitudinally, we included arrival records east of 94°W, which is the approximate range limit for Ruby-throated Hummingbirds. Outliers were removed at 3 standard deviations by time period and 1° latitudinal band to remove first arrivals that were likely incorrectly reported by citizen volunteers. In sum, we analyzed 36,457 first arrival records (N = 4,652 from 1880-1969 and N = 31,805 from 2001-2010; Fig. 2.1).

Weather data

To approximate annual weather conditions in the eastern U.S., we used monthly weather data (1895-2010) from the National Oceanic and Atmospheric Administration Time Bias Corrected Divisional Temperature-Precipitation Drought Index Data Set (http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/offline/readme.html), reported by climate division (designations of the United States National Climate Data Center that group areas of similar elevation, temperature, and precipitation). Weather variables previously linked to changes in bird phenology (i.e., winter temperature, spring temperature, and spring precipitation; Gordo 2007) were joined to arrival records by year and climate division using ArcGIS 10 (ESRI 2011). We used mean monthly temperatures in January and February for winter values and mean monthly temperatures in March and April for spring values. To approximate temperatures encountered in Central American wintering grounds, we searched for weather stations in the Global Historical Climatology Network (http://www.ncdc.noaa.gov/ghcnm/) located near the center of hummingbird winter ranges (southern Mexico to northern Panama) that reported long-term monthly
temperature records from 1895-2010. In general, such stations were scarce. Only one (Aerop.Interna, GHCN Station #41476644000, 20.98°N, -89.65°W, Yucatan, Mexico) met our criteria and was therefore used to approximate temperatures in the Ruby-throated Hummingbird wintering grounds. We used mean February temperatures to approximate temperatures on wintering grounds because February is typically the last full month hummingbirds overwinter prior to their departure to North America (Robinson et al. 1996).

Statistical analyses

We compared mean arrival dates by latitudinal band using a model with time period as a predictor. We initially examined mean arrival dates by decade and noted that arrivals in our recent time period were significantly earlier than mean arrival dates in each of the previous decades. Therefore to simplify our output, we grouped arrival dates into a pre- and post-climate change period based on noted similarities of arrival dates within time periods and a general consensus that a climatic change point occurred in the mid-1970s, after which many phenological events began to advance (Walther et al. 2002, Gordo and Sanz 2009). To adjust for micro-scale differences within bands we included latitude, longitude, and altitude in our models, along with possible interaction terms. To examine remaining variability in arrival date, we then explored differences among the environmental variables associated with arrival dates (winter and spring temperature in breeding grounds, precipitation in breeding grounds, and temperature in wintering grounds) by latitudinal band and time period, using t-tests, and noted that environmental variable means differed between time periods.
Given the mean differences in both arrival dates and environmental variables, we used stepwise regression to identify environmental variables that were related to arrival date at each latitudinal band. Initial analyses indicated that relationships between environmental variables and bird arrivals were inconsistent between time periods and that there was a high correlation among environmental variables. Therefore, we analyzed the relationship between arrival date and weather variables separately, for each time period and band combination using simple linear regression. All statistical analyses were conducted using JMP 9 (SAS Institute 2010).

Migratory rates were calculated by subtracting mean arrival times at subsequent latitudinal bands and dividing by 111 km (the approximate distance between 1° latitude). Total migratory passage time was calculated by subtracting mean arrival dates at 33°N from 44.99°N for each time period. To compare arrival dates graphically, we generated a smoothed raster map from point data for each time period using inverse distance weighting (IDW; ArcGIS 10), a procedure that assigns raster cells values based on known values of surrounding cells. For our IDW models we calculated mean arrivals by time period and climate division and included all divisions between 29-46°N that had a minimum of 10 arrival points per time period; this included 99 climate divisions from 1880-1969 and 195 climate divisions from 2001-2010. Although variability was higher for mean arrival dates between 29-32°N and 45-46°N in our historical time period, we chose to include these data in this analysis for comparative purposes. We assigned each mean arrival date a latitude and longitude based on the centroid of the climate division it
represented. For our graphical analysis, we considered a 9-cell search radius, and delineated arrivals using an 8-day time interval.

Results

Mean first arrival dates differed dramatically between time periods at all latitudes (Fig. 2.2), with hummingbirds arriving 11.4 to 18.2 days earlier in the more recent period (Table 2.1). Moreover, differences in first arrival date varied by latitude (Fig. 2.3). At lower to middle latitudes (33-41°N) hummingbirds arrived ~15 days earlier in the recent time period but, at higher latitudes (42-44°N), they arrived ~11.5 days earlier (Table 2.1).

Overall, hummingbirds averaged 33.7 days to travel between 32-45°N during 1880-1969 (a rate of 36.2 km/day) and 38.0 days to travel between 32-45°N during 2001-2010 (a rate of 32.1 km/day). Migratory rate (inversely related to passage days; Fig. 2.4) increased at higher latitudes in both time periods.

Climate variables associated with arrivals varied between time periods, with warmer winters and warmer and wetter springs reported in our recent time period at higher latitudes (Table 2.2). In general, winter and spring temperatures were highly correlated in both time periods (r = 0.90). On average, February temperatures in Central America wintering grounds were 0.90 ± 0.02°C warmer for arrivals in 2001-2010 (P < 0.0001) than in 1880-1969.

Several weather variables predicted arrival dates at various latitudes during the recent time period (2001-2010; Table 2.3a). Most notably, birds arrived earlier in warmer winters at lower to middle latitudes (33-39°N), but later in warmer winters at higher
latitudes (42-43°N). Similarly, birds arrived earlier in warmer springs at low latitudes (33, 35°N), but later at higher latitudes (38-39, 41-44°N). Wetter springs were correlated with earlier arrivals at 33 and 34°N, but with later arrivals at 37 and 40°N (Table 2.3a). In general, birds arrived earlier when February wintering ground temperatures were warmer. Weather variables during the 1880-1969 time period were less predictive of avian arrivals; although some trends were similar to the recent time period, only 4 of 48 possible variables were significant at our 12 latitudes (Table 2.3b).

Discussion

One challenge in understanding the effects of climate change is to understand how effects on species and ecosystems vary across spatial as well as temporal scales (Primack et al. 2009). The innate urgency to complete northward migration in time for breeding activities to occur when required food and other resources are plentiful is constrained by availability of suitable temperatures and sufficient food at a variety of latitudes en route (Hüppop and Winkel 2006, Tøttrup et al. 2008). Our findings demonstrate that Ruby-throated Hummingbirds are arriving at breeding areas throughout the eastern United States 11.4 to 18.2 days earlier than they did historically (Fig. 2.1), a result generally consistent with site-specific reports at various latitudes. For example, we report a 11.8 day advancement in hummingbird migration at 42°N, whereas Ledneva et al. (2004) reported an 18.4 day advancement in Middleborough, Massachusetts (41.89°N, 70.91°W) from 1970-2002; and Butler (2003) reported a 6.3 day shift in Worcester, MA (42.26°N, -71.80°W) from 1932-1993. Butler (2003) also reported a modest two day shift (P =
0.051) toward earlier arrivals at Cayuga Lake Basin, NY (42.92°N, -76.73°W), but arrival periods were grouped differently (i.e., 1903-1950 and 1951-1993) than in our study. At 44°N, we report a 11.4 day advancement, whereas Wilson et al. (2000) found a 4-day advancement in Maine (~44°N, 70°W; comparing intervals 1899-1911 and 1994-1997) and Swanson and Palmer (2009) found an 18.1-day advancement in South Dakota (~44°N, 100°W; between 1971-2006). Swanson and Palmer (2009) found no evidence that hummingbird arrivals were becoming earlier in Minnesota between 1964-2005 and, although Minnesota (~46°N, 95°W) is outside our study region, this result is somewhat consistent with our finding that advancement in arrival dates decline at higher latitudes (Fig. 2.3).

Effects of climate on hummingbird arrivals

Our climate findings are consistent with a growing body of evidence indicating that winters and springs are warming in recent years, especially at higher latitudes (i.e., above 35°N; Karl and Trenberth 2003, Loarie et al. 2009; Table 2.2). Earlier hummingbird arrivals in our study were correlated with weather variables in both time periods (Table 2.3), consistent with a general trend reported across bird taxa (Gordo 2007, Lehikoinen and Sparks 2010). Photoperiod has long been regarded as the primary cue that triggers migration in birds (Carey 2009), with weather conditions such as temperature and precipitation helping to fine-tune migration timing (Tøttrup et al. 2010, Knudsen et al. 2011). Interestingly, our results showed that climate variables affected arrival dates to a much greater extent in recent times, with 29 of 48 climate metrics significant in the more recent time period and only 4 of 48 significant historically (Table
2.3). This may suggest that local-scale weather or climate-related cues are emerging as factors of increasing importance to bird phenology, in both North America and Central American wintering grounds.

From 2001-2010, hummingbirds migrated north at a rate of 32.1 km/day, a rate similar to the 32.2 km/day (or 20 miles/day) estimated by the popular citizen science website hummingbirds.net. Our results suggest that migration occurred faster historically (36.2 km/day), meaning hummingbirds currently take 4.3 additional days to travel between 33-45°N. It is somewhat surprising that migratory rate has slowed in recent times, even though the migratory period occurs much earlier in the spring (Fig. 2.2), given recent increases in hummingbird populations and the likelihood that competition for nesting sites may be intensified (Walther et al. 2002).

During our recent time period (2001-2010), birds arrived earlier to most latitudes when February temperatures were higher in their wintering grounds prior to departure (Table 2.3a). Few studies have used temperature on the wintering ground to predict migratory arrival to North America because long-term data from tropical areas in the western hemisphere are limited (Gordo 2007). Evidence from Europe, however, suggests that migrants return earlier when winters are warmer in Africa (Boyd 2003, Cotton 2003). Our study also shows that recent arrivals are earlier when winters and springs are warmer in North America, but only at lower latitudes (Table 2.3a), suggesting that hummingbird migration is likely constrained by weather or foraging conditions en route (Marra et al. 2005, Tottrup et al. 2008).
Our data show that warmer winter temperatures advance migration below 40°N, but delay hummingbird migration above 40°N (Table 2.3a). It is possible that a lack of winter chilling requirements being met recently in warmer winters in the southeastern United States may delay bud break for some plant species below 40°N (Zhang et al. 2007, Morin et al. 2009, Harrington et al. 2010); meaning that migratory birds, such as hummingbirds, could be extending their stopover periods to obtain sufficient food resources to complete migration (Strode 2003) or in response to another plant phenology cue. In addition, we report a migratory delay (i.e., an increase in the number of passage days; Fig. 2.4) between 37-39°N in our recent time period which appears consistent with this hypothesis. Interestingly, spring temperatures were also correlated with later arrivals at high latitudes but this may be because spring and winter temperatures were highly correlated in our study (r = 0.90). Another possible explanation for our result is that some birds delay migration in years with high productivity and extend stopovers to take advantage of improved foraging conditions (Tøttrup et al. 2008, Robson and Barriocanal 2011). Regardless of the mechanism(s) governing these interactions, hummingbirds are arriving less early at northern latitudes, which is late in relation to the spring and a potential mismatch between hummingbird arrival and initial availability of food resources at higher latitudes. Moreover, our results clearly demonstrate that hummingbird migration rates are slowed at lower latitudes, especially between 33-38°N, thus highlighting the importance of considering latitude and possible reasons for stopover when interpreting migratory studies that assess phenology.
First arrival dates and growing hummingbird populations

By combining first arrival dates by latitudinal band (Table 2.1) and requiring ≥75 observations, our study compares mean first arrival dates instead of using first arrival dates of individuals. This method obviates a common criticism that first arrival dates are affected by differences in observer effort across space (Gordo and Sanz 2006, Dickinson et al. 2010). Other biases of using first arrival dates were impossible to address in our study, such as the tendency for early migrants to be influenced more by climate change (Vähätalo et al. 2004, Tøttrup et al. 2010) and the tendency for first arrival dates to advance more than mean or median migration dates (Lehikoinen et al. 2004, Rubolini et al. 2007, Miller-Rushing et al. 2008a; although most studies report a strong positive correlation between first and mean arrival dates; Lehikoinen et al. 2004).

We also point out that hummingbird populations in the Eastern United States have more than doubled in Eastern North America since 1966 according to data from the North American Breeding Bird Survey (Sauer et al. 2011). We chose not to include this in our analyses because we lacked a reliable estimate of hummingbird populations from 1880-1966. In general, an increasing population may be correlated with earlier arrivals (Tryjanowski and Sparks 2001, Miller-Rushing et al. 2008a) and a higher probability of detecting early migrants, both because of their increased number and because of the increase in territorial displays that ensue (Tryjanowski et al. 2005). However, while Swanson and Palmer (2009) reported that first arrival dates advanced for 70% (7 of 10) of species with increasing populations in Minnesota and South Dakota from 1964-2006, they also reported that first arrival dates advanced for 57% of species (16 of 28) with
stable populations, suggesting that migratory advancement is not necessarily related to a growing population and enhanced detectability. While it is was not possible to account for every factor influencing arrival changes in this study, we remain convinced that our results illustrate biologically meaningful spatial and temporal patterns and note that a study of this spatial and temporal magnitude (Fig. 2.2) would be nearly impossible to conduct without using first arrival dates.

*Backyard bird-feeding*

Another important consideration when interpreting our results is the increase in popularity of backyard bird-feeding in the United States in past decades (Robb et al. 2008). Currently an estimated 43% of United States' households feed birds (Martinson and Flaspohler 2003), especially charismatic birds such as hummingbirds. While we are confident that data reporters in our historical time period (1880-1969) were competent naturalists, it is unlikely that the majority of observations were made at hummingbird feeders, perhaps decreasing their abilities to detect the first arriving individuals. To our knowledge no study has demonstrated that bird feeders affect the likelihood of observing first-arriving birds, but we suspect such a relationship could exist. In addition, the winter ranges of hummingbirds could be advancing northward into the southern United States as bird-feeders and warming winter temperatures provide more predictable food resources (Parmesan and Yohe 2003). This could potentially decrease the distance and time a hummingbird needs to migrate and cause birds to arrive earlier (Robb et al. 2008, Visser et al. 2009), although birds would still face similar environmental constraints migrating northward. While we were not able to completely account for this possibility in our study,
we did define our study area north of 33°N, which almost certainly eliminates the chance for wintering birds to be reported as first arrivals (Hauser 1966, Robinson et al. 1996).

*Migration distance and foraging patterns*

Butler (2003) analyzed changes in migration dates of 103 migrants in New York and Massachusetts and found that, on average, short-distance migrants advanced migration dates by 13 days between 1903-1950 and 1951-1993, whereas long-distance migrants (i.e., not regularly wintering in the United States; Butler 2003) advanced only 4 days. Most (Lehikoinen et al. 2004, Rubolini et al. 2007, Hurlbert and Liang 2012), but not all studies (Jonzen et al. 2006) suggest that responses to climate change (i.e., earlier arrivals) are less pronounced for long-distance migrants. According to this metric, hummingbirds in our study advanced their arrival dates more than other long-distance migrants (Table 2.1, Fig. 2.2; Butler 2003). We expect that factors mentioned previously may partially explain this apparent difference, but also point out that the Central American wintering grounds of hummingbirds are closer than that of many other long-distance migrants that winter in South America; thus, climate conditions in Central America might better approximate environmental cues present in North American breeding grounds (Butler 2003, Tryjanowski et al. 2005, MacMynowski and Root 2007, Tøttrup et al. 2010, Wiebe and Gerstmar 2010) and allow hummingbirds to migrate earlier in warmer springs. Hummingbirds are opportunistic in migration, feeding on both nectar and insects (Robinson et al. 1996), perhaps being more flexible in arrival dates and responding to general spring green-up dates more than other migrants that rely on a particular food source (Strode 2009, Hurlbert and Liang 2012). Future studies that assess
the phenology of plants and insects that hummingbirds rely on for food, correlate hummingbird migration to recent remotely sensed green-up data, and examine the history and spatial distribution of backyard bird feeding will help clarify hummingbird migration in relation to migratory and foraging patterns.

We demonstrate a major phenological shift in the past century for the Ruby-throated Hummingbird, one of North America’s most popular and charismatic bird species. Migratory advancement appears to be most pronounced at lower latitudes and largely climate-related. Extended migratory stopovers in mid-latitudes during warmer winters when spring is actually earlier in the north, may present a double effect on synchrony between birds and their breeding habitats. Taken together, our results demonstrate advanced migration arrival dates but with spatial variation for Ruby-throated Hummingbirds and suggest that climate-related cues, in both North American breeding and Central American wintering grounds, are emerging as factors of increasing importance to bird phenology. Comparative studies such as this could help conservationists, policy makers, and farmers identify where ecosystem services provided by birds (e.g., pollination and pest suppression) are most likely to be impeded and help inform management decisions.
Tables

Table 2.1. First arrival dates of Ruby-throated Hummingbirds (N = 36,457) are earlier at all latitudes when comparing recent (2001-2010) and historical (1880-1959) data.

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\(^{a}\)Arrival dates expressed as ‘day of year’ and corrected for leap years; for example, ‘95’ is equivalent to April 5.
Table 2.2. Differences in climate variables in our study region between historical (1880-1969) and recent (2001-2010) time periods.

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<th>Spring temperature ($^\circ$C)$^b$</th>
<th>Spring precipitation (cm)$^c$</th>
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<td>Diff. SE P-Value Trend</td>
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$^a$Mean January and February temperatures in North American breeding grounds
$^b$Mean March and April temperatures in North American breeding grounds
$^c$Mean sum of February to April precipitation in North American breeding grounds
$^d$Differences calculated by subtracting 1880-1969 climate means from 2001-2010 climate means
$^e$Summary of how recent climate data (2001-2010) compare with historical climate data (1880-1969)
Table 2.3. Significant predictors (P < 0.05) of hummingbird arrival dates in our (a) recent (2001-2010) and (b) historical (1880-1969) time periods. We used regression models to identify the environmental variables that predicted arrival date at each latitudinal band. Latitude, longitude, and altitude were included as covariates to adjust for possible regional effects within latitudinal bands.

(a) Recent data (2001-2010)

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<th>P-Value</th>
<th>Description</th>
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*Mean January and February temperatures in North American breeding grounds
*Mean March and April temperatures in North American breeding grounds
*Mean sum of February to April precipitation in North American breeding grounds
*Mean February temperature in Yucatan, Mexico (20.98°N, -89.65°W) used to approximate temperatures in wintering grounds
Figure 2.1. Locations within our study region (33-44°N, 67-94°W) reporting hummingbird arrivals from the North American Bird Phenology Program (1880-1969; blue) and Journey North (2001-2010; red). Numbers represent approximate degrees north latitude. First arrivals in our study were grouped by time period and 1° latitudinal band.
Figure 2.2. Mean Ruby-throated Hummingbird first arrival dates advanced at all latitudes in eastern North America between 1880-1969 and 2001-2010. Figure generated using inverse-distance weighted (IDW) interpolation (ArcGIS 10; ESRI 2011).
Figure 2.3. Differences in mean first arrival dates between (1880-1969) and (2001-2010) by 1° latitudinal band. Changes in first arrival dates are less pronounced in northern latitudes.
Figure 2.4. Mean days spent between 1° latitude intervals during spring migration by first-arriving hummingbirds. Migration rate increased (i.e., fewer passage days) in northern latitudes in both time periods.
Acknowledgments

We thank L. Chambers from hummingbirds.net and E. Howard and Journey North, with funding from the Annenberg Foundation, for collecting and compiling thousands of recent first arrival reports. We are grateful to the countless contributors from Journey North and hummingbirds.net for more than a decade of careful observation, without which, a study of this magnitude would not be possible. We thank J. Zelt and S. Droegge for their commitment to providing and protecting historical migration records through the North American Bird Phenology Program (USGS, Patuxent Wildlife Research Center) and for their expertise and support, which underscores the vision of the hundreds of early naturalists who faithfully contributed arrival cards from 1880-1970. We thank R.F. Baldwin from Clemson University, W.W. Bowerman from the University of Maryland, and A. Arab from Georgetown University for help with our study design and analysis. We thank Clemson University students K. Auman, C. Boaman, J. Burroughs, J.H. Collins, B. Crawford, F. Kaiser, M. Kyroch, B. Lang, F. Purcell, D. Stone, M-K. Spillane, C. Stucyk, and S. Taylor for transcribing arrival cards and help with our analysis, and P. Leonard and S. Essewein for help with ArcGIS. This study was funded primarily by Clemson University with additional support from a Carolina Bird Club grant.

References


CHAPTER THREE

WEEKEND BIAS IN CITIZEN SCIENCE DATA REPORTING: IMPLICATIONS FOR PHENOLOGY STUDIES

Abstract

Studies of bird phenology can help elucidate the effects of climate change on wildlife populations, but data over a broad spatial scale are difficult to collect without networks of observers. Recently, networks of citizen volunteers have begun to report first arrival dates for many migratory species. Potential benefits are substantial (e.g., understanding ecological processes at broad spatial and temporal scales) if known biases of citizen data reporting are identified and addressed. One potential source of bias in bird phenology studies is the tendency for more “first” migratory arrivals to be reported on weekends than on weekdays. We investigated weekend bias in data reporting for five common bird species in North America (Baltimore Oriole, Icterus galbula; Barn Swallow, Hirundo rustica; Chimney Swift, Chaetura pelagica; Purple Martin, Progne subis; and Ruby-throated Hummingbird, Archilochus colubris), and assessed whether this bias affected mean arrival dates reported using data from historic (1880-1969; N = 25,555) and recent (1997-2010; N = 63,149) citizen science databases. We found a greater percentage of first arrivals reported on weekends and small but significant differences in mean arrival dates (approximately 0.5 days) for four of five species. Comparing time periods, this weekend bias decreased from 33.7% and five species in the historical time period to 32% and three species in the recent, perhaps related to changes in human activity patterns. Our results indicate that weekend bias in citizen data reporting
is decreasing over time in North America and including a ‘day of week’ term in models examining changes in phenology could help make conclusions more robust.

Introduction

Studies of phenology, such as first arrival dates for migratory bird species, can help in understanding the impacts of climate change on wildlife species and potential asynchronies with habitat or food resources. Phenological information could help identify how climate change influences the rate of bird migration (Lehikoinen et al. 2004), when and where asynchronies between birds and their food resources might occur (Visser and Both 2005), and how adaptive management strategies could be implemented (Miller-Rushing 2010). Birds are charismatic, easy to identify, and long-term monitoring efforts have been in place for more than a century (Dickinson et al. 2010). Phenological bird data has long been collected by amateur naturalists and is continuing in present-day with web-based citizen science programs that track annual first arrival dates across species’ ranges (e.g., hummingbirds.net, Journey North http://www.learner.org/jnorth/). As advancing technology makes citizen science programs more accessible to the general public, an increasing number of people with wide-ranging levels of expertise are contributing to growing databases (Dickinson et al. 2010, Beaubien and Hamann 2011). These data could improve our understanding of how climate change affects wildlife populations if known biases associated with data collection methods are accounted for and addressed (Miller-Rushing et al. 2008, Silvertown 2009).
Many of the biases in first arrival reporting by citizen scientists such as unequal sampling effort across space and time and differences in detectability among species are becoming well-understood (Tryjanowski et al. 2005, Miller-Rushing et al. 2008, Dickinson et al. 2010). One potential source of bias that is easily identified, but often overlooked, is the tendency for “first” arrivals to be reported on weekends (Fraser 1997). Sparks et al. (2008) examined over 14,000 first arrival reports from the United Kingdom between 1947-2004 and found that 44% of reports were made on weekends, instead of the 28.6% or ‘2 out of 7’ expected to occur by chance; “familiar” species (i.e., those with familiar songs, that fly in groups, or that have populations with over 1 million pairs) showed slightly less weekend bias (41.4%). While they did not completely rule out the possibility that migration patterns could be influenced by environmental conditions such as traffic and pollution levels that differ slightly on weekends (Qin et al. 2004, Marani 2010), they found it most likely that an increase in observer effort on weekends explained this difference. To our knowledge, a similar investigation has not been conducted in North America, which is somewhat surprising given the number of studies that use citizen science data to assess changes in bird phenology (Wilson 2011, Miller-Rushing et al. 2008, Swanson and Palmer 2009, DeLeon et al. 2011). In addition, no study has quantified the degree to which weekend bias affects first arrival dates reported.

Our study objectives were to determine the extent of weekend bias in first arrival reports made in North America and whether this pattern has changed over time. We also wanted to identify characteristics of species more likely to be reported on weekends in
North America, and to examine differences in weekend reporting between North America and Europe.

Methods

We chose five species that were familiar to most birders and had broad monitoring schemes in place during historical (1880-1969) and recent (1997-2010) time periods. Our focal species included Baltimore Oriole (*Icterus galbula*), Barn Swallow (*Hirundo rustica*), Chimney Swift (*Chaetura pelagica*), Purple Martin (*Progne subis*), and Ruby-throated Hummingbird (*Archilochus colubris*).

Historical bird migration data (1880-1969) for all species were transcribed from arrival cards provided by the North American Bird Phenology Program (NABPP; http://www.pwrc.usgs.gov/bpp/) by the senior author and student volunteers. Recent first arrival reports (1997-2010) were accessed from popular online citizen science databases that recruit amateur naturalists to submit annual first arrival observations. First arrivals for Ruby-throated Hummingbird, Baltimore Oriole, and Barn Swallow were provided by Journey North (http://www.learner.org/jnorth/), Purple Martin arrivals were reported from the Purple Martin Conservation Association (http://purplemartin.org/), and Chimney Swift arrivals were accessed from the Driftwood Conservation Association (http://www.chimneyswifts.org/). In sum, we analyzed 88,794 first arrival records in eastern North America (24°N - 49°N, 67-94°W).

Arrival dates were converted into day of week using the ‘weekday’ function in Microsoft Excel 2010 and grouped into weekend and weekday observations. We
compared the percentage of weekend arrivals observed with those expected to occur by chance (i.e., 28.6% or ‘2 out of 7’) with all species and years combined and also by species and time period (i.e., 1880-1969 and 1997-2010), using Pearson chi-square tests and contingency analysis. Mean first arrival dates were then calculated by species to assess possible differences in weekend and weekday arrival reports. We included latitude, longitude, altitude, and time period as covariates, along with all two-way interaction terms; outliers were removed at 3 standard deviations to account for possible errors in first arrival reporting by citizen volunteers. Least square means were compared using one-tailed t-tests (JMP 9, SAS Institute 2010).

Results

Among species and time periods, we found that 32.5% of first arrivals in North America were reported on weekends, compared to 28.6% (or 2 out of 7) expected by chance ($\chi^2 = 420.9$, $P < 0.0001$; Fig. 3.1). Overall, differences decreased between time periods with 33.7% of observations reported on weekends, historically (1880-1969), and 32% of observations reported on weekends in our recent time period (1997-2010; $\chi^2 = 24.6$, $P < 0.0001$). Most notably, the percentage of observations made on Sundays decreased between time periods (17.8% vs. 15.9%; Fig. 3.2). When examining trends among species, a greater number of observations were made on weekends for all species in our historical time period, and for 3 of 5 species in our recent time period (Table 3.1). In general, weekend bias in data reporting decreased over time, particularly among Chimney Swifts ($\chi^2 = 7.6$, $P = 0.006$), Purple Martins ($\chi^2 = 8.8$, $P = 0.003$), and Ruby-
throated Hummingbirds ($\chi^2 = 28.1, P < 0.0001$; Table 3.1). Small, but significant, differences (~0.5 days) were noted in mean first arrival dates when comparing first arrivals calculated from weekend and weekday reports for four of five species, including Baltimore Oriole, Barn Swallow, Purple Martin and Ruby-throated Hummingbird (Table 3.2).

Discussion

Our results demonstrate the tendency for first arrivals to be reported on weekends in North America. The degree of bias, however, is less than has been reported in Europe by Sparks et al. (2008; Fig. 3.1). Overall, 43% of first arrivals were reported on weekends in Europe between 1947-2004, whereas 32.5% of observations were reported on weekends in North America between 1880-2010 (both higher than 28.6% of observations that would be expected if first arrival were reported uniformly throughout the week).

Even among "familiar species" in Europe, weekend bias was higher (i.e., 41.4%) than for any of the five species we report (Table 3.1). The only species reported in both studies was the Barn Swallow; we report 39.5% of observations made on weekends, whereas Sparks et al. (2008) report 43.8%. There are a number of possible explanations for this disparity. First, arrival data from Europe were from "county" bird reports, perhaps being reported by bird club members gathering for weekend field trips; whereas many of the early reports from the United States (1880-1969) were made by farmers or wildlife managers observing birds during their daily routines (Merriam 1885, J. Zelt, person. comm.). Many of the recent arrivals in the United States were reported and immediately
posted online (compared to county bird reports that were likely submitted by mail and later published), perhaps allowing enthusiastic birders to know when to expect charismatic species, such as hummingbirds (L. Chambers, person. comm.).

Unfortunately, data used in this study did not include detailed observer information that may have allowed for demographic comparisons to be made between American and European data contributors, such as differences in observer age, income, and gender (Cooper and Smith 2010), factors that contribute to the discretionary time observers have during the week to look for birds.

Our results suggest that weekend bias has lessened over time in North America (Fig. 3.2, Table 3.1), a finding similar to what Sparks et al. (2008) report in Europe. Weekend habits of many have changed over time, with a greater percentage of people working on weekends (Presser 1999). We suspect that, historically, people spent more time outside on Saturday and Sunday afternoons, potentially observing birds; whereas today a ‘day off’ may also occur during the week. It is also possible that, in recent time periods, everyday encounters with birds have increased as backyard feeding has increased in popularity and allowed many to view birds during their daily routines (Robb et al. 2008). Weekday observations may also be increasing as more citizen science programs are being geared toward school-age youth (Bombaugh 2000, Delaney et al. 2008, Bonney et al. 2009); perhaps increasing the chance that first arrivals would be reported during the school week. The availability of regularly updated migration reports online (e.g., hummingbirds.net, Journey North) may encourage some contributors to be more vigilant during the week (L. Chambers, person. comm.) and increase effort among competitive
birders that seek to report the first arriving bird for a given area (Schaffner 2009, Cooper and Smith 2010). Regardless of the mechanism(s) explaining this trend, we interpret a decrease in weekend first arrival reporting over time as a positive sign that first arrivals are being reported more accurately in recent time periods.

Although weekend bias was not uniform across species, it tended to decrease over time in each of the species we analyzed although change was significant for only three of the five species (Table 3.1). The percentage of Ruby-throated Hummingbird arrivals reported on weekends declined 3.5% between historical and recent time periods (Table 3.1), perhaps because of the increase in backyard bird feeding in past decades (Robb et al. 2008) and a growing interest in this species by citizen science monitoring projects (e.g., Journey North, hummingbirds.net), both of which, could increase the likelihood that a hummingbird would be detected upon arrival (Tryjanowski et al. 2005). A similar increase in monitoring interest among Purple Martin enthusiasts (e.g., members of Purple Martin Conservation Association) may also explain the 2.3% decline in weekend bias observed over time in this species (Table 3.1). Baltimore Orioles and Chimney Swifts showed only a small degree of weekend bias in our historic time period and no bias in our recent time period (Table 3.1), perhaps because both are highly detectable. For example, Chimney Swifts fly in flocks, give notable trill calls, and occur in urban areas near people (Cink and Collins 2002); similarly, Baltimore Orioles have a unique song and are easily recognized by their bright plumage (Rising and Flood 1998).

When comparing mean first arrival dates from weekends and weekdays, we found that mean arrival dates tended to be later on weekends for four of five species (Table 3.2).
This result supports our hypothesis that weekend bias could influence the accuracy of first arrival dates reported in many phenology studies; we also interpret this to mean that weekday arrival reports more closely approximate true first arrival dates. While we find it somewhat unlikely that a bias as small as a fraction of a day would change conclusions made in most phenology studies, including a “weekend/weekday” term as a covariate in models that assess phenology, would be a simple way to account for potential weekend bias among species, make conclusions more robust, and may reduce barriers to incorporating citizen science data into research. To our knowledge, this is the first time the effects of weekend bias have been quantified in a study of phenology. Conversely, this method may also be used to identify and account for potential weekday bias in phenology studies conducted by professional ecologists who may be more likely to sample during the week.
### Tables

Table 3.1. Percentage of first arrival observations reported on weekends for five species and changes in weekend bias between time periods, assessed using contingency analysis and Pearson chi-squared tests.

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</tbody>
</table>

*a* Percentage of first arrivals reported on Saturday or Sunday

*b* A difference exists between the percentage of weekend observations reported and those expected to occur at random (i.e., 28.6%)

*c* Difference in percentage weekend observations reported between 1880-1969 and 1997-2010 time periods
Table 3.2. Differences in mean first arrival dates of five species calculated using weekend and weekday arrival dates. Latitude, longitude, altitude, and time period variables included as covariates in each model along with possible two-way interaction terms. Least square means compared using one-tailed t-tests.

<table>
<thead>
<tr>
<th>Species</th>
<th>Weekend arrivals&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Weekday arrivals&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Days Diff.&lt;sup&gt;d&lt;/sup&gt;</th>
<th>SE Diff.</th>
<th>t-value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Arrival DoY&lt;sup&gt;e&lt;/sup&gt;</td>
<td>SE</td>
<td>N</td>
<td>Arrival DoY</td>
<td>SE</td>
</tr>
<tr>
<td>Baltimore Oriole</td>
<td>2223</td>
<td>1238</td>
<td>0.15</td>
<td>5015</td>
<td>.23.4</td>
<td>0.11</td>
</tr>
<tr>
<td>Barn Swallow</td>
<td>1352</td>
<td>1075</td>
<td>0.34</td>
<td>2031</td>
<td>0.69</td>
<td>0.29</td>
</tr>
<tr>
<td>Chimney Swift</td>
<td>2557</td>
<td>1160</td>
<td>0.20</td>
<td>5624</td>
<td>16.0</td>
<td>0.16</td>
</tr>
<tr>
<td>Purple Martin</td>
<td>6929</td>
<td>83.1</td>
<td>0.16</td>
<td>14944</td>
<td>82.8</td>
<td>0.13</td>
</tr>
<tr>
<td>R.-t. Hummingbird</td>
<td>1535</td>
<td>1188</td>
<td>0.09</td>
<td>31517</td>
<td>18.6</td>
<td>0.08</td>
</tr>
</tbody>
</table>

<sup>a</sup> First arrivals reported on Saturday or Sunday

<sup>b</sup> First arrivals reported on Monday, Tuesday, Wednesday, Thursday, or Friday

<sup>e</sup> Mean arrival 'day of year' accounting for leap years; for example, '100' correlates to April 10

<sup>d</sup> Difference in mean first arrival date when comparing weekend and weekday first arrival reports
Figure 3.1. Percentage of first arrivals reported on each day of the week in the United States compared with European records reported by Sparks et al. (2008). All species and time periods are included. Horizontal reference line indicates percentage of observations expected at random (i.e., 14.3%).
Figure 3.2. Percentage of observations reported on each day of the week during our historical (black) and recent (gray) time periods in North America for all species. Note the decrease in percentage of Sunday observations between time periods. Horizontal reference line indicates percentage of observations expected at random (i.e., 14.3%).
Acknowledgments

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References


CHAPTER FOUR

OPTIMIZING AVIAN CONSERVATION AND FUNCTION IN AGROECOSYSTEMS
USING GROWING DEGREE-DAYS

Abstract

In temperate regions, birds typically nest when the onset of spring brings accumulation of sufficient heat and associated food resources. Growing degree-days (GDDs) provide a measure of accumulated heat and are used in agriculture to predict insect emergence and plant growth. Birds that depend on insects as food sources or that feed insects to their young, rely on sufficient heat accumulation to initiate insect emergence. Thus, GDDs might also provide an approach to predict nesting times of birds and a spatially-explicit yardstick to compare potential impacts of climate shifts on bird nest initiation in relation to food resources over a wide geographic extent. Using first egg dates from Project NestWatch (N = 34,341), we examine how growing degree-days can be used to predict nesting dates for four common bird species in the eastern United States (Eastern Bluebird Sialia sialis, House Sparrow Passer domesticus, House Wren Troglodytes aedon, and Tree Swallow Tachycineta bicolor). We compare six methods of degree-day calculation that include base temperatures of 41°F (5°C) or 50°F (10°C) and, as starting dates for degree-day accumulation, either a traditional January 1 or March 1 starting date or a novel spatially-explicit start-of-season date calculated from satellite-based MODIS “green-up” data. Degree-days calculated using a base temperature of 41°F showed the least variability for predicting avian nesting dates and using spatially-explicit start-of-season dates identified from MODIS reduced variability explained by latitude in
all species. Birds consistently nested at higher degree-day accumulations at lower latitudes in our study region. Using MODIS-based green-up dates and including latitude terms in degree-day models could reduce barriers to implementing common degree-day prediction methods across wide geographical areas. Our results provide a mechanism for improved communication between researchers and farmers regarding bird conservation and biological pest suppression on farms. Understanding how degree-days influence life cycle events in diverse taxa, such as birds and their associated food resources, and communicating this information to practitioners through emerging web-based mediums, could provide value to conservation-minded farmers and ecologists seeking to understand trophic links and ecosystem services in agroecosystems.

Introduction

Bird conservation and agriculture

A major global issue is producing food and fiber for growing human needs while conserving species that contribute important ecosystem services such as pollination, pest suppression, nutrient cycling, and watershed protection (Matson et al. 1997, Foley 2005, MEA 2005). The importance of birds and the services they provide are being recognized by conservationists, farmers, and the general public (Sekercioglu 2006, Whelen et al. 2008, Wilson et al. 2010). Birds function as important insect predators (Mols and Visser 2002), pollinators (Clout and Hay 1989), scavengers (Sekercioglu et al. 2004), seed dispersers (Levey et al. 2005), seed predators (Holmes and Froud-Williams 2005), and ecosystem engineers (Valdivia-Hoeflich et al. 2005). In addition, bird-watching
contributes substantially to cultural function, by providing recrecational opportunity, generating substantial annual economic output (>US $80 billion annually), and supporting over 800,000 jobs (Sekercioglu 2002).

At the same time, agricultural practices are negatively affecting bird populations by reducing habitat and food availability (Chamberlain et al. 2000). Newton (2004) identified weed-control and herbicide use, the change from spring-sown to autumn-sown cereal varieties (and the associated earlier plowing regimes), land drainage, and intensification of grassland management as practices that cause significant declines in bird populations. Oftentimes the nesting (Bas et al. 2009) and feeding strategies (Gregory et al. 2004, Reif et al. 2008) of birds influence their vulnerability to agricultural intensification, with ground-nesting birds and diet specialists at higher risks. While direct negative impacts of pesticides on birds are less apparent than during the 1950s and 1960s (Newton 1995), pesticide use near nesting areas contributed to brood reduction in European farmland birds by means of decreased food abundance (Boatman et al. 2004). In the United States, pesticide use contributes to avian mortality, most commonly in corn and cotton crops, although formulations are less hazardous than those used in past decades (Mineau and Whiteside 2006).

Large-scale changes in agricultural policy have helped curb avian population declines in the United States (Herkert 2009) and Europe (Kleijn and Sutherland 2003, Wretenberg et al. 2007), whereas a market-based strategy of developing “bird-friendly” coffee has reduced the negative impact of farming on birds in Latin America (Philpott and Dietsch 2003, Perfecto et al. 2005). At a local scale, efforts to promote bird
conservation can be well-received by farmers if economic incentives are provided (Philpott et al. 2007) and farmers provide input on how programs are developed and implemented (Lentijo et al. 2008). In many cases, farmers’ attitudes vary based on farm type (organic vs. conventional), previous experiences, and other economic factors (Jacobson et al. 2003). In surveys conducted by Jacobson et al. (2003), 95% of Florida farmers reported they were able to recognize most of the birds on their farms, but were rarely provided with specific recommendations on how to manage their land to enhance avian biodiversity and biological pest control in ways compatible with other farm goals (Herzon and Mikk 2007). Decision tools are needed to facilitate mutual benefits between farming and birds, especially during critical life cycle stages of birds such as nesting and fledging. It is important that these tools are conveyed in ways that are readily understood and easily accessed by both farmers and conservationists.

*Growing degree-days (GDDs)*

‘Growing degree-days’ is a temperature-based concept familiar to most farmers because it provides a measure of seasonal progress and a guide for timing farm management activities. It is based on the principle that physiological processes in many organisms, such as plants and pokilothermic invertebrates (e.g., insects), are temperature-dependent (Trudgill et al. 2005). One advantage of using GDDs is that they are collective measures of heat, independent of calendar date. Because of the correlation between accumulated heat and developmental rate, farmers use GDDs to predict insect emergence (Herms 2002, Naves and de Sousa 2009) and to identify stages of plant development (e.g., maturity and harvesting dates of crops; Russelle et al. 1984, Slafer and Rawson
GDDs accumulate one day for each degree the average daily temperature exceeds a pre-defined base temperature. Base temperatures have been identified physiologically and statistically for numerous plant and insect species (Bonhomme 2000, Ruml et al. 2010); in agricultural systems, base temperatures of 41°F and 50°F (5°C and 10°C, respectively) are commonly used (Russelle et al. 1984, Herms 2002, Mix et al. 2009). Degree-days can be calculated using the following basic equation, although various modifications have been developed to improve results (Herms 2002):

\[
\text{Degree-days} = \left[ \frac{(\text{maximum daily temperature} + \text{minimum daily temp})}{2} \right] - \text{base temp}
\]

When calculating degree-days it is also important to define a biologically meaningful starting date from which degree-day accumulation begins (Snyder et al. 1999, Trudgill et al. 2005). In agricultural systems, this often coincides with the start of the growing season and approximates when heat begins to contribute to metabolic function in plants and insects (Feng and Hu 2004). Traditionally, starting dates for GDD accumulation have been broadly defined as January 1 or March 1, but are somewhat imprecise (Naves and Sousa 2009) and may vary by latitude (Honek 1996). Some studies have defined a starting date as the date that shows the least amount of variability when degree-days are calculated for a particular life cycle stage of a plant or insect over multiple years in a particular region (Naves and Sousa 2009). Feng and Hu (2004) attempted to improve this definition by using a moving start of season date, defined as the appearance of five consecutive days with an average daily temperature higher than 5°C.
Recently, remotely sensed Normalized Difference Vegetation Index (NDVI) data and Moderate-resolution Imaging Spectroradiometer (MODIS) data have emerged and can pinpoint green-up and start-of-season dates at broad spatial extents with similar accuracy to site-based observations (Zhang et al. 2004, Studer et al. 2007, Chang et al. 2011). To our knowledge, however, no one has investigated whether using spatially-explicit start-of-season dates based on vegetation green-up might reduce variability in degree-day calculations.

_Growing degree-day applications_

Many university extension programs (e.g., Cornell University, University of Illinois, Michigan State University, University of California-Davis) maintain websites that assist farmers in fine-tuning the timing of pest control efforts and harvesting. Stewart et al. (2002) compared an Integrated Pest Management (IPM) program that fine-tuned pest control efforts based on predictions made from GDD estimates to a traditional cover spray program and found the IPM program was cost effective in three out of ten trials and used less pesticide. Similarly, GDD was a more effective predictor of corn development (e.g., absolute growth rate, leaf area ratio, net assimilation ratio) than using traditional calendar date predictions (Russelle et al. 1984). Other studies have correlated growing degree-days to plant distributions (Rannie 1986), plant niche properties (Thuiller et al. 2005), range management (Frank and Hofmann 1989), fish development (Neuheimer and Taggart 2007), building material design and energy use (Eto 1988), and rate of parasite transmission in humans (Yang et al. 2006) and plants (Eizenberg et al. 2004, Eizenberg et al. 2005).
Temperature and avian lifecycles

An increasing number of studies are demonstrating relationships between avian lifecycle events and temperature (Crick and Sparks 1999, Winkler et al. 2002, Matthysen et al. 2011). Moller et al. (2008) reported that European migratory bird species that were unable to adjust their spring migrations to use peak food resources, significantly declined during the period 1990-2000. Because food resources and birds may be responding differently to climate warming, there is a need for a ‘yardstick’ or measure to quantify responses across trophic levels and demonstrate whether the degree of shift among trophic levels is similar (Visser and Both 2005), a need that GDDs might fulfill.

Although measures of temperature are certainly more direct predictors of life cycle stages in ectotherms (i.e., insects and plants), the onset of annual events in endotherms, and particularly birds, is closely related to the ecology of insects and plants that serve as their primary food sources (Visser and Both 2005, Dunn et al. 2011). Cues to initiate migration are thought to be primarily under endogenous control and influenced by photoperiod (Berthold 1996), but many reproductive events (e.g., nesting, egg-laying, fledging) are triggered by fine-tuned reproductive cues in breeding areas, such as temperature, rainfall, or snowpack (Jensen 2004). These fluctuations in weather, at a local scale, influence food availability (Visser et al. 2006, Dunn et al. 2011) and regulate life cycle events (Carey 2009). In a review of previous studies, Dunn (2004) showed that 79% (45/57) of temperate birds in North America showed a negative relationship between the date of egg laying and air temperature, with most birds laying eggs earlier in warmer springs. In the UK, the date of egg-laying was related to temperature or rainfall
in 86% (31 of 36) of studies (Crick and Sparks 1999). Although the natural history of a species may dictate the degree to which temperature regulates life cycle events (e.g., aerial insectivores that rely exclusively on flying insects vs. predatory raptors that eat small mammals; Dunn 2004), most birds rely on temperature cues to time reproduction to some extent (Carey 2009). Doing so allows birds to raise young during periods of maximal food abundance and is critical to successfully fledging offspring (Both et al. 2006a, Bourgault et al. 2010).

*Growing degree-days and bird conservation*

Considering the attention given to the influence of temperature on birds and an increased awareness of growing degree-days, surprisingly few studies have integrated these concepts. Beale et al. (2008) and Araujo et al. (2009) used GDDs as predictors of bird distributions in Europe, but to our knowledge, no one has used growing-degree days to predict events in avian lifecycles. Combining these concepts and presenting them in a management context could help promote bird conservation on farms and assess whether an uncoupling between birds and their food (insects to feed young) is occurring over time. As such, GDD would serve as a ‘yardstick’ to assess responses to temperature change across predator-prey food webs (Visser and Both 2005) and to track the ability of birds to provide biological pest suppression on farms.

The objectives of our study are to: (1) Assess how GDDs can be used to predict nesting dates for common birds in the eastern United States, (2) Compare common calculation methods for GDDs and determine whether using spatially-explicit starting dates improves nesting date predictions, and (3) Describe how GDDs can be used to
benefit avian conservation in agricultural systems and to track temperature response across trophic levels.

Methods

Study area and focal species

We analyzed first egg dates (N = 34,341) of common bird species reported in the eastern United States (35.48°N, 68.95°W; Fig. 4.1) by citizen volunteers through Cornell University’s Project NestWatch (www.nestwatch.org). We used data from 2001-2010, although records date back to 1997, because sample sizes and observer effort were most consistent during these years. Focal species were selected based on high data availability, the likelihood that birds would be found on farms, and the tendency for species to feed their nestlings insects during the breeding season (Gowaty and Plissner 1998, Johnson 1998, Lowther and Cink 2006, Winkler et al. 2011). They included Eastern Bluebird Sialia sialis (N = 16,382), House Sparrow Passer domesticus (N = 2,081), House Wren Troglodytes aedon (N = 4,592), and Tree Swallow Tachycineta bicolor (N = 11,286). Eastern Bluebirds, House Sparrows, and House Wrens forage primarily on the ground and in the subcanopy (Gowaty and Plissner 1998, Johnson 1998, Lowther and Cink 2006), whereas Tree Swallows capture aerial insects on the wing over open areas of ground and water (Winkler et al. 2011).

For single-brooded species (i.e., Tree Swallow; Dunn and Winkler 1999, Winkler et al. 2011), we fit a model using first egg date as the response variable and latitude, longitude, altitude, and year, along with possible interaction terms as predictor variables;
we then exported residuals and removed outliers at 3 standard deviations to account for nesting dates that may have been incorrectly reported by citizen volunteers. House Sparrow data also exhibited a uni-modal distribution, therefore we analyzed them as we did for Tree Swallow (although nesting dates were somewhat erratic and multiple broods are known to occur in some places; Lowther and Cink 2006). Nesting dates of Eastern Bluebird and House Wren, both multi-brooded species, exhibited predictable bi-modal distributions; therefore we used multivariate cluster analysis to divide residuals of mean nesting dates into two groups that approximated first and second brood attempts, excluded second attempts for each species, and removed outliers at 3 standard deviations (JMP 9; SAS Institute 2010).

We used ArcGIS 10 (ESRI 2011) to display first egg dates by species, year, and climate division, a designation of the United States National Climate Data Center (http://www.ncdc.noaa.gov) that groups areas of similar elevation, temperature, and precipitation. To account for multiple nesting reports within the same area and year and to decrease the variability associated single observations, we calculated a mean nesting date for every climate division that had ≥ 5 nesting dates reported for a given year and species. This resulted in 951 unique year, species, and climate division combinations from 2001-2010. Mean nesting dates were rounded to the nearest ‘day of year’ (e.g., ‘99.8’ was rounded to ‘100,’ which corresponds to ‘April 10’).

*Weather variables and growing degree-day calculations*

We identified the centroid of each climate division (Fig. 4.2), and a weather station from the National Climate Data Center (http://www.ncdc.noaa.gov/) nearest each
centroid (Yang et al. 2006), that consistently reported daily maximum and minimum temperatures during our study period (ArcGIS 10; ESRI 2011). Based on the weather stations we identified, we calculated the number of GDDs (Baskerville-Emin sine-wave method; Baskerville and Emin 1969, Roltsch et al. 1999, Naves and Sousa 2009) that accumulated in each climate division at the time of nesting using the Climate Information for Management and Operational Decisions (CLIMOD) interface from the High Plains Regional Climate Center (http://climod.unl.edu/). We used four standard combinations of degree-day parameters (Russelle et al. 1984, Herms 2002, Mix et al. 2009, Jarosik et al. 2011) which included using January 1 and March 1 starting dates, and base temperatures of 41°F (5°C) and 50°F (10°C). We also used a novel approach to calculate GDDs, again using base temperatures of 41°F and 50°F, but using spatially-explicit start-of-season (SOS) dates as starting dates for GDD accumulations. The SOS or “green-up” date represents the first inflection point in the spring when index values begin to rise. Mean SOS dates were calculated for each climate division and year combination, by averaging individual MODIS-based Normalized Difference Vegetation Index (NDVI) SOS values collected at a 250-m resolution. MODIS-based SOS values were available from 2001-2009 and provided by the USGS EROS Center (http://phenology.cr.usgs.gov/).

**Statistical analyses**

To first understand data spatially, we generated smoothed raster maps to display mean spring growing degree-day accumulations from 2001-2010 in our study area and mean first egg dates by species. We used inverse distance weighting (IDW), a procedure that assigns raster cells values based on known point values of surrounding cells (in our

70
case, mean degree-day accumulations and mean nesting dates by climate division) with a fixed 12-cell search radius (ArcGIS 10; ESRI 2011). We included only locations that had mean nesting dates for ≥3 years to make nesting maps. We generated box plots to examine yearly variation in nesting dates and degree-days accumulated at the time of nesting, by species, and linear regression to examine how degree-days associated with first egg dates accumulated across latitudes. Because of the high degree of variation noted by latitude, we generated a regression model for each calculation method to assess the effects of time and space on degree-day accumulation at the time of nesting. We initially included latitude, longitude, altitude, and year, along with possible interaction terms in our models, but found that only latitude and year consistently explained notable variation; so we reran models using only these two terms and noted the variation explained by each. We generated a coefficient of variation (CV) for each degree-day calculation method using the following equation:

\[
\text{Coefficient of Variation} = \frac{\text{Standard Deviation in Degree-day Accumulation at Time of Nesting}}{\text{Mean Degree-day Accumulation at Time of Nesting}} \times 100
\]

Coefficients of variation account for differences in magnitude among degree-day calculation methods and lower CV values indicate less variability associated with a calculation method (Yang et al. 1995, Ruml et al. 2010).

We grouped observations into 2° latitudinal bands (e.g., all Eastern Bluebird observations between 35-36.99°N were grouped in the '35-36°N' band) and generated
region-specific estimates for degree-days associated with mean nesting dates. All statistical analyses were conducted using JMP 9 (SAS Institute 2010). We present results in Fahrenheit degree-days because it is the commonly used notation of our target audience (i.e., integrated pest management agencies in the United States). Conversion between Fahrenheit and Celsius degree-days is: Degree-day Celsius = 5/9 Degree-day Fahrenheit (http://www.ipm.ucdavis.edu/WEATHER/ddconcepts.html).

Results

Degree-days accumulated earlier in the year in the southern portion of our study region as predicted by latitude (Fig. 4.3). Birds also nested earlier in southern latitudes, but nesting day-of-year varied among regions (Fig. 4.4) and species (4.5). On average, Eastern Bluebird nested earliest (day-of-year = 108), followed by Tree Swallow (138), House Wren (142), and House Sparrow (143; Fig. 4.5).

Consistent differences in how degree-days accumulated at the time of nesting were noted among calculation methods for all species (Table 4.1). Using higher base temperatures and later starting dates (i.e., either March 1 or remotely sensed start-of-season dates) generally resulted in fewer degree-days accumulated at the time of nesting and lower standard deviation values, although coefficients of variation (i.e., magnitudes of differences relative to degree-day means) were generally higher (Fig. 4.6). For all species, lower CVs (i.e., better predictions) were generated when using 41°F as a base temperature (Table 4.1). In addition, for House Wren and Tree Swallow, CVs were
minimized when using 41°F as a base temperature in conjunction with a MODIS-based starting date for degree-day accumulation.

Methods differed in degree of variation explained by latitude and year (Table 4.1), with the smallest amount of variability in latitude noted for Eastern Bluebird and the smallest of variability in year noted for House Sparrow (Table 4.1). In general, using start-of-season dates generated from remotely sensed MODIS data reduced percent of variation explained by latitude (Table 4.1), although overall variability associated with MODIS-based methods was still high. The majority of variability in all models was residual variation (range 64-87.7%; Table 4.1).

Birds nested at fewer degree-days in northern latitudes (Fig. 4.2); however this trend was less apparent when using MODIS-based ‘green-up’ to identify starting dates for degree-day accumulations (Fig. 4.6). Temporal trends in degree-day accumulation at time of nesting (P < 0.05) were noted only in House Wren, with birds nesting at fewer degree-days from 2001-2009 (Fig. 4.7).

Discussion

*Avian nesting dates and degree-day methods compared*

Our results demonstrate the potential of using degree-days days to predict lifecycle events in birds and better understand trophic links in agroecosystems. First egg dates that we report for Eastern Bluebird, Tree Swallow, and House Wren (Figure 4.5) are within common range estimates for the northeastern United States (Gowaty and Plissner 1998, Johnson 1998, Winkler et al. 2011). Nesting dates for House Sparrow,
however, are later than normal estimates for our study region (March-April; Lowther and Cink 2006) and may reflect the somewhat erratic nesting habits of this species and the associated difficulty of identifying first broods. Variability associated with degree-day accumulation at the time of nesting was lowest for House Wren and Tree Swallow (Table 4.1), perhaps because they feed almost exclusively on insects (Johnson 1998, Winkler et al. 2011) and their diets are less variable than diets of Eastern Bluebird and House Sparrow (Lowther and Cink 2006, Winkler et al. 2011).

**Degree-day methods compared**

Using a base temperature of 41°F reduced variability in all calculation methods (Table 4.1). Although birds are endothermic, lower base temperatures (i.e., 41°F instead of 50°F) may better approximate those of available food resources at the time of nesting (i.e., insects) and more closely approximate the temperature cues that birds rely on for migration and nest building (Crick 2004, Carey 2009). Base temperatures near 41°F are commonly used in agroecosystems to track the development of insect pests such as Cabbage maggot (*Delia radicum*), Strawberry root weevil (*Otiorhynchus ovatus*), and Stalk borer (*Papaphena nebris*) (Levine 1983, Umble and Fisher 2000, Murray 2008). Using MODIS-generated start-of-season dates, in conjunction with 41°F base temperatures, reduced variability associated with degree-day accumulation in House Wren and Tree Swallow, but not Eastern Bluebird (Table 4.1). On average, Eastern Bluebird nested approximately one month earlier than House Wren and Tree Swallow in our study, and sometimes even before green-up, perhaps illustrating the difficulty of using MODIS-based methods to predict reproductive events in early-nesting species.
Using GDDs at broad spatial scales

Nesting generally occurred at higher degree-day accumulations in the southern latitudes of our study region, which demonstrates the challenge of implementing GDD-based predictions across an even relatively narrow latitudinal gradient (i.e., temperate North America; 35-48°N, 68-95°W). Honek (1996) reviewed the thermal constraints of 355 insect species and found considerable latitudinal variation in lower development thresholds (i.e., base temperatures) and effective temperatures of insects, with species in temperate regions (i.e., 40-60°N or S) initiating development at significantly lower base temperatures than those in tropical regions (i.e., 0-23°N or S). Similarly, Qi et al. (1999) adjusted base temperatures from 1° to 9° C to account for differences in effective temperature requirements in temperate vs. tropical legumes. Likewise, our work suggests that optimal base temperatures and starting dates for degree-day accumulation in birds may also vary spatially (Fig. 4.2), and may indicate a degree of phenotypic plasticity in our focal species; such that, even intraspecifically, birds may be adapted to unique thermal environments (Trudgill et al. 2005).

MODIS-based GDD methods reduced variability associated with latitude compared to traditional GDD methods (Fig. 4.1), but did not eliminate latitudinal variability altogether (Fig. 4.6). Using a MODIS-based green-up date and including a latitude term in degree-day models may reduce barriers to implementing a common degree-day prediction method over a wide geographical area.

Residual variability in degree-day estimates
Several possible explanations exist for the high degree of residual variability in our degree-day models (Table 4.1). Because focal species in our study likely fed opportunistically on a variety of available arthropods (Gowaty and Plissner 1998, Johnson 1998, Winkler et al. 2011), selecting a biologically meaningful base temperature was more difficult than in a controlled laboratory or greenhouse setting (Naves and Sousa 2009, Rum et al. 2010). In addition, birds are endothermic, and although strong relationships between nesting dates and local temperatures are well-documented (Dunn and Winkler 1999, Dunn 2004), other mechanisms such as rainfall (Styrske and Brawn et al. 2011, Robinson et al. 2012), conditions along migratory routes (Both et al. 2006b, Wiebe and Gerstmar 2010), and sexual selection (Reudink et al. 2008) also influence nesting decisions. Temperatures used to calculate growing degree-days were provided by the weather station nearest the centroid of each climate division and may have provided an imprecise approximation of the microclimate in which birds actually nested and foraged (Wang 1960, Bonhomme 2000). Our results also rely heavily on the assumption that only first broods were included in our analysis. Although careful measures were taken to remove outliers and to summarize nesting attempts by region, a small number of renesting or second brood attempts were almost certainly missed which could have led to overestimations in degree-days accumulated at the time of nesting. It is also possible that the mean start-of-season dates we used in our MODIS-based models did not represent the true start-of-season date at each nest site. Assigning a spatially-explicit start-of-season date for each nesting observation, as opposed to a mean value calculated for an entire climate division, may help reduce variability in future models. Improved MODIS-based
models may be useful in studies attempting to implement a consistent degree-day method across space, particularly in regions where calendar-based measurements do not account for the high degree of variability in warming and chilling hours during winter months (Zhang et al. 2004).

Understanding variability associated with nesting dates may provide a better understanding of how temperature affects species with different feeding ecologies (e.g., insectivores vs. omnivores), and help predict how species might respond to climate change (Thuiller et al. 2005). High variability in degree-day accumulations at the time of nesting may suggest that species are generalists and more adaptable to climate change (Diamond et al. 2011), whereas low variability may indicate that species are more at-risk from climate change and more likely to signal the impacts of climate change (Wilson 2009).

*Bird conservation and biological pest suppression*

Our results provide a mechanism for improved communication between researchers and farmers regarding bird conservation and biological pest suppression. Specific decision tools and management recommendations to enhance avian diversity on farms could be provided based on degree-days; for example, to reduce pesticide application to 20 m of the functional edge (Puckett et al. 2009) between 150-300 GDD when Eastern Bluebirds are nesting. While it is unlikely that most farmers would shift management regimes solely to promote bird conservation, most farmers indicate interest in bird conservation when reasonably compatible with farm operations (Jacobson et al. 2003). In addition, crops produced on farms with “bird-friendly” management may also
gain a marketing advantage in direct value-added sales, as now done with bird-friendly coffee (Bagdley 2003, Perfecto et al. 2005). Tradeoffs could also exist where an increase in avian diversity could enhance biological pest suppression (Sekercioglu et al. 2004). Many USDA Cooperative Extension and other outreach programs provide a range of degree-day values that correspond to critical life cycle stages in insect pests; for example the Michigan State Integrated Pest Management Program reports that Gypsy Moth (Lymantria dispar) larvae begin actively feeding between 145-200 growing degree-days (January 1, Base 50°F), and that Japanese Beetle (Popillia japonica) emerges and begins feeding at 950 degree-days (http://www.ipm.msu.edu/landscapeipm/gddlandchart.htm).

Using degree-days to identify overlaps in critical lifecycle stages of insect pests and periods of high insect consumption by birds may help land managers and farmers identify, and manage for, bird species that most closely align with pest control objectives (Jones and Sieving 2006).

Comparing temperature responses across trophic levels

In a broader sense, GDDs could provide a unique ‘yardstick’ (Visser and Both 2005) to assess the effects of temperature across trophic levels and the impact of climate change on farms and food webs. If birds and insects or plants respond differently to GDD, a trophic uncoupling could be occurring (Parmesan and Yohe 2003, Visser et al. 2004, Both et al. 2009) whereby important pest control and pollination functions of birds might be inhibited (Cannon 1998, Sekercioglu et al. 2004) and populations of birds might be at risk for decline (Both et al. 2006a). We report a negative trend in degree-day accumulation at the time of nesting for House Wren from 2001-2009 (Fig. 4.7); although
no temporal trends were noted in our remaining focal species, our results provide a baseline to compare with future studies.

**Conclusion**

We lay a foundation for broadening the scope of degree-day based conservation efforts in North America by demonstrating how degree-days can be used to predict avian nesting dates and how spatial variability in degree-day models can be reduced using MODIS data. Recently, the Integrated Plant Protection Center at Oregon State and collaborators released a web-based interface to calculate degree-days at a national scale using near real-time weather station data (http://uspest.org/) and many other universities are improving interactive degree-day calculators that farmers rely upon to fine-tune pest control efforts. At the same time, the impacts of agriculture intensification and climate change are threatening biodiversity worldwide. Understanding how degree-days influence life cycle events in diverse taxa, such as birds, and communicating this information to practitioners through emerging web-based mediums, will provide value to conservation-minded farmers and ecologists seeking to understand trophic links and ecosystem services in agroecosystems.
Tables

Table 4.1. Mean degree-day accumulations at the time of nesting for four focal species from 2001-2009. Six degree-day calculation methods compared using different combinations of starting dates and base temperatures. Methods ordered by increasing coefficients of variation. Variance partitioned by latitude and year to illustrate variability associated with each (JMP 9: SAS Institute 2010).

<table>
<thead>
<tr>
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<th>CV³</th>
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<th>Year⁴</th>
<th>Residual %⁴</th>
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<td>Jan_41</td>
<td>277</td>
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¹ Mean degree-days accumulated at time of nesting
² Standard deviation of all degree-day values based on model (y = GDD method + error)
³ Coefficient of variation calculated as (SD / Mean) * 100
⁴ Percent variation explained in model (y = GDD method + latitude + year + error) by given variable
Table 4.2. Mean degree-days at time of nesting and standard deviations for four species using common degree-day calculation methods and base temperatures of 41°F and 50°F. Nesting dates (2001-2010) grouped by 2° latitudinal band and species (e.g., Eastern Bluebird observations between 35-36.99°N grouped as ‘35°N’). Only bands with ≥5 mean nesting observations included.

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<th>GDD (Mar 41) SD³</th>
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</table>

¹ Latitudinal band based on the centroid of the climate division where observations were reported
² Number of climate divisions used to calculate mean nesting date and degree-days (see Fig. 4.2)
³ Standard deviation of degree-day values based on model (y = GDD method + error)
Figure 4.1. Locations of first egg dates reported for four focal species by citizen volunteers through Cornell University’s Project NestWatch (2001-2010).
Figure 4.2. Climate divisions used to group nesting dates. A mean nesting date was calculated for any climate division that had ≥5 observations per species per year and was assigned the latitude and longitude of the climate division's centroid. Degree-day values were calculated using data from a weather station from the National Climate Data Center (http://www.ncdc.noaa.gov) nearest the centroid of each climate division.
Figure continued on following page. Caption on page 85.
Figure 4.3. Mean degree-day accumulation in our study region from 2001-2010 through March, April, May, and June, using a starting date of January 1 and a base temperature of 50°F (10°C). Total degree-day accumulation for each month calculated using CLIMOD (http://climod.unl.edu/) and based on data from the weather station nearest the centroid of each climate division (Fig. 4.2). Figure generated using inverse-distance weighted interpolation (ArcGIS 10; ESRI 2011).
Figure 4.4. Mean first egg dates for four focal species during 2001-2010. Figure generated using inverse-distance weighted interpolation (ArcGIS 10; ESRI 2011) and based on mean nesting dates, by species, within climate division (Fig. 4.2). Mean nesting dates from climate divisions with ≥3 years of data for each species are included in analysis.
Figure 4.5. Box plots of mean first egg dates for four focal species in our study region during 2001-2010. Nesting dates expressed as ‘day of year’ and corrected for leap years; for example, ‘100’ refers to April 10.
Eastern Bluebird

Growing degree-days at Nesting

Figure continued on following page. Caption on page 91.
House Sparrow

Growing degree-days at Nesting

Figure continued on following page. Caption on page 91.
House Wren

Growing degree-days at Nesting

Figure continued on following page. Caption on page 91.
Figure 4.6. Degree-days accumulated at the time of nesting by latitude for four focal species using six different calculation methods and base temperatures of 41°F and 50°F (5 and 10°C). Fahrenheit degree-days presented (degree-day Celsius = 5/9 degree-day Fahrenheit).
Figure 4.7. Box plots demonstrating yearly variation in degree-day accumulation at time of nesting for four focal species from 2001-2009 using six degree-day calculation methods. Negative temporal trend in degree-days accumulated at time of nesting ($P < 0.05$) in House Wren indicated with an asterisk.
Acknowledgments

We thank countless volunteers who collected and reported nesting observations through Cornell’s Project NestWatch from 2001-2010 and J. Martin and the Cornell Lab of Ornithology for providing nesting data. We thank C. Cooper, J. Dickinson, J. Lowe, and B. Zuckerberg for helpful suggestions for our degree-day analysis and W. Esaias and B. Tan from NASA for help using MODIS start-of-season data. We thank the High Plains Regional Climate Center for access to the Climod interface and Clemson University students E. Gettler, D. Stone, and C. Boamar for calculating degree-day accumulations from nesting data. We also thank E. Gettler, P. Leonard, and S. Essewein for help with ArcGIS and figure layouts. This study was funded primarily by Clemson University and a Carolina Bird Club grant, with additional support provided by the Clemson University Creative Inquiry Program.

References


CHAPTER FIVE

REVIVING A LEGACY CITIZEN SCIENCE PROJECT TO ILLUMINATE SHIFTS IN BIRD PHENOLOGY

Abstract

Climate change has been of high interest to both the scientific community and the public at large since the phenomenon was first suggested. Subsequently, and with growing evidence of its impending ramifications, numerous studies have attempted to illuminate climate change impacts on bird migration. Migration is a key event in the annual lifecycle of birds, and changes in migration in response to climate may indicate that species populations are at risk. Previous studies report earlier arrival dates in response to climate change in many bird species, although specific mechanisms are often difficult to explain at broad spatial and temporal scales. Using a newly revived dataset of historical migration cards for over 870 species and spanning 90 years throughout North America, we are developing an historical baseline of bird arrival dates to compare with contemporary records. Here we chronicle the history and re-emergence of the North American Bird Phenology Program. We present two case studies illustrating how data from this program have been used to model historical arrival dates of Ruby-throated Hummingbird (Archilochus colubris) and Purple Martin (Progne subis) throughout eastern North America. Our results show the importance of considering spatial and temporal variability in studies that assess changes in avian migration.
Introduction

Climate change is a leading threat to the survival of species and integrity of ecosystems (Parmesan and Yohe 2003, Hulme 2005); and in response to climate change, bird migration times are changing throughout much of the world (Lehikoinen et al. 2004). Shifting spring arrivals have been documented in North America, Eurasia and Australia for a broad range of species and locations (IPCC 2007). Not only are birds arriving earlier to their spring breeding grounds, they are also departing later in the autumn (Jenni and Kery 2003, Smith and Paton 2011). Migratory changes have been correlated to changing temperatures in wintering grounds, breeding grounds, and along migration routes; and to a variety of other variables such as rainfall, humidity, and wind speed (Lehikoinen et al. 2004). Migration must align with favorable environmental conditions to reduce stress incurred through mistiming arrivals with maximal food abundance and vegetation growth (Root et al. 2003, Møller et al. 2008, Pau et al. 2011). Phenology studies, those that track the timing of annual lifecycle events, are often used to assess biological changes in species in response to climate change (IPCC 2007). Because phenological sequences in birds (e.g., migratory arrivals and departures) are often influenced by environmental cues, studies of bird phenology are often used to assess the possible impact of climate change (Møller et al. 2008).

Relationships between climate variables and migration times remain difficult to assess at broad scales, however, because many phenological records are from small geographic areas, recent time periods, and contain only small subsets of species. In this paper we introduce or, to a few, reintroduce, the North American Bird Phenology
Program (BPP), a citizen science program unsurpassed in geographic, taxonomic, and chronological extent. The BPP houses the most comprehensive legacy dataset in the world for bird migration. This data set contains several million historical arrival and departure records for migratory birds, collected between 1881 and 1970 by leading naturalists and the general public. Although first envisioned to study the distribution and migration of birds, it is now being adapted to investigate shifts in bird arrivals over time, a question with broad ecological implications. Here we chronicle the history and reemergence of the BPP and present two case studies to demonstrate the potential usefulness of this dataset.

**History of the BPP**

In 1881, Wells Woodbridge Cooke, a Mississippi teacher interested in the seasonal movements of birds, started a regional cooperative collection of migration records with acquaintances and colleagues throughout the Mississippi Valley (Palmer 1917). With the support of the American Ornithologists’ Union (AOU), Cooke expanded the cooperative which grew to >3,000 participants in the United States, Canada, and a portion of the West Indies, at the program’s height (Palmer 1917). Participants consisted of both prominent naturalists as well as citizens interested in contributing data to a scientific study. The program was placed under the jurisdiction of the newly formed United States Department of Agriculture (USDA) in the late 1880s, where participation peaked, before being passed onto the predecessors of the United States Fish and Wildlife Service (USFWS), and later to the United States Geological Survey (USGS). Cooke was
responsible for bringing the survey to the Washington D.C. area, where he worked as a naturalist for the USDA and used the records to better understand the geographical ranges and migratory patterns of avian species. After Cooke’s death in 1916, the program was guided by others who carefully tended and added to the records. Data collection protocols remained largely consistent throughout the program’s existence.

In sum, records were collected over a 90 year span for more than 870 species, and were used to develop the American Ornithologists’ Union’s Check-list of North American Birds and the first ornithological field guides (Allen 1910, Palmer 1917, Droege 2009). Participation in the BPP declined in the 1960s as private sector bird watching groups began actively maintaining bird distribution and migration records, and the program ended in 1970. The once formidable BPP was largely forgotten after years of little recognition and sat idle for more than 40 years.

In March of 2008, the program was revived in response to the growing realization that changes in avian migration could be used to assess the possible impacts of climate change. Funding was limited, however, and because the majority of records were handwritten in various formats, they could not simply be converted into digital form using optical character recognition. Records were therefore scanned as image files and displayed online through a data entry interface for transcription by the general public. After months of scanning records in-house, a public website was launched in February 2009. The program currently relies on a growing network of over 2,500 volunteers to complete a double-blind transcription of each record, which upon matching, is sent into a custom built database. More than one million records have been scanned, to date, and
500,000 cards transcribed online. Once validated, the records will be accessible online by biologists, managers, and members of the general public.

**Volunteer Recruitment, Training, and Data Management**

Volunteers for the BPP program are recruited through media outreach, presentations at local and national ornithological meetings, and word-of-mouth. Volunteers of all ages are invited to become BPP transcribers, as long as they have Internet access and a web browser (www.pwrc.usgs.gov/bpp/). After registering with the program, each volunteer must watch a 15-minute training video that explains how to transcribe different versions of migration cards. Then, using a web-based application, the volunteer selects observation records to transcribe at random, or for a desired state or species. Volunteers transcribe cards by filling in fields of an online form. Each card is entered by at least two independent volunteers for quality assurance. When two entries for the card match, data are sent into the BPP database. If two entries do not match, or if a transcriber marks the card as a “problem card,” the card is flagged and reviewed in the BPP office.

Volunteers can track their individual progress as well as the progress of the volunteer community through an expandable window on the transcription screen and charts on the main website. Volunteers are ranked based on the number of cards they submit and receive recognition through certificates, prizes, and mention in the BPP monthly newsletter.
Case Study 1: Modeling Ruby-throated Hummingbird Arrival Dates Across Eastern North America

Ruby-throated Hummingbirds (*Archilochus colubris*) are charismatic, neotropical migrants that have fascinated naturalists for centuries (Robinson et al. 1996). They are easily identified and the only regularly reported hummingbird in eastern North America, making them suitable targets for long-term monitoring programs. Hummingbirds winter in Central America between northern Panama and southern Mexico and most migrate across the Gulf of Mexico, arriving at their breeding grounds in North America between February-April (Robinson et al. 1996) where they help pollinate at least 31 plant species (Austin 1975). Recent studies indicate that hummingbirds are arriving earlier to their breeding grounds than in historical time periods in some places (e.g., Maine: Wilson 2000; Massachusetts: Butler 2003, Ledneva et al. 2004; South Dakota: Swanson and Palmer 2009; and New York: Butler 2003), but not others (Minnesota: Swanson and Palmer 2009). Proposed mechanisms for such changes include climate change, increasing hummingbird populations, and an increase in popularity of backyard bird-feeding. It remains difficult to explain possible mechanisms for changes, however, when examining migration at site- or region-specific scales.

Recent hummingbird migration patterns are becoming well-documented throughout North America, thanks to emerging networks of citizen science observers reporting first arrivals online through popular websites such as Journey North (http://www.learner.org/jnorth/), hummingbirds.net, and eBird (http://ebird.org/content/ebird/). At the same time, changes in climate (Karl and
Trenberth 2003, Loarie et al. 2009) and land-use (Foley et al. 2005, Ellis et al. 2010) have also been well-documented as mapping technology (e.g., United States Geological Survey Land Cover Institute http://landcover.usgs.gov/usgslandcover.php) and historical climate data have become widely accessible (e.g., The Nature Conservancy’s Climate Wizard http://www.climatewizard.org/). Both migration and environmental data are needed to understand how meteorological conditions and land-use influence bird migration at broad spatial scales, but to understand bird migration across both space and time, we need to better understand how bird migration occurred historically. Until recently, a continent-wide baseline to compare with recent arrivals has been largely unavailable.

The objective of this study is to demonstrate how data from the recently revitalized North American Bird Phenology Program (BPP) can be used to generate an historical understanding of migration in Ruby-throated Hummingbirds. This understanding could help prompt future studies that assess changes in bird migration at broad spatial and temporal scales in response to climate and land-use changes.

First arrival dates of Ruby-throated Hummingbirds in eastern North America (29–47°N, 67-95°W) were transcribed from arrival cards reported through the North American Bird Phenology Program. Each arrival location was then assigned a location (i.e., latitude, longitude, and altitude) based on the centroid of the reported arrival city using the GPS visualizer geocoding service (www.gpsvisualizer.com). Longitudinally, arrival records east of 95°W (approximate range limit for Ruby-throated Hummingbirds) were divided into Central, Appalachian, and Eastern Regions (Fig. 5.1). Regions were
delineated based on categories used by the Breeding Bird Survey (www.pwrc.usgs.gov/bbs) and the Environmental Protection Agency (Level III Ecoregions; http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm).

In sum, we analyzed 5,065 first arrival records from the BPP card files between 1880 and 1969. We used multiple regression to assess the effects of latitude, longitude, and altitude on hummingbird arrival dates in the eastern United States and ANOVA to assess the differences in mean hummingbird arrival dates by region (Central, Appalachian, Eastern) while including latitude as a covariate. It should be noted that these findings are preliminary and based on statistical methods with strict assumptions about the data (e.g., independence) that are difficult to meet due to potential dependence structures over space and time.

Our model (adjusted $r^2 = 0.66, F_{3,5061} = 3267.1$, $P < 0.0001$) indicated that latitude, longitude, and altitude were related to hummingbird arrival dates. In summary, from 1880-1969, hummingbirds arrived 3.4 days later for every 1° increase in latitude, 1.2 days later for every 10° longitude increment, moving from west to east, and 7.5 days later for every 1000 m increase in elevation. Mean arrival dates also differed by region (Fig. 5.1), with birds arriving $1.3 \pm 0.33$ S.E. days earlier in the central United States than in the Appalachian Region ($P < 0.0001$) and $1.1 \pm 0.27$ S.E. days earlier in the central United States than in the Eastern Region ($P < 0.0001$). No significant differences in arrival dates were noted between the Appalachian and Eastern Regions ($P = 0.52$; Fig. 5.2).
Earlier arrivals in the central United States (Fig. 5.2) could be explained by a difference in travel distance with central migrants travelling directly north from Gulf States where many hummingbirds make landfall (i.e., Alabama, Mississippi, Louisiana; Robinson et al. 1996) and eastern migrants travelling northeast, a less direct route. Another possibility is that central migrants may have migrated over land (i.e., Mexico and Texas; Robinson et al. 1996), perhaps requiring less time to refuel than their eastern counterparts that make dangerous and exhausting trips across the Gulf of Mexico. Later arrivals in mountainous regions are not surprising (Sparks and Braslavska 2001) given that melting snowpack and cooler spring temperatures can delay spring phenology at high altitudes (Inouye et al. 2000).

Our findings highlight the importance of considering spatial variables such as altitude and region in studies of phenology, and provide a basis for a number of future research questions. For example, are hummingbirds responding to recent climate change events? Does climate change slow or speed up migration in hummingbirds? Do hummingbirds increase stopover periods in areas such as mountains that are disproportionately affected by warming climates (Fyfe and Plato 1999). Where are changes in migration most pronounced and are these changes synchronized across food webs (e.g., birds, insects, plants)? Have these changes impeded or enhanced pollination services hummingbirds provide?

Efforts such as the North American Bird Phenology Program help provide the missing puzzle piece of data for understanding historical migration patterns. As recent migration data emerge along with more sophisticated tools to assess climate and land use
changes of the past century, the availability of historical data allows us to better understand changes in bird phenology and related global changes at broad temporal and spatial scales.

**Case Study 2: Changes in Purple Martin Arrival Dates**

Purple Martins (*Progne subis*) are the largest member of the swallow family in North America (Brown 1997). They spend the non-breeding season in Brazil and migrate to North America to nest; adults commonly return to the same nesting sites where they were successful in previous years (Brown 1997). Once a pair is established, they cooperate equally in building the nest out of mud, grass and twigs. This species is of special interest to birders, in large part, because of the close proximity of their nesting sites to human settlements (Brown 1997).

Based on an initial dataset of Purple Martin arrival records provided by the BPP (N = 5,345), arrival dates were aggregated by decade from the 1880s through the 1950s. We found that the arrival dates for 1920s, 1930s and 1940s were earlier than the arrival dates for the 1880s through the 1910s (P < 0.0001; Fig. 5.3). Reforestation in the northeast during the beginning of the 20th century (Litvaitis 1993) and increasing use of artificial martin houses (Allen and Nice 1952) may have increased martin populations during this time and may partially explain the migratory advancements noted (Miller-Rushing et al. 2008). Increased competition for nest cavities with introduced species, such as European Starlings (*Sturnus vulgaris*) and House Sparrows (*Passer domesticus*; Brown 1981), may have also contributed to advancing migration dates.
Discussion of Future Analysis using BPP Data

Previous approaches to predicting species’ responses to climate change have generally addressed migratory changes at either broad spatial or temporal scales, but rarely both (Hulme 2005). The original BPP dataset covers 90 years, and by integrating it with contemporary migratory data, we now have more than 130 years of migration data, with which to better understand spatial, temporal, and inter-specific variation in bird migration processes in North America. This could provide unprecedented insight into how climate and environmental variables are shaping, and have shaped, a broad-scale ecological process.

A number of related studies are possible using BPP data; for example, these data could be used to develop decision support tools for avian and habitat management plans in the face of climate variability and directional change. These data could contribute to our understanding of patterns and processes related to bird-related diseases, such as avian influenza, a virus that is affected by changing migration phenology and impacts human health. In addition, these data could assist modelers in developing species vulnerability assessments and creating tools for ecological forecasting – oftentimes phenological asynchrony with food resources indicates that populations will decline in size in response to climate change (Møller et al. 2008, Willis et al. 2008).

Historical data, such as those preserved by the BPP, are of special importance because they are irreplaceable. This dataset provides a wealth of information about bird migration, and converting it to a digitally usable format is the first step to making it widely useful and accessible. Collecting, and now transcribing original records over 130
years later, has only been possible with the assistance of hundreds of volunteers from around the world. Through standardized protocols and the collective effort of the public, the scope of this monitoring program has been magnified beyond any capability the government would have had to collect and transcribe data. As such, a public/private partnership has been established in which a dedicated team of governmental employees and academics have created an appropriate home and structure for data, and members of the general public have collected and transcribed data; each making an important contribution to a project that will ultimately help us better understand large-scale ecological processes that affect us all.
Figure 5.1. Our study area (29-47°N, 67-95°W) divided into three regions based on classifications used by the Breeding Bird Survey (www.pwrc.usgs.gov/bbs) and the Environmental Protection Agency (Level III Ecoregions; http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm).
Figure 5.2. Difference in mean first arrival dates (± S.E.) of Ruby-throated Hummingbirds in the Central (N = 2,002), Appalachian (N = 1,075), and Eastern Regions (N = 1,988, see Fig. 5.1 for region designations) from 1880-1969. Arrival days are expressed in ‘day of year’ and corrected for leap years; for example, ‘130’ corresponds to May 10. Inset letters represent differences that are significant at the P < 0.05 level.
Figure 5.3. Interval plots for mean martin arrival dates from 1880-1950, presented with 95% confidence intervals. Figure generated from a randomized block analysis of variance (ANOVA) of arrival day using ‘decade’ as the main effect and ‘latitudinal band’ as the blocking effect. Arrival days are expressed in ‘day of year’ and corrected for leap years; for example, ‘95’ corresponds to April 5. The sample sizes are $N = 501$ (1880s), $N = 565$ (1890s), $N = 700$ (1900s), $N = 1,126$ (1910s), $N = 1,152$ (1920s), $N = 738$ (1930s), and $N = 444$ (1940s). The large standard error in the 1950s likely due to low sample size ($N = 119$).
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References


CHAPTER SIX

GRADUATE STUDENTS IN CONSERVATION BIOLOGY: BRIDGING THE RESEARCH-IMPLEMENTATION GAP

Abstract

There is a growing consensus that a gap exists between research conducted at academic institutions and information available to practitioners that implement this research. Here, I review four common recommendations for bridging the Research-Implementation Gap, highlight the unique abilities of graduate students to participate in this process, and propose five ways research institutions and professionals can help facilitate graduate student participation. While some may appropriately point out that the main purpose of graduate school is to focus on research and that students have the rest of their careers to become involved in implementation, being exposed early to the broader issues of research and implementation may enhance the graduate research experience and help train students to become future leaders in conservation science. This paper identifies graduate students as possible contributors of solutions to this problem and provides novel suggestions to graduate students, advisors, and university administrators on how to best support this process.

Introduction

‘Conservation biology’ is a relatively young discipline that has grown quickly in popularity since its inception in the mid-1980s (Soule 1985). According to the Society for Conservation Biology website (http://www.conbio.org/resources/Programs), there are
currently 520 colleges and universities that offer academic programs in conservation biology, including many graduate programs. In these programs, students learn basic and applied ecology, become familiar with the socioeconomic challenges of solving conservation problems, and develop skills to use conservation modeling software.

While quickly growing in popularity, especially among students, the field of conservation biology has also faced many challenges. Recent articles in *Conservation Biology* (Knight et al. 2006a, Knight et al. 2008, Manolis et al. 2009) and *BioTropica* (Born et al. 2009, Sunderland et al. 2009) highlight a Research-Implementation Gap that exists in conservation biology, whereby conservation assessments are rarely translated into meaningful conservation action. Many facets of this problem have been identified, including a lack of knowledge-sharing between researchers and practitioners, a lack of access by practitioners to information, and a disconnect between conservation research and realistic implementation goals, given real-world management objectives and constraints (Knight et al. 2008).

Suggestions have been proposed to narrow the Research-Implementation Gap (Boreux et al. 2009, Sunderland et al. 2009). Most of these “calls for action,” however, are directed toward research scientists and large research institutions (Knight et al. 2008). While these groups are certainly appropriate target audiences to consider, the role of graduate students in narrowing this gap has been largely overlooked (Duchelle et al. 2009).

Here, I review four common recommendations for bridging the Research-Implementation Gap and highlight the unique abilities of graduate students to participate
in this process. I conclude by proposing five ways research institutions and professionals can encourage graduate students to participate in this endeavor.

**Recommendation #1** Facilitate communication between researchers and practitioners in designing and developing conservation assessments (Born et al. 2009, Jacobson 2009, Sunderland et al. 2009).

Goals and designs for conservation assessments often differ between researchers and practitioners. While some large conservation groups (e.g. The Nature Conservancy, the Wildlife Conservation Society) have active research programs and carry out implementation, the majority of “successful” conservation assessments that are published in highly respected journals are not designed or implemented by field practitioners (Knight et al. 2008). The importance of including practitioners in the development phase of a research project has been recognized (Jacobson 2009) and graduate students may be able to contribute by promoting communication between researchers and practitioners.

Within most graduate departments (whether in Biological Sciences, Conservation Biology, and/or Wildlife) there are students who intend to pursue careers in academia and basic research and students who intend to pursue careers in applied management. During graduate school, students who intend to pursue a career in basic research should present research at a meeting that focuses on applied issues in their field (e.g., a meeting of The Wildlife Society or the Association of Applied Biologists), and students who intend to pursue a career in applied disciplines should present research at a basic biology conference (e.g., a meeting of the AAAS or the Animal Behavior Society). Often students
can apply for travel grants and attend meetings at discounted rates. Developing patterns early in a graduate student’s academic career of bridging the gap between basic and applied science may facilitate direct knowledge sharing between researchers and practitioners and foster continued relationships that may develop throughout a student’s academic career.

Some universities provide considerable flexibility for students to select committee members and students should think carefully when making this decision. By including both practitioners and scientists on graduate committees, students will become familiar with broad issues related to their study system and become comfortable discussing their research using different vocabulary (Jacobson and McDuff 1998). It is also possible that committee meetings could facilitate positive communication between diverse committee members (i.e., practitioners and research biologists) that may lead to future collaborative efforts. Even if it is not possible to include a field practitioner on a committee (e.g., if a school requires all committee members to have earned a PhD or formally acquire adjunct status), graduate students should still consider sending a copy of their research proposal to a field practitioner for critique and review.

**Recommendation #2** Expand the social dimension of conservation assessments and support conservation plans with transdisciplinary social learning institutions (Knight et al. 2006b, Knight et al. 2008, Sunderland et al. 2009).

Conservation research is unlikely to be implemented if it is not recognized as important by a variety of social institutions. Collaboration is often necessary among
governmental agencies, city planners, legislators, citizens, and private-interest groups to implement and achieve desired conservation actions (Schindler et al. 2011, Shanley and Lopez 2009). It is critical that conservation assessments are designed to encompass social and economic issues relevant to citizens and stakeholders (Kainer et al. 2009).

Graduate students may be well-positioned to assist in this process. Typical general education requirements of most four-year colleges and universities include courses in a variety of disciplines, including economics, communication, political science, business, sociology, foreign language, and philosophy. Some undergraduate programs (e.g., environmental studies) are intentionally broad. Concepts learned from recent interdisciplinary coursework may be useful in communicating with people from a variety of institutions regarding the implementation of research findings (Jacobson 1990, Jacobson and McDuff 1998). Graduate students may also offer different perspectives on how to facilitate communication among parties; including the use of newly developed social networking tools (e.g., twitter, Facebook). An increasing number of graduate students are now including a chapter on the socio-economic impacts of their results in their dissertations (Duchelle et al. 2009).


A third barrier to bridging the Research-Implementation Gap is that research scientists are given little positive incentive to educate landowners and management agencies about their findings. Most university promotion systems are built upon...
researchers obtaining grant funds and publishing articles in highly cited research journals. While perhaps easier to quantify research production, this system largely overlooks and indirectly discourages knowledge sharing with practitioners as an important responsibility of a researcher (Born et al. 2009).

Graduate students should recognize the pressure faculty members face to publish and assist faculty members in the information dissemination process. This could mean speaking at a local Audubon, garden club, or farm meeting, representing a university at a community event, or helping plan training seminars for field practitioners (Kainer et al. 2009, Shackleton et al. 2009). Even helping with the logistics of a meeting (e.g., reserving a meeting place or advertising for a seminar) may make it easier for a faculty member to make time for community outreach. As a result of this process, graduate student research could also benefit from stakeholder feedback.

In addition, graduate student organizations should formally recognize outstanding efforts in education and outreach. For example, awards such as ‘Teacher of the Year Award’ or ‘Outstanding Community Achievement Award’ should be given regularly to deserving professors with notification sent to deans and appropriate university administrators. Graduate students (and graduate student organizations) may be in a unique position to encourage community organizations and field practitioners to notify university officials and local media outlets after receiving exceptional guidance or service from a university employee. While long-term changes in faculty incentive structure may occur gradually, drawing positive attention to valuable information sharing efforts may encourage this process.
**Recommendation #4** Increase the availability of information to practitioners (Knight et al. 2008, Born et al. 2009).

Information generated by researchers is not always readily available to practitioners. Results from conservation research conducted in developing countries are often published in English-language journals (Duchelle et al. 2009) that are difficult for local resource managers to access. In addition, high subscription costs may prohibit many practitioners (in both developing and developed countries) to learn about and implement relevant research findings (Sunderland et al. 2009).

Graduate students may help increase accessibility to information by supporting the development of open-access journals (Coloma and Harris 2005). Open-access journals are journals accessible online, worldwide, without a subscription fee (for example, see ‘Conservation Evidence’ www.conservationevidence.com or ‘PLoS Biology’ www.plosbiology.org). Publishing results and citing papers from open-access journals or encouraging their home institutions to support articles published using the open-access option will help these journals increase in popularity. The demands and expectations of researchers (including graduate students) ultimately drive the publication of scientific journals. Expectations from graduate students have the potential to affect decisions made by publishers. Student opinions regarding open-access journals can be appropriately conveyed to journal publishers at ‘meet the editor’ sessions and other student forums that commonly occur during society meetings.
Support from Research Institutions and Established Professionals

More and more graduate students are entering conservation biology or a related field and are interested in bridging the gap between research and implementation. Graduate students have the ability to substantially contribute to this endeavor and their contributions could be enhanced by the following measures of support from research institutions and established professionals:

(1) Continued support for graduate students to attend meetings and conferences in multiple subdisciplines to begin networking with researchers and practitioners in their fields.

(2) Support for graduate students to communicate research results with stakeholders, government agencies, and the general public. This may include speaking at community meetings, sharing results with local agencies, and organizing relevant training seminars. While initially requiring training and mentoring from an academic advisor (Kainer et al. 2006), this practice has both immediate and long-term benefits in minimizing barriers between conservation research and implementation efforts (Duchelle et al. 2009).

(3) Relaxing requirements for qualified professionals to serve on graduate committees. For some professionals, acquiring adjunct status or being approved by an entire department may be time consuming and make serving on a committee undesirable. Making a provision that at least one committee member outside a student’s home institution could be added to a committee and quickly approved by the committee itself, would make it easier for
graduate students to assemble a diverse committee (i.e., researchers and practitioners).

(4) Recognizing and rewarding of outreach as an important duty of graduate students, along with necessary coursework and research (Noss 1997). Incentives for graduate student participation could include course credit and assistantship funding.

(5) Continued development of fellowship opportunities to support research and implementation efforts among young scientists (e.g., Collaborative Initiative Fund from the Switzer Foundation, David H. Smith Conservation Research Fellowship).

While some may appropriately point out that the main purpose of graduate school is to focus on research and that students have the rest of their careers to become involved in implementation, the benefits of graduate student participation in narrowing the Research-Implementation Gap outweigh the costs and graduate students are well-positioned to contribute to this endeavor. Being exposed early to the broader issues of research and implementation may enhance the graduate research experience and help train students to become future leaders in conservation science.

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References


CHAPTER SEVEN

USE OF THREAT ANALYSIS TO ASSESS THE EFFECTS OF LAND DEVELOPMENT ON BIODIVERSITY IN A BLUE RIDGE-PIEDMONT LANDSCAPE

Abstract

Urbanization – conversion of rural and forested landscapes to housing and associated infrastructure – has variable effects on biodiversity with the trend being towards biotic homogenization. The southern Blue Ridge and upper Piedmont are rich in biodiversity and near growing urban centers, providing an opportunity to anticipate future habitat conditions for species with different life histories. We produced 1) a habitat reduction model based on development pressure, percent of each species range protected, and ability to resist disturbance, and 2) a threat analysis based on development pressure, habitat suitability, and management authority. We selected two birds (Eastern Towhee *Pipilo erythrophthalmus* and Swainson’s Warbler *Limnothlypis swainsonii*) and amphibians (upland chorus frog *Pseudacris feriarum* and shovel-nosed salamander *Desmognathus marmoratus*) as focal species, each pair including a broadly- and narrowly-distributed species. Using 2000-2008 census data we projected housing unit growth 2000-2010 and estimated development pressure for 2020 and 2030. Our habitat reduction model showed the broadly-distributed chorus frog negatively affected by more intense development of lower-elevation habitats (7-20% reduction) and the narrowly distributed salamander by loss of higher-elevation riparian areas (6-18% reduction). The narrowly distributed warbler showed a greater sensitivity to development pressure (10-30% reduction) than the broadly distributed towhee (5-16% reduction). The rural
Piedmont faced a greater degree of threat (all species) from projected increases in housing units and limited land protection compared to the Blue Ridge, which had more extensive protected lands. We suggest that habitat-reduction and threat-analysis models accounting for biological responses of species are helpful developments in predicting risk to multiple taxa in urbanizing regions.

Introduction

Land development is characteristic of a growing economy, but often proceeds without considering ecological consequences (Theobald et al. 1997, Aguayo et al. 2007). While many land use change models focus on anthropocentric concerns (e.g., congestion, pollution, transportation; Allen and Lu 2003, Henriquez et al. 2006, Aguayo et. al 2007), a growing number of researchers are considering the ecological impacts of development (Theobald et al. 1997, Naves et al. 2003, Theobald 2003). Development pressure, often measured by increases in human influence (e.g., roads, housing units, population), has been correlated to declines in species’ populations through habitat loss, removal of native vegetation, and alteration of species activity or feeding patterns (Theobald et al. 1997, Hansen and Brown 2005).

Recent advances in modeling (e.g., spatially and temporally specific gap and threat analysis) have assisted land managers, city planners, and conservation biologists identify important conservation areas that face increased development pressure. Gap analysis uses vegetation indices and historical trends in land use change to predict likely animal distributions. Predicted animal distributions are then overlaid with a map of
protected areas using GIS software to identify possible “gaps” in the protection of biodiversity (Scott et al. 1993, Axelsson and Oslund 2001). A threat analysis is a process in which a gap analysis is expanded by including different environmental variables that are quantified based on each variable’s potential influence on conservation of selected species. A threat analysis is designed to assess species’ current and future responses to developmental pressure (Theobald 2003).

One region in the United States experiencing substantial development pressure is upstate South Carolina (Fig. 7.1). This area contains portions of the Blue Ridge and upper Piedmont ecoregions, encompassing montane regions of the Southern Appalachians and neighboring lowlands with a diverse array of geological and hydrological features (Campbell et al. 2007). Being located in the southeastern United States, this region is rich in biodiversity and endemism, and warrants special conservation attention (Montanucci 2006). Given the high degree of habitat heterogeneity, the region houses a variety of bird and amphibian species that are of high conservation concern at both the state and federal level. Because of the combination of high development pressure and high biodiversity, we selected upstate South Carolina as our study area to assess the possible effects of development on four representative species. We selected two bird species, Eastern Towhee Pipilo erythrophthalmus and Swainson’s Warbler Limnothlypis swainsonii, and two amphibian species, upland chorus frog Pseudacris feriarum and shovel-nosed salamander Desmognathus marmoratus, with each pair consisting of a narrowly- and a broadly-distributed species within the region.
Our objectives were: (1) to assess varying degrees of threat to selected species in our study area, (2) to evaluate how future development pressure will affect distributions of birds and amphibians that have narrow and wide distributions, and (3) to consider which species to target for conservation action and whether certain species (or certain groups of species) might serve as indicators for others with similar sensitivity levels and habitat needs.

Methods

Field Site Description

We selected eight counties comprising the Upper Piedmont and Southern Blue Ridge ecoregions within the state of South Carolina (Pickens, Greenville, Greenwood, Laurens, Spartanburg, Oconee, Anderson, and Abbeville counties) as our study region (Fig. 7.1). Broad-leaved deciduous and coniferous evergreen forests are the dominant land cover types. A human population density of 83.6 per km² (Campbell et al. 2007), a human population growth rate of 15.3% between 2000-2010 (Allen and Lu 2003), rapid development of high-amenity areas of the Blue Ridge, and urbanization around the cities of Greenville, Clemson, and Anderson have stressed this region’s natural ecosystems and biodiversity. Between 1990 and 2000, developed land grew from 90,142 to 233,235 ha in upstate South Carolina and over 607,028 ha are expected to be developed by 2030 (Allen et al. 2006). The Saluda – Reedy River watershed is recognized as an imperiled watershed by the Environmental Protection Agency and falls within seven (except Oconee) of the eight upstate countries (Ulbrich 2007). In addition, the northernmost
counties of our study region (Oconee, Pickens and Greenville) serve as the natural range for numerous fauna and flora that are restricted to the Southern Appalachian Mountains (Montanucci 2006).

Selected species

The Eastern Towhee is a common, year-round resident of South Carolina that is broadly distributed and prefers thickets and forest edges (Greenlaw 1996). Although common in South Carolina, populations in adjoining states are declining, suggesting that South Carolina may host important sources. The Swainson’s Warbler is a neotropical migrant classified as a ‘Species of Special Concern’ in South Carolina (SC DNR 2006a). There, it has a narrow distribution during the summer months when it nests in shrubby undergrowth along riparian corridors in the northwest corner of the state (Brown and Dickson 1994). The upland chorus frog is distributed broadly throughout the temperate zones of the eastern United States. It is primarily a forest species, inhabiting the flood plains and upland woodlands of South Carolina (IUCN Redlist of Threatened Species 2009). The shovel-nosed salamander is primarily a riparian species that prefers lotic waters in association with undisturbed forested habitats, and is narrowly distributed in the northwest corner of the upstate (IUCN Redlist of Threatened Species 2009). It is primarily found in cool upland streams under rocks and, like the Swainson’s Warbler, is considered to be a ‘Species of Special Concern’ in South Carolina (SC DNR 2006a).

Overview of models

Our threat assessment consisted of two main steps: (1) generating a habitat reduction model to reflect projected species declines for our four study species in
response to land development; (2) producing threat analyses models for our selected species to identify the extent to which habitats in our study area are imperiled by land development. All the spatial and temporal analyses were done using the ArcGIS Version 9.3 (ESRI, Canada).

Habitat reduction model

We projected habitat reductions for the four species using development pressure, proportion of protected lands within a species range, and the likelihood an individual in a population would survive anthropogenic disturbance. To calculate the growth rate of housing units, we calculated the percentage increase in the number of housing units in the eight counties of concern from 2000 to 2008 using census data from the Topologically Integrated Geographic Encoding and Referencing (TIGER) database (http://www.census.gov/geo/www/tiger/) and then projected the average change in number of housing units over a 10-year period for our entire study area (15%). Then, we calculated the proportion of unprotected lands that fell within the distribution of a given species in the study area, which we termed Percentage Range Unprotected. We obtained species distribution rasters and polygons for land stewardship of South Carolina from the SC DNR data clearinghouse (SC DNR 2006b). Finally, we calculated an Index of Decline to represent a predicted species response in the face of adverse anthropogenic activities. We derived the Index of Decline based on our review of published literature and historical, local-scale reduction in area of occupancy of selected species in face of human-induced habitat loss (Martof et al. 1980, Conant and Collins 1991, Mitchell 1991, Brown and Dickson 1994, Greenlaw 1996, Petranka 1998, Blackburn et al. 2001) and the
IUCN Redlist of Threatened Species (2009). Values are expressed in units of 0.1, range from 0.1-1.0, and represent the probability an individual would be excluded from a habitat as a result of human development. For example, we assigned Swainson’s Warbler a value of 0.8 because our review suggested that land development within its current area of occupancy (i.e., bottomland forests, mesic woodlands) would result in extirpation of 80% of its population. Finally, we combined this information to derive a projected percentage habitat reduction using the following equations:

**Development Pressure** = % Δ Housing units

% Δ Housing Units = (No. of housing units in 2008 – No. of Housing units in 2000) / (No. of housing units in 2000) * 100

**Percentage Range Unprotected** = Species distribution within study area that is protected / Total distribution within study area

**Percentage Habitat Reduction** = Development Pressure * Percentage Range

Unprotected * Index of Decline

*Threat analyses models*

Our threat analyses models were based on the growth rate of the housing units in the study area, a habitat suitability index for each species, and the protection status in the study-area distribution of each species (Baldwin and deMaynadier 2009). We used a
similar approach as outlined for our habitat reduction model to calculate development pressure for these models, but used a county-specific growth rate of housing units. To generate Habitat Suitability Indices, we obtained geographical distributions of our four selected species from the South Carolina Department of Natural Resources SC GAP analysis project website in raster format (SC DNR 2006b). These raster layers were originally classified based on different land cover types that fall within the distribution regime of our species. We reclassified based on habitat suitability for selected species as determined by a review of published literature (Martof et al. 1980, Conant and Collins 1991, Mitchell 1991, Brown and Dickson 1994, Greenlaw 1996, Petraska 1998, Blackburn et al. 2001) and the IUCN Redlist of Threatened Species (2009). Available information was inadequate to implement a continuous scale, so we ranked the suitability of each major habitat type on an ordinal suitability gradient ranging from very high suitability to low suitability, and assigned a fixed value for each habitat that occurred within the distribution range of each species. The habitat suitability values were assigned as following: 1 – very high suitability, 0.75 – high suitability, 0.50 – moderate suitability and 0.25 – low suitability. We eliminated any habitat that was deemed unsuitable for long-term persistence of a given species and calculated suitability values for the reclassified habitats of our selected species (Table 7.1). To determine the protection given to the distribution of our four species, we recategorized the study region into five groups based on management authority; federally owned, state owned, protected private lands, protected lands with unknown ownership, and unprotected areas (Land Stewardship Data Clearinghouse- SC GAP database). Based on land use practices allowed by different
management authorities (e.g., recreational use, hunting, harvesting), we derived values from 1 to 5 to indicate the likelihood that selected species would be safeguarded from future anthropogenic disturbance (Table 7.2). We used the Spatial Analyst extension of ArcGIS Version 9.3 (ESRI, Canada) to produce the threat indices based on the following equation:

\[
\text{Threat Index} = \frac{\text{Growth Rate of Housing Units} \times \text{Habitat Suitability Index}}{\text{Protection Status}}
\]

Results

Our habitat reduction model showed that both amphibian species had similar projected habitat declines in response to development by the year 2030 (upland chorus frog, 19.8% habitat reduction; shovel-nosed salamander, 18%; Table 7.3). Bird responses differed from each other, however, with projected habitat reductions for Swainson’s Warbler nearly twice as much as that of Eastern Towhee (30.1% and 15.8% respectively). Overall, among the bird and amphibian species studied, the Eastern Towhee appeared to be the most resistant to development pressure.

Threat analyses indicated that for Eastern Towhee and upland chorus frog, areas of highest threat exist in the north-central portion of our study region, an area that overlaps with a significant degree of development (Fig. 7.2). For Swainson’s Warbler and shovel-nosed salamander, areas of highest threat were found in the central portions of their respective ranges (Oconeé, Pickens, and Greenville counties) closer to urban and
suburban areas. In general, lower threats for all species were found in mountainous regions that were protected by federal management authorities, particularly in the Blue Ridge ecoregion and Southern inner Piedmont ecoregion (northeastern Oconee county and northern Pickens county). Further, for broadly distributed species, threat was lowest in relatively undeveloped areas with a significant degree of agricultural activities (the southernmost counties of our study region).

Reclassification accounting for habitat suitability within distribution areas for our four species revealed a higher percentage of ‘high’ and ‘very high’ suitability values for habitat specialists (Swainson’s Warbler - 100%, shovel-nosed salamander - 85%) than for habitat generalists (Eastern Towhee - 23.5%, upland chorus frog - 12%), although habitat specialists had much narrower overall distributions than habitat generalists. Overall, 12% of our study region was protected by a combination of federal agencies (e.g. Army Corps of Engineers, National Park Service, US Forest Service), state agencies (e.g., University Experimental Forests, Department of Natural Resources), and private agencies (e.g., the Nature Conservancy), with most protected areas occurring in the northernmost portion of our study region. Relatively small portions of the ranges of Eastern Towhee, Swainson’s Warbler, and upland chorus frog were protected (12%, 16%, 12%, respectively), whereas 60% of the range of shovel-nosed salamander was protected (Table 7.3).

**Discussion**

Land development typically results in long-term change and detrimental effects on biodiversity, a result found in both our habitat reduction model (Table 7.3) and threat
analysis model (Fig. 7.2). The habitat reduction model evaluated species-specific responses to development based on amount of habitat vulnerable to development (i.e., unprotected) and species resistance (i.e., Index of Decline or ability to persist with loss of habitat quality resulting from development). In contrast, the threat analysis evaluated suitability of habitats available (habitat suitability index rankings) and degree of development risk based on level of habitat protection. Together, the two approaches assess current threat to species based on species-specific resistance to development and projected reductions in habitat carrying capacity (degree of habitat suitability and likelihood of reduced suitability through development).

Our habitat reduction model projects range declines that differ among our selected species (Table 7.3), with the Eastern Towhee showing the least decline, a result consistent with its ability to adapt to anthropogenic disturbance as an edge-associated generalist (Greenlaw 1996). Swainson’s Warbler, a habitat specialist preferring moisture-rich, old-growth forests (Brown and Dickson 1994), showed the greatest potential for decline, given its inability to adapt to development pressure and smaller percentage of range protected. Projected declines in the distribution of upland chorus frog and shovel-nosed salamander were similar but illustrate two different aspects of development pressure. The shovel-nosed salamander, although having low resistance to development, was relatively unaffected because >60% of its range in South Carolina was protected (most of its range falls within areas of the Blue-ridge ecoregion and the southern Appalachian mountains that have broad conservation appeal). Although the upland chorus frog had a broader area of occupancy and was somewhat resistant to development,
most of its distribution is in the outer Piedmont ecoregion, which had less area protected (12%) and more of its habitat susceptible to human development. Overall, threat was lowest for broadly-distributed species in the relatively undeveloped areas with agriculture; a result indicating the value of maintaining sustainable or wildlife-friendly agriculture (Fisher et al. 2008).

Our habitat reduction model provides a regional perspective for species declines over time with consideration of biological characteristics of selected species. We assumed a constant development pressure of 15% across all counties in our study region, similar to Allen and Lu (2003) and Campbell et al. (2007) and calculated the percentage of each species’ habitat protected within our entire study region. Attributed to its simple mathematical calculation, model inputs can be adjusted to reflect changes at multiple spatial scales (e.g., state-level, county-level, U.S. census block).

Our threat analyses (Fig. 7.2) were based upon a model developed by Baldwin and deMaynadier (2009) and accounted for growth of housing units, habitat suitability, and protection status based on land ownership. By reclassifying distribution rasters according to habitat suitability for selected species, we selectively weighted land cover types that provide optimal habitat conditions for long-term survival of selected species. Considering differences among management authorities made our model more robust, compared to approaches that simply categorize areas as ‘protected’ or ‘unprotected.’ Using a finer scale that reflects all possible management practices would strengthen our model by accounting for the wide range of conservation applications and sustainable uses employed by a given management authority. Our threat analyses differed from our habitat
reduction model (Table 7.3), by accounting for a unique growth rate for each county within our study region. This approach recognizes rural areas as less likely to be affected by intense land development, a point that could affect conservation planning depending on species and conservation goals. Martorell and Peters (2008) used a similar fine-scale approach to assess threats encountered by native species in a disturbed landscape.

Only 12% of our study region was protected, compared to 27.1% of terrestrial ecosystems in the United States (WDPA 2008), even though the Environmental Protection Agency recognized a portion of the area as a priority watershed (the Saluda-Reedy watershed; Allen et al. 2006). Protected areas in the northernmost portion of our study region (Oconee, Pickens, and Greenville Counties) appeared to curb habitat declines and alleviate threats. Similar habitat protection might reduce threat levels for lands in the central portion of our study region where threat levels currently appear to be high (Fig. 7.2). Alternatively, biodiversity threat levels might be reduced through conservation programs that engaged the interests of landowners, agencies, and other stakeholders toward mutual conservation and land-use goals. Continued cooperation among different management authorities that hold jurisdiction over protected lands in our study region will be crucial to maintain and ensure long-term species protection.

In both of our models, we assumed that changes in housing density best approximated development pressure. Using growth rate of housing units as a measure of development considers second homes, which may be unoccupied at the time of a population census and are most often located close to wilderness areas that are important to wildlife conservation (Baldwin et al. 2009). Although other variables (e.g., access to
roads, urbanization, sewer lines, human population density) are often combined to
calculate development pressure (Sanderson et al. 2002, Aguayo et al. 2007, Campbell et
al. 2007), Claggert et al. (2004) showed that models based on housing units generated
similar projections to complex models that consider multiple variables.

Used in conjunction with one another, our models could help conservation
authorities more accurately predict species declines and implement well-focused
location-specific, management strategies. For example, our habitat reduction model could
be used to establish a surrogate relationship between well-studied Species A and a lesser-
studied Species B if they have similar portions of their ranges unprotected (Percentage
Range Unprotected values) and similar resistance to change (Index of Decline values,
Table 7.3). Using this relationship, a threat analysis could then be conducted to indicate
specific locations where conservation efforts are most needed for species B. Future
models could be improved by more accurately quantifying the degree of management and
potential for land use / land cover change on protected areas (e.g., degree of resource
extraction by management authorities) and by a better understanding of life histories and
habitat associations of target species.

Pressures for land development will increasingly involve multiple landscape
variables and stressors such as housing unit growth, land use / land cover change, habitat
availability and quality, and species life history characteristics. Our findings demonstrate
the value of integrating multiple components to yield projected scenarios that can help
guide and inform land-use decisions from regional to local scales, depending on input
data available.
Table 7.1. Values used to calculate habitat suitability indices. Each habitat occupied by the selected species was assigned a numerical value reflecting the degree of suitability of that habitat as following: 1 – complete suitability, 0.75 – high suitability, 0.50 – moderate suitability and 0.25 – low suitability. Values derived based on literature review.

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>Eastern Towhee</th>
<th>Suitability Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry scrub/Shrub thicket</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Wet scrub/Shrub thicket</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Open canopy/Recently cleared forest</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Closed canopy evergreen forest/Woodland</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Dry deciduous forest/Woodland</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Dry mixed forest/Woodland</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Mesic deciduous forest/Woodland</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Mesic mixed forest/Woodland</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Pine woodland</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Urban residential</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>Swainson’s Warbler</th>
<th>Suitability Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesic deciduous forests/Woodlands</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Bottomland hardwood forests</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Floodplain forests</td>
<td>0.75</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>Upland chorus frog</th>
<th>Suitability Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Bottomland hardwood forests</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Floodplain forests</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Wetlands with aquatic vegetations</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Mesic deciduous forests/Woodlands</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Mesic mixed forests/Woodlands</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Grasslands</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Pastures</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Cultivated/Agricultural lands</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>Shovel-nosed salamander</th>
<th>Suitability Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesic deciduous forests/Woodlands</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Mesic mixed forests/Woodlands</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Freshwater</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>
Table 7.2. Protection levels based on management authorities of lands in upstate South Carolina. A value of 5 indicates the highest protection level and 1 indicates the lowest protection level.

<table>
<thead>
<tr>
<th>Land ownership</th>
<th>Values on conservation potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal lands</td>
<td>5</td>
</tr>
<tr>
<td>State lands</td>
<td>4</td>
</tr>
<tr>
<td>Private conservation lands</td>
<td>3</td>
</tr>
<tr>
<td>Protected lands with unknown ownership</td>
<td>2</td>
</tr>
<tr>
<td>Unprotected lands</td>
<td>1</td>
</tr>
</tbody>
</table>

*based on Land Stewardship Data Clearinghouse (SC DNR 2006b)
Table 7.3. Projected habitat reduction (%) in 2010, 2020, and 2030 for selected species based on Development Pressure, Percentage Range Unprotected, and Index of Decline.

<table>
<thead>
<tr>
<th>Species</th>
<th>Development Pressure</th>
<th>Percent Range Unprotected</th>
<th>Index of Decline</th>
<th>Percent: Habitat Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>Eastern Towhee</td>
<td>15</td>
<td>0.88</td>
<td>0.4</td>
<td>5.28</td>
</tr>
<tr>
<td>Swainson’s Warbler</td>
<td>15</td>
<td>0.84</td>
<td>0.8</td>
<td>10.02</td>
</tr>
<tr>
<td>Upland chorus frog</td>
<td>15</td>
<td>0.88</td>
<td>0.5</td>
<td>6.6</td>
</tr>
<tr>
<td>Shovel-nosed salamander</td>
<td>15</td>
<td>0.4</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

aPercentage increase in the number of housing units in study region from 2000 to 2008 projected to a 10-year interval (TIGER database-US Census Bureau)
bProportion of protected lands that fell within the entire distribution range of a given species (SC DNR 2006b)
cProbability an individual would be excluded from a habitat as a result of human development, ranked from 0.1-1.0 (based on review of published literature)
dDevelopment pressure × Percentage Range Unprotected × Index of Decline
Figure 7.1. Our eight-county study region in South Carolina. This region contains portions of the Blue Ridge and upper Piedmont ecoregions of the Southeastern United States.
Figure 7.2. Varying degrees of projected threat (low, moderate, very high, extremely high) for (a) Eastern Towhee, (b) Swainson’s Warbler, (c) upland chorus frog, and (d) shovel-nosed salamander under a 2030 development scenario, in counties where species are known to be present (SC DNR 2006b). Projections are based on Growth Rate of Housing Units per County, Habitat Suitability, and Protection Status.
Acknowledgments

We thank the Strom Thurmond Institute at Clemson University and S. Brame from the Department of Environmental Engineering and Earth Sciences at Clemson University for providing assistance with our project design. We thank J. Pike and C. Marion for providing us with information about biological risks associated with housing development in the Saluda-Reedy Watershed and J.J. Courter for helping us prepare figures for publication.

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CHAPTER EIGHT

REFLECTION AND CONCLUSIONS

The ecological challenges facing humanity are well-documented (Rockström et al. 2009), but science and technology are also advancing. I believe that implementing creative interdisciplinary strategies such as those presented here will provide guidelines for positive conservation outcomes. My work demonstrates the impacts of climate change and urbanization on avian species and provides solutions to these challenges by proposing innovative tools to improve conservation efforts, bridging gaps between researchers and field practitioners, and overcoming barriers to incorporating citizen science data into research.

Continuing to address conservation issues at a global scale will require continued participation and cooperation across disciplines and among diverse stakeholders (Carpenter and Folke 2006). Citizen science appears to be well-positioned to allow assessment of ecological processes at broad spatial and temporal scales by providing necessary data in a time- and cost-effective manner (Devictor et al. 2010, Wood et al. 2011). While there is nearly unanimous agreement that citizen science is a useful tool in education, opinions vary within the scientific community regarding its usefulness in research (Bonney et al. 2009). Some scientists remain skeptical of basing understanding of natural processes on information collected by amateur naturalists (Cohn 2008, Dickinson et al. 2010).

As debates about using citizen science in research continue, citizen science efforts continue to rapidly advance (Bonney et al. 2008, Cohn 2008, Silvertown 2009). Since the
late 1990s, nearly 600 citizen science projects have emerged and serve as the basis for hundreds of scientific papers that are being and have been published on a variety of topics, ranging from bird phenology and range shifts to landscape and community ecology (Dickinson et al. 2010). This year, the first ever Public Participation in Scientific Research Conference will be held in conjunction with the 97th Annual Ecological Society of America Meeting. In response to concerns raised by skeptics, scientist-citizen scientist partnerships are developing to carefully guide the design and implementation of emerging citizen projects such as eBird (http://ebird.org/) and Project NestWatch (http://nestwatch.org/); for example, I currently serve on the Project NestWatch advisory board. Addressing broad-scale ecological challenges (e.g., climate change, biodiversity loss) often requires broad-scale ecological data, and if carefully conceived, citizen science appears well-positioned to contribute this information. Moreover, citizen science research participants often become spokespersons for research findings and resource conservation (Thody et al. 2009). I expect that citizen science will continue to grow in popularity in the coming decades and may ultimately reshape the way ecology is practiced.

I am currently working on a number of research projects that will continue after I graduate from Clemson University. I am working with collaborators from Georgetown University and Patuxent Wildlife Research Center to assess the impacts of climate change on different feeding guilds of migratory birds using data collected by citizen volunteers. I am also using NDVI and spatially explicit start-of-season dates to assess the synchrony between hummingbird and honey bee phenology with collaborators from NASA’s Honey
Understanding the impacts of climate change across trophic levels is important to inform farmers, land managers, and policymakers of best management practices under future climate change scenarios; and I look forward to further developing innovative ways to gather and disseminate this information. I am also interested in collaborating with cooperative extension personnel at land grant universities to publish our growing degree-day findings on websites that farmers visit regularly for up-to-date pest and crop information. Providing farmers with specific decision tools and management recommendations based on when certain birds are nesting could benefit avian conservation efforts and enhance biological pest control on sustainable farms.

The themes of my research while at Clemson University have been providing innovative solutions to broad-scale ecological problems, bridging gaps between disparate disciplines to improve conservation outcomes, and demonstrating how citizens can meaningfully contribute to an understanding of ecological processes. While most of my work has occurred in avian systems, I have learned the importance of framing research questions and communicating research findings in their broader ecological contexts. My hope is that my work contributes to a better understanding of global conservation challenges facing humankind and to meaningful conservation solutions.

References


