GIS & Remote Sensing in Avian Migratory Research

There are many different types of animals that participate in migratory behavior every year, including terrestrial animals like the caribou or marine mammals like the humpback whale. Understanding large-scale movements of these migratory animals can be a challenge, especially when it involves migration over a large distance like those undertaken by some species of birds, like the Arctic Tern who is known to travel more than 45,000 miles during their migration (Egevang, 2009). Without the advancement of remote sensing and Geographic Information Systems (GIS) technology and techniques, capturing the migratory movements of animals like the Arctic Tern would be a nearly impossible task. This paper will highlight past and current case studies that showcase the effectiveness and benefit of using GIS and remote sensing systems to inform their respective research in avian migration movements and patterns.

These papers are perfect examples of how remote sensing along side a GIS platform can help answer a variety of different questions regarding the behavior and distribution of migratory birds. Each respective case study developed specific methodology that is dependent on: (i) bird surveying techniques, (ii) remote sensing data, (iii) use of additional environmental data, and (iv) use of statistical analysis. (Gottschalk, 2005) Although the methodology for each study varied, they used the technology to capture or analyze two basic factors: (i) species distribution (predicted & actual), or (ii) habitat suitability.

When attempting to understand the migratory behavior or range of birds, capturing their spatial distribution via global location sensors attached to individual birds is the most direct way. One of studies attempted to examine the long-distance year-round movements of two species of storm-petrels using the data captured from GLS tags, which was then projected and analyzed using ArcGIS (ESRI, v.10.2). The authors of the study used various Geospatial Modeling Environment (v. 0.7.3) tools ("kde" & "iso" tools) to calculate average reported errors of GLS locations and utilization distributions (UD), which represent areas of use at different densities. By analyzing the calculated utilization distributions for each reading, the authors were able to derive and project the breeding and migratory range of the two species of storm-petrels. (Halpin et al. 2018)

Tagging individual birds with GLS trackers to examine distribution may not be a feasible or appropriate option for all studies involving avian migratory patterns. The authors of the case study, Modelling bird distributions—a combined GIS & Bayesian rule-based approach, sought to develop bird distributions models for three separate species of birds (Golden Plover, Coal Tit, Snipe) using a Bayesian Theorem approach, which can estimate the probability of finding a species in a given area. They linked known habitat preferences for each species with land use data readily available in ArcGis to create habitat variables (layers) that were applied to each study site. They were then able to project a final GIS map with predicted distribution for each species. This paper illustrated that a GIS approach can be successful in developing species distribution models that can be applied to any species of bird or habitat. (Tucker 1997)

Another remote sensing technique that can benefit avian migratory research is the use of active remote sensing systems like Doppler Radar (WSR-88D) to capture flight behavior of birds. Radar technology is especially useful because it is able to not only get data during night hours but is also capable of revealing large-scale flight patterns of birds during any weather conditions. (Diehl et al. 2003) Two of the papers aimed to examine...
radar-captured observations of nocturnal migrating birds as they flew to and over the Great Lakes. The purpose of the Tuck paper was to understand the morning flight patterns of nocturnal pattern using a single ground radar station that captured bird reflectivity data as they approached the southern coast of Lake Eerie. The authors were able to derive radial velocity (mean target velocity relative to radar station) for each observed bird flight. From the radial velocity they were also able to determine the orientation for each bird, which helped explain the response to reaching a large body of water. (Tuck et al 2018)

While the Tuck paper used reflectivity data from only one radar station, the Diehl paper utilized ten separate radar stations along side reflectivity data from ten separate portable radar systems to project detailed bird migratory behavior near the Great Lakes. Aside from the spatial data they were able to capture, the authors were also able to prove that: (i) migrating birds can be observed and measured using radar reflectivity data and (ii) there is a quantifiable relationship between reflectivity levels and density of migrating birds. Future research, including the Tuck paper, is based on the relationship between reflectivity data and bird density that was confirmed in Diehl paper. (Diehl et al 2003)

Large-scale animal migratory research, in particular long range avian monitoring, can benefit greatly from advancements in GIS and remote sensing technology. More important than the ease in using these systems will be the open access to the technology, which provides means for any researcher to capture and analyze large-scale spatial and temporal data. The information and data derived from these systems can also be used to inform future conservation management plans when dealing with birds that have habitats in two separate locations. In particular predicted species distribution or habitat suitability models can be beneficial in locating areas of interest for future conservation.

This paper illustrates how certain remote sensing systems, like the WSR-88D, can be used in several different applications including but not limited to mapping large-scale migratory patterns over a large area, like Great Lakes. They utilized reflectivity data from 10 WSR-88D radar stations that were located throughout the Great Lake area, as well as data gathered from 10 portable 3cm wavelength radar systems. By analyzing the reflectivity data from both radar systems, they were able to estimate bird density at a given point, identify lake crossings or avoidance by flocks, and morning ascent and orientation of flocks. In order to estimate bird densities, they compared reflectivity data from the 10 larger radar stations with the reflectivity data from the 10 smaller portable radar systems. Their results indicate that: (i) migrating birds can be captured using reflectivity data from WSR-88D systems and (ii) there is a quantifiable and direct relationship between reflectivity data and volumetric density of migrating birds. Once migrating bird densities were calculated, the authors were able to capture and analyze separate flocks and their behavior when approaching open water. Morning ascent and orientation of separate flocks were derived from captured radial velocity data. This paper exhibits the many ways that data captured from remote sensing systems, like the WSR-88D, can be used to explain complex biological processes, like large-scale bird migration.


In this study, the researchers were looking to gain insight on the year-round movements of two species of migrating shore birds, the Fork-tailed and Leach’s storm-petrels. Their objective was to capture and analyze the foraging and migration movements of the two species of shore birds. They modified global location sensors, which were sutured onto to individual birds, to record changes to levels of ambient light. This data provided an estimate to the length of daylight, which the authors used to estimate the captured bird’s flight path. This spatial data that was projected in the World Geodetic System 1984 in ArcGIS, which they were able to extract shape files that estimated population density in a given area. Working with the “kde” tool and the “iso” tool in Geospatial Modeling Environment (v.0.7.3), they were able to obtain an average reported GLS location error and utilization distributions for each species. Using ArcGIS desktop, they were also able to calculate various spatio-temporal characteristics of the specie’s movement including: (i) distance from the colony during breeding, (ii) total distance traveled during breeding season, (iii) migration departure date, (iv) maximum foraging range, (v) total distance traveled during migration, and (vi) date of return to the breeding area. This paper shows that GIS can be used to not only project spatial data, like the GLS locations of individual birds, but can also be used to calculate essential spatio-temporal characteristics as well as average reported location errors.

The aim for the researchers in this study was to analyze the relationship between migration patterns of the three-wattled bellbird (*Procnias tricolor*) and the seasonal patterns of vegetation, specifically their food resources. They used three remotely sensed vegetation indices in order to develop ecological niche models: (i) MODIS EVI (enhanced vegetation index), red index (RI), and normalized water index (NDWI). Using the summaries of these data points, they were hoping to explain the known migration movements of the species. Although the data did not show a significant relationship between these vegetation models and known migratory movements, it did exhibit how it was possible to use “indirect” remotely sensed data points to predict the migratory patterns of different species of birds. Utilizing remotely sensed data to develop ecological niche models can potentially be an important tool for conservationists when determining areas of future habitat conservation for migrating animals.


The objective of this study was to develop an object-oriented image approach to map suitable habitats of four separate species of migratory birds (Anatidae, Charadriidae, Ardeidae, and Laridae) in the nature reserve. By analyzing the qualitative and quantitative relationship between key habitat factors and bird populations, they developed a method to capture up-to-date spatial information on suitable habitats. They utilized a multi-spectral Landsat Thematic Mapper image (acquired 11/27/2005) that covered the nature reserve during low tide for their analysis and ERDAS Imagine software to geometrically correct the image. A Quickbird image of the reserve was also used to improve the accuracy of the classification of tidal creeks in the area. A Normalized Difference Vegetation Index (NDVI) was used to classify land cover and a supervised classification was performed, using Maximum Likelihood Classifier in ERDAS Imagine. The segmented image was then uploaded to a GIS platform for mapping. A rating system was then developed for suitable habitats for each species that ranged from “very good” to “poor”, which was then mapped using a GIS platform. Using different analytical methods and procedures they showed how GIS could assist in developing habitat suitability models that can be applied to any species or habitat.

Tuck, P., Gesicki, D.V., and Bingman, V.P. 2018. Morning flight behavior of nocturnally migrating birds along the western basin of Lake Erie. J. Field Ornithol. 89: 140-148.

In this case study, the authors intent was to understand the morning flight behavior of birds that migrate at night. There is sufficient evidence that explains the reasoning for morning flight orientations in shore birds that migrate along the coast but there is little known of the morning flights behaviors of birds that migrate over land. In order to help capture bird’s radial velocity and general direction at night, an active remote sensing system, Level II
WSR-88D, was used to obtain the necessary radar and infrared data. They were able to derive the velocity and orientation of individual birds by calculating the bird's radial velocity, which is the measure of the bird's velocity relative to the radar station. Evidence suggests that knowing the velocity of an individual bird can provide an estimate of the direction of its current flight. Although the study dealt with morning flight orientations, determining flight direction and speed during the night is necessary in analyzing the functional significance of their observed morning data. This study is an example of how active remote sensed data can be used to capture movements and speed of flocks of migrating birds without attaching GLS trackers to individual birds.


The purpose of this paper was to develop a simple habitat suitability model that would predict breeding bird distribution within the study area. Although habitat suitability models have since been more prevalent in recent ecological studies, the authors were using GIS systems as a means to analyze spatial ecological patterns early in the technology. By combining complex statistical analytical tools (Bayes Theorem for conditional probability) with GIS technology of the time, they were able to develop methodology that would produce maps of predicted species distribution. All associated GIS map layers used in the study to create GIS habitat variables were obtained from ITE Landsat imagery of Great Britain, which includes map layers with features like altitude and land cover types. In spite of the history of intensive research on bird distribution in Great Britain, this paper showed that GIS analysis could be an important tool in ecological studies going forward. The approach described in this paper can also be applied to other spatial decision support systems that may include a variety of suitability models including: ecological, economic, or hydrological models.

Additional Citation:
