UNIVERSITY OF CENTRAL OKLAHOMA

Edmond, Oklahoma

Jackson College of Graduate Studies

Modeling in Biology Research and the Biology Classroom

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

In partial fulfillment of the requirements

For the degree of

MASTER OF SCIENCE IN BIOLOGY

By

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Edmond, OK

2020

Modeling in Biology Research and the Biology Classroom

A THESIS

APPROVED FOR THE DEPARTMENT OF BIOLOGY

May 2020

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ABSTRACT OF THESIS

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73

ABSTRACT:

Over the last few decades, science education has shifted from a focus on knowing facts about science to a focus on carrying out science practice in the classroom. However, few secondary science teachers have first-hand experience with scientific research. To this end, Dr. Beth Allan and Dr. Mike Nelson have suggested a new model for biology teachers seeking a master's degree. In this unique program, students have the opportunity to engage in both a biology research project and an education action-research project. Therefore, my thesis and is made up of two distinct projects: “Projected changes in range

suitability for *Gavia"* & "Implementing Model-based Instruction A Method to Improve Science Instruction."

Chapter 1: Projected changes in range suitability for Gavia

Most species are expected to be impacted by anthropogenic climate change. In the past, studies focused on tracking avian range shifts in response to changing temperatures. However, few studies have examined how avian distributions may change under different climate change scenarios. We used a maximum entropy approach to model the distribution of five loon species (*G. adamsii, G. arctica, G. immer, G. pacifica, and G. stellata)* under four climate change scenarios. We found that suitable habitat for *G. adamsii, G. pacifica, and G. stellata is* expected to decline under every scenario. However, highly suitable habitat will increase for *G. arctica* and remain relatively unchanged for *G. immer*. The centroid for all species shifted northward. Overall, centroids shifted at a median rate of 100.5 km/decade over all scenarios. A range of behavioral and phenological characteristic of loons will likely cause significant shifts in both range and populations across the species.

Chapter 2: Implementing Model-based Instruction A Method to Improve Science Instruction

The implementation of scientific modeling in science curriculum has the potential to improve students' ability to reason scientifically. However, there is little research that examines the impact modeling has on student content knowledge. In this study, we used an experimental design to demonstrate whether a cause and effect relationship exists between the type of curriculum implemented and

student outcomes. The study took place over the course of one semester, 90 instructional days, and included two experimental and two control units designed to meet Oklahoma Academic Science Standards. Pre- and post-tests provided the evidence of student learning. Student attitude surveys and records of student work completed provided evidence of student engagement. Data analysis revealed no significant difference in either gains in student content knowledge or student attitudes toward science between treatment and non-treatment units.

INTRODUCTION

Over the last few decades, science education has shifted from a focus on knowing facts about science to a focus on carrying out science practice in the classroom. Years of research on science education culminated in the Next Generation Science Standards (NGSS). NGSS suggests a three-dimensional approach to science education: disciplinary core ideas (science content knowledge), cross-cutting concepts (ideas such as cause and effect that transcend science disciplines), and science and engineering practices. The three dimensions allow students to learn science as science is done. However, few secondary science teachers have first-hand experience with scientific research, making it difficult to teach students to carry out science. To this end, Dr. Elizabeth Allan and Dr. Mike Nelson suggested a new program at the University of Central Oklahoma. In this unique program, students have the opportunity to engage in both a biology research project and an education action-research project. Therefore, my thesis and is made up of two distinct projects: "Projected changes in range suitability for *Gavia"* & "Implementing Model-based Instruction: A Method to Improve Science Instruction."

Chapter 1

Projected changes in range suitability for *Gavia*

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INTRODUCTION

Many studies have shown a link between changes in the phenology and distribution of many organisms and the rise in global mean surface temperature by 0.87±0.12 degrees in the last 165 years (1). Anthropogenic climate change has been linked to changes in abundance and distribution of species (2, 3). In an interspecies study, Thomas (2010) found that between half and two-thirds of species moved their ranges in response to climate change. Climate change has impacted the distribution of avian species through contracting ranges (4), expanding ranges (5), and range shifts (6). Species that are highly vagile, such as migratory birds, may be both most impacted (7) and most successful in moving to new habitats (8, 9). A 2012 study of threats to avian species lists climate change as an important, but lacking, area of focus (10).

The rate of warming is almost twice as great in far northern latitudes compared to the rest of the world due to loss of sea ice and changes in poleward heat transfer (11-13); impacts of warmer temperatures in these ecosystems include glacier retreat, increasing river discharge, decreases in duration and extent of both snow cover and sea ice, and other changes to ecosystem structure and function (14). Ponds, lakes, and wetlands may experience even more dynamic change than rivers and coastline (15). Both the extent and distribution of wetlands are changing as a result of saltwater inundation, permafrost melting, and increased erosion (16). Avian species such as loons *(Gavia)* whose breeding grounds are in far northern latitude wetlands (17) may experience a variety of impacts. There are five extant species of loons: Yellow-billed Loons (*Gavia* *adamsii*), Arctic Loons (*Gavia arctica*), Common Loons (*Gavia immer*), Pacific Loons (*Gavia pacifica*), and Red-throated Loons (*Gavia stellata*). Most species occur in the Arctic and subarctic (17), but Common Loons extend as far south as central Mexico (18).

Loons, or divers in Europe, are migratory water birds similar to seabirds (19). Loons are characterized by medium-sized bodies with thick plumage, thin wings, a short tail short, robust legs, and webbed feet (17, 20). Loons are largely piscivorous, typically overwinter in marine environments, and breed on freshwater lakes (21).

Fossil record of Gaviiformes, which today include only the five *Gavia* species, occurred circumpolarly in the Holarctic since the middle Eocene (22). Recently, the alleged Austrian fossil auk *Petralca austriaca* points toward higher *Gavia* diversity in the Early Miocene of Europe (23). However, during the Cretaceous, Gaviiformes appear to occur only in the Southern Hemisphere (22). It is likely that Gaviiformes from the Late Cretaceous of Vega and Marambio islands dispersed to the Northern Hemisphere in the early Eocene (22). The Northern Hemisphere provided an ecological niche Gaviiformes could fill as competition as competition increased with a growing number of penguin species (22). Though loons have adjusted to climate change in the past, climate change is occurring much faster than in the past.

In the northern United States, the Common Loon *(Gavia immer)* has retracted its range to the north (18) and is ecologically important (24). Because of their trophic position, Common Loons have been proposed as indicators of aquatic health in the northern lake ecosystems they inhabit (25-27). Common Loons have been studied as primary indicators of mercury accumulation and other pollutants (28, 29) and as indicator species when predicting habitat recovery (30). Poor reproductive success in Common Loons is strongly linked to mercury pollution and acid precipitation (27). Thus, loons serve as a proxy species, alerting wildlife managers to potential changes to water quality and species fitness.

Ecological niche modeling has been used to predict changes in range and distribution for a variety of plant (31-33), animal (34, 35), and other species (36); however, studies on the effects of anthropogenic climate change on the projected distribution of loons have only been carried out at the regional scale (37), and there are no studies specifically examining the potential effects of this change on the future distribution of loons across the Northern Hemisphere. However, climate change research for loons consists largely of surveys (38-42) or specific management impacts (43). Much is known about loon nesting habitat requirements, and modeling studies have used that data to predict areas suitable for breeding (24, 44). Some studies have used modeling to predict the impact of climate change on loons. One such study focused on birds of the northeast United States, including loons. (45), and another modeled the distribution of breeding birds in Britain and Ireland, including loons (37).

Ecological niche modeling, also known as species distribution modeling, is widely used to address a variety of issues in biogeography, ecology, and evolution (46). Ecological niche models combine distribution data with environmental variable data to predict species distributions across time and space (47). There are a variety of modeling methods for evaluating the changing distribution of species such as loons through time (47-49). Models that use bioclimatic variables to predict distribution based on ecological niches are well suited to predicting changing distribution in response to climate change (50-53). A maximum entropy approach (Maxent) is particularly well-suited because it uses only presence data rather than presence and absence (pseudo-absence) data to model species distribution (53-55). Many studies have used Maxent to predict the future distributions of a wide range of taxa e.g, (2, 53, 56, 57).

In this study, we used Maxent to predict the ranges of five species of loons in the northern hemisphere. We then attempted to predict the impacts of climate change on these species by modeling their future niches under multiple climate change scenarios.

METHODS

Using methods described by Butler et. al (58), we modeled the current and projected distributions of breeding areas for five loon species (*G. stellata, G. immer, G. pacifica, G. arctica, and G. adamsii*) (54, 59). We download records of these species from eBird and Vertnet (60, 61), eliminated duplicate records, cleaned the data sets of errors, (62) and a incorporated locality data from the literature (63-66). We resampled the locality data so that there was only one record per 25 km^2 (67). We obtained range maps showing each species of loon breeding grounds from NatureServe (68) and then clipped the data to include only points within the breeding ranges for each species. We obtained data for elevation and 19 bioclimatic variables at a resolution of five arc-minutes from Worldclim (69). We clipped the geographic extent of the variables to include only the northern hemisphere (±180° longitude, 30° to 9° latitude) using ArcGIS (70). Only the variables with the highest gain when used in isolation were used because they appeared to have the highest predictive value. Also, those environmental variables that decreased the gain the most when omitted were used, as they seemed to have unique predictive information. We checked variables for high multicollinearity (71). We used the R package ENMEval to optimize regularization parameters to avoid model overfitting. We also used the small sample corrected variant of Akaike's information criterion (AIC_C) scores to evaluate the regularization of models (72) using all possible combinations of the variables that did not exhibit high multicollinearity. Receiver operating characteristic (ROC) curves were created by plotting sensitivity vs specificity, and tenfold cross-validation area under the curve (AUC) scores were used to evaluate the accuracy of the resulting model. Models with an AUC score of 1 indicated a perfect model, and models with an AUC score of 0.5 indicted a model that performs no better than random (54). It has been suggested that AUC scores be used in conjunction with other methods of evaluating models since they are not without limitations (73). Therefore, we determined the models that best describe the current distribution of the five loon species using AIC_C scores and model weights in conjunction with AUC scores. Based on these results, we created models of current and projected distribution of the five loon species using Maxent (54, 59). We used the R package ENMEval to optimize regularization parameters to avoid model overfitting. We used Climate BC as our GCM (74). Then we used that model to predict to the year 2070, using 4 different RCP scenarios. These included RCP 2.6 (projects that carbon dioxide emissions will peak before 2020 and decline after), RCP 4.5 (emissions peak about 2040 then decline), RCP 6.0 (emissions peak around 2080 and then decline), and RCP 8.5 (emissions continue to increase throughout the 21st century) (75).

Results

The best model for Yellow-billed Loons (i.e., with the lowest AIC score) included the variables maximum temperature of warmest month (BIO 5), minimum temperature of the coldest month (BIO 6), and elevation (Table 2). The AUC for this model was 0.951 ± 0.001. Areas that were predicted to have suitability >50% had a maximum temperature of the warmest month of 7.3-14.9°C, a minimum temperature of the coldest month of -37.7–33.1°C, and elevation that was below 200 meters. Areas that are currently shown as >50% suitability were nearly circumpolar, extending from Baffin Island (Canada) through northern Canada, northern Alaska, and northern Russia (Figure 2).

The best model for Arctic Loons included the variables annual mean temperature (BIO 1), mean diurnal range (BIO 2), precipitation of driest month (BIO 14), and elevation (Table 2). The AUC for this model was 0.940 ± 0.007. Areas that were predicted to have suitability >50% had an annual mean temperature of -1.8-7.3°C, a mean diurnal range of 5.2-8.6 °C, precipitation of the driest month between 24.3-61.9mm, and elevation that was below 359 meters. Areas that are currently shown as >50% suitability were nearly circumpolar, extending from Greenland through northern Canada, northern Alaska, northern Russia, and to Svalbard (Norway) (Figure 3).

The best model for the Common Loon included the variables annual mean temperature (BIO 1), precipitation of the driest quarter (BIO 17), and elevation (Table 2). The AUC for this model was 0.743 ± 0.005. Areas that were predicted to have suitability >50% had an annual mean temperature -0.8-6.8°C, precipitation of the driest quarter of 120.2-311.4mm, and elevation that was below 589 meters. Areas that are currently shown as >50% suitability were nearly circumpolar, extending from the Svalbard (Norway), through Iceland, Greenland, Canada, and Alaska (Figure 4).

The best model for Pacific Loons included the variables mean temperature of wettest quarter (BIO 8), mean temperature of coldest quarter (BIO 11), and elevation (Table 2). The AUC for this model was 0.882 ± 0.010. Areas that were predicted to have suitability >50% had a mean temperature of the wettest quarter of 3.3-11.9°C, a mean temperature of the coolest quarter of -31.6-22.0°C, and elevation that was below 90 meters. Areas that are currently shown as >50% suitability were nearly circumpolar, extending from Baffin Island (Canada) through northern Canada, northern Alaska, and northern Russia (Figure 5).

The best model for the Red-throated Loon included the mean diurnal range (mean of monthly [max temp − min temp]) (BIO 2), maximum temperature of warmest month (BIO 5), and elevation (Table 2). The AUC for this model was 0.855 ± 0.006. Areas that were predicted to have suitability >50% had a mean diurnal range of 4.3-7.8°C, a maximum temperature of the warmest month of