Spring 2019

Landscape Factors Affecting Foraging Flight Altitudes of Great Blue Heron in Maine; Relevance to Wind Energy Development

Lauren Dolinski
University of Maine

LANDSCAPE FACTORS AFFECTING FORAGING FLIGHT ALTITUDES OF GREAT BLUE HERON IN MAINE: RELEVANCE TO WIND ENERGY DEVELOPMENT

by

Lauren Dolinski

A Thesis Submitted in Partial Fulfillment
of the Requirements for a Degree with Honors
(Wildlife, Fisheries and Conservation Biology)

The Honors College

University of Maine

May 2019

Advisory Committee:
Erik Blomberg, Associate Professor of Wildlife Ecology, Advisor
Danielle D'Auria, Biologist, Maine Department of Inland Fisheries and Wildlife
R.W. Estela, Preceptor in the Honors College
Parinaz Rahimzadeh-Bajgiran, Assistant Professor of Remote Sensing of Natural Resources
Katharine Ruskin, Lecturer in Ecology & Environmental Sciences

ABSTRACT

In an attempt to increase alternative energy sources, there has been greater development of wind farms across the United States. This expanded development may pose a potential threat to birds that are flying overhead (EIA 2017, Leung and Yang 2011). More information is needed on the factors that affect a bird's behavior while flying and if the current policies and dimensions of wind turbines interfere with flight altitudes. We used data from GPS-marked great blue herons (*Ardea herodias*) in Maine to classify their flight altitudes relative to wind turbine height and assess different landscape factors that affect flight altitude. We found an altitude range of 1 m to 924 m, compared to a range of wind turbine heights in Maine from 24 m to 156 m, with 43% of observed flight altitudes falling within that range. We found elevation, speed, proximity to open water and wetlands, and the proportion of surrounding urban development and forest cover to have a positive effect on flight altitude. Slope had a negative effect on heron flight altitudes. Our results can help to better understand how the flying behavior of birds is affected by the surrounding landscape, and therefore how that behavior may be affected by human developments, such as constructed wind turbines.

ACKNOWLEDGEMENTS

GPS data was provided by the Maine Department of Inland Fisheries and Wildlife. I would like to thank my thesis advisor Dr. Erik Blomberg for all of his help, guidance, expertise, patience, and for always promptly answering my anxious emails throughout my entire thesis process. I would like to thank wildlife biologist and committee member Danielle D'Auria for her expertise and for helping me navigate through the data of this study. My thanks go out to the rest of my committee members: Dr. Katharine Ruskin, Dr. Parinaz Rahimzadeh-Bajgiran, and R.W. Estela for their expertise and suggestions throughout my thesis process. I would also like to thank Val Watson for being the mutual connection between me and Danielle that started this project in the first place. Lastly, a huge thank you to all of my friends for their unwavering support throughout this whole process.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Development of alternative energy sources has increased globally, growing in popularity and creating new political and ecological controversies. Wind power has grown in particular, accounting for 8% of generating capacity in the United States in 2016, which occurs from inland grasslands to along coastlines, with an average annual growth of 30% (EIA 2017, Leung and Yang 2011). In 2016, almost 25% of the wind capacity in the U.S. was credited to Texas alone, with Iowa, Oklahoma, California, and Kansas contributing another 20% combined generating capacity (EIA 2017). However, other states, such as Maine, have increased their wind power production in an ever-growing effort to become less dependent on carbon-based energy sources. The wind power established in Maine has grown to over 900 megawatts, making up 20% of the generating capacity in the state (DOE 2017). Given the past and likely continued expansion of wind energy development in Maine, greater information is needed to understand potential conflicts with the states natural resources.

Many studies have assessed the possible risks of wind turbines to birds, specifically the risk of mortality due to collision with turbine blades (Larson and Guillemette 2007, Osborn and Higgins et al. 2000, Osborn and Dieter et al. 1998, Niemuth and Walker 2013, Pearce-Higgins and Stephen 2009). Although difficult to quantify, bird mortality due to turbine collision is thought to be higher than that associated with power lines (Barrio and Rodriguez 2004). While a number of studies have found that the effect of wind turbines on bird mortality is minimal, that effect is dependent on the specific site, species, and season (Aschwanden et al. 2018, Larsen and

Guillemette 2007, Barrio and Rodriguez 2004, Osborn and Higgins et al. 2000). Greater information is needed on how surrounding landscape factors affects a bird's altitude during flight. The influences of these factors, and how a bird in flight uses the air column as a result, is necessary to more accurately assess the relative risk of collision from wind turbines.

Great blue herons (*Ardea herodias*) are colony nesters, meaning multiple breeding pairs all nest in the same group of trees, commonly putting more than one nest in one tree. Herons usually nest in trees that are nearby to wetlands or other bodies of water but distant from human noise and development. During their breeding season, herons fly back and forth from their colony to their foraging site to hunt for fish or amphibians several times a day (Howell, Lewington and Russell 2014). In 2007, the great blue heron was listed as a species of special concern in the state of Maine, after censuses conducted confirmed that the coastal population had decreased by 82.5% since 1983 (MDIFW). This decline has been partly attributed to habitat disturbance (MDIFW 2015). Most of the information on great blue herons in the state of Maine has historically focused on coastal colonies and the factors that influence their habitat selection. With such a strong increase in the construction wind farms during recent decades, more information on behavior during flights is needed to better understand potential risks alternative energy sources could pose to the Maine heron population.

In this study, our objective (that of Maine Department of Inland Fisheries and Wildlife biologist Danielle D'Auria and myself) was to better understand the factors that affect the height at which a great blue heron flies during commuting flights between breeding colonies and foraging areas (hereafter foraging flights) during the breeding season. In the spring of 2016, the Maine Department of Inland Fisheries and Wildlife (MDIFW) deployed five 48g Bird Solar Unit GPS transmitters from e-obs on 5 great blue heron breeding in Maine in order to gain more information on their movement patterns and behaviors during breeding and migration. Our specific objectives for this work were to utilize the information collected by the tagged herons to: 1) to better understand the landscape factors that affect flight altitude and 2) to broadly characterize flight altitudes relative to the range of observed wind turbine heights in the state. We focused on how elevation, slope, and different land cover types affected the flight altitude of the herons, as well as how a heron's flight speed was affected by its height above ground.

METHODS

Study Area

Four herons were captured in central Maine, while the fifth was captured in southern Maine. Within central Maine, three herons were from the greater Bangor area in Penobscot County, and the other in the town of Palmyra in Somerset County. Bangor is the third largest city in Maine with a population of around 30,000 people (United States Census Bureau 2017), and is located along the Penobscot River, the largest watershed in the state. Palmyra is a small agricultural town of approximately 2,000 residents (United States Census Bureau 2017).

The fifth heron was captured in New Gloucester, Maine, in Cumberland County. New Gloucester is a rural town that has a population of almost 6,000 people, but is part of the greater Portland metropolitan area (United States Census Bureau 2017).

Capturing Birds

Great Blue Herons were captured by the Maine Department of Inland Fisheries and Wildlife (MDIFW) during spring 2016. Herons were baited using live, locally captured fish contained within bait pans, placed in locations where heron foraging activity was observed. Each basin, which was approximately 70 cm long × 63 cm wide × 16 cm deep and had multiple 3mm holes to ensure water movement, was filled with bait and then anchored with bricks. Following a multiple day baiting period, we set 30-40 modified foot-hold traps around the basin, at least 30 cm away from its edge (Brzorad and Maccarone 2014). We observed from a blind 50-100m away from the traps until a bird was captured.

Once a heron was captured, we attached a 48g Bird Solar GPRS Unit from e-obs GmbH (Germany) (Bird Solar, e-obs digital telemetry; www.e-obs.de) onto the bird using a backpack-style harness using Teflon ribbon and metal clips. These transmitters record date and time, location coordinates, ground speed, heading, and ellipsoidal height every 5 minutes, assuming the battery is appropriately charged or the heron is moving regularly. Ellipsoidal height is defined as the height above the reference ellipsoid that approximates the earth's shape and surface. Data is transmitted daily via SMS/Text messaging technology to Movebank, an open-source website (www.movebank.org).As the tags are solar-powered, shady conditions or feathers blocking the transmitter may affect battery level and thus inhibit regular collection of data.

Processing Data

We used movement data to distinguish migration periods from breeding for each individual bird and excluded data not associated with the breeding period. The post-breeding period, prior to migration, was also excluded because the daily behaviors of the herons tend to change after completion of the breeding season. Thus, our inferences are restricted to foraging flights made while herons are actively associated with their breeding colonies. While the specific dates of data extracted for each bird varied, the breeding season generally lasted between April and July. Three seasons of data were available for 2 of the birds, while only 1 season was downloaded for the remaining individuals.

We used the speed of the herons to distinguish locations collected during flight versus those collected while the bird was stationary. We explored the distribution of speed measurements, which ranged from 0.0 m/s to 29.0 m/s, and we used 4.0 m/s as a cutoff speed where every point collected >4.0 m/s was considered a flight location. All other points were excluded from the dataset.

Transmitters recorded the height above ellipsoid which does not equate directly to height above ground, so, we converted these values to height above ground using a WGS 1984 geoid height GIS layer. To find the height above ground, we subtracted the geoid height from the height above ellipsoid, and then subtracted elevation for each heron location. For our analysis, we only included positive values that fell within 99% quantile of the range of flight altitudes to eliminate extreme outliers.

GIS Analysis

We used ArcGIS version 10.6 (ESRI) to derive landscape variables that we hypothesized may affect heron flight height. We set the projection for the imported points as NAD 1983 UTM zone 19, as that zone encompasses Maine. Additionally, we obtained geographic information system (GIS) layers for land cover and geoid height from the United States Geological Survey (USGS) (www.usgs.gov) and the GIS layer of Maine elevation from the National Oceanic and Atmospheric Administration (NOAA) (www.noaa.gov). We used a digital elevation model (DEM) to extract the elevation at each heron flight point, as we hypothesized that herons would increase altitude as elevation increased. This same layer was used to derive slope values for each point as well.

The specific land cover types we were interested in analyzing were forest, wetland, open water, and low intensity urban development. Herons are known to minimize their contact with humans and are therefore primarily found within and around these types of land cover for nesting, foraging, and flying in between sites (Gibbs and Woodward et al. 1987). As herbaceous wetlands and woody wetlands are often found together, we combined them into one land cover type: wetlands. We calculated the Euclidean distances from each flight point to two different land cover types: open water and wetland. In addition, we performed a moving window analysis to calculate a mean input for the cells surrounding a flight point that included forest land cover, and then again for low intensity urban development and medium/high intensity urban development. Focal statistics analysis was performed for each of those land cover types at four different distances, in order to account for a range of distances and timings required for a heron to alter its height depending on the land cover below. The average heron flight speed was 11 m/s, so we used this speed to calculate the average distance the herons were traveling at 15-, 30-, 45-, and 60-second intervals, which approximately corresponded with 175 m, 345 m, 520 m, and 690 m buffers, respectively. We also assessed how many different land cover types were within a 345 meter radius of each flight point. Finally, we used the spatial analyst tool to extract the values from each raster layer at each flight point.

Statistical Analysis in R

Prior to model building, we z-standardized the numeric variables and created a correlation matrix to ensure there were no highly correlated variables. Any combination of variables with correlation >0.6 were considered highly correlated, and we excluded one of the pair from our models. We fit a linear mixed-effect model to the data that included an individual random intercept term, starting with a null equation (intercept plus individual random effect) and then continuing with each variable. We included all variables that were supported and not highly correlated with each other to create a final linear mixed-effect model. We used an Akaike's Information Criterion (AIC) to assess model support and determined variables were supported when models were within 2.0 AIC units. We used the AIC of this model to compare to the other AIC scores for each individual variable. We also evaluated 95% confidence intervals for the slope coefficient (β) of each variable, and considered a variable supported when the interval did not overlap 0.0.

RESULTS

The flight speeds of the 5 herons ranged from 4.0 to 27.0 m/s, with an average of 11m/s ± 2.9. Flight altitudes ranged from 1 m to 924 m above ground level with an average of 50m. Each bird had some variation in their range of flight altitudes. Two birds flew within the general range of 1 to 200m above ground, while the remaining 3 birds flew more consistently at lower altitudes, between 1 and 100 m (Fig. 1). While these are the general ranges that the herons flew within, there were numerous outliers at higher altitudes for 3 of the birds. Overall, we found that 43% of heron flight altitudes fell within the range of normal turbine height construction in Maine, which we found was between 24 m and 156 m (Fig.2).

Our correlation matrix revealed that the only highly correlated variables were the focal statistics for low intensity urban development at distances of 175, 345, 520, and 690 m, as well as the focal statistics for forest land cover at the same distances. While all models for the focal statistics of low intensity urban development were supported with positive effects, the lowest AIC value out of these models was at a distance of 345 m (Table 1). For this reason, we used only the values at a distance of 345 m for additional statistical analysis of urban development land cover. After performing the general linear mixed model regressions on all of the variables and a null model, the AIC values were ranked from lowest (most supported) to highest (least supported) in comparison to the value for the null model, which was 28661.41 (Table 1). The proximity to open water model and proportion of forest land cover did not have any effect on flight altitudes. Slope had a negative effect on flight altitude. The rest of the variables had positive effects on flight altitude (Fig 3.). The model for speed had the best fit out of our tested variables, with the lowest AIC value of 28596.48 (Table 1).

DISCUSSION

We found that herons increased their flight altitudes as they flew at faster speeds, or more likely, flying at greater altitudes facilitated faster flight. Previous studies have shown that birds generally fly faster at higher altitudes, usually to minimize travel time and maximize energy intake at their destination, whether it be a migration stop-over or foraging patch (Chevallier and Handrich et al . 2010, Hedenstrom and Alerstam 1995, Brigham and Fenton et al. 1998, Nilsson and Klaasen et al. 2013). The speed and altitude of bird flights has been found to be influenced by travel distances and wind speed, as higher wind speeds may occur at higher altitudes, which will affect flight height, especially during longer flights (Chevallier and Handrich et al. 2010, Hedenstrom and Alerstam 1995, Allen 1939). Most of the literature concerning flight speed with relevance to altitude focuses on migration flights, which do not directly apply to foraging flights. Our study supports that flight speed is an important influence on flight heights and may affect it in similar ways.

We found that the type of land cover the herons flew over influenced their flight height. Two of our land cover variables were supported in our models with positive effects. The greater the distance between a heron and any type of wetland, the greater the flight altitude. Altitude also increased with proportional low intensity urban development cover, at all of the distances that we tested. However, the distance with the best AIC value was within 345 meters. This suggests that 345m, or about 30 seconds of flight speed, may be the distance at which herons assess their surroundings and adjust altitude accordingly. Our findings imply that risk of collision may increase around wetlands as herons decrease their altitude, presumably prior to landing or following take off near these features. These implications support guidelines imposed by MDIFW that proposed developments cannot be near to sensitive or significant areas and habitats (WEF guidebook).

Elevation had a positive effect on heron flight altitude, so when elevation increases, flight altitude increases as well. In addition, slope had a negative effect on flight altitudes. Therefore, while herons flew higher at higher elevations, if the increase in elevation was steep, they flew closer to the ground than over gradual elevation increases. Another study has supported that birds adjust their flight heights for changes in elevation and additional obstacles on the ground, such as wind turbines, the first ones being as early as Osborne and Dieter et al. 1998. Our findings imply that herons are more likely to fly higher rather than diverting their path to avoid obstacles such as that presented by a change in elevation. Due to this behavior, herons may avoid wind turbines, which are often placed at locations with higher elevation, by virtue of increased altitude.

While our study did not examine mortality rates for these herons or explicitly evaluate collision risk, our results imply that herons may be at risk of collision during foraging flights, according to the range of altitudes we observed. The five great blue herons in this study flew at heights that ranged from 1 m to 446 m, with an average of 118 m. Today, the average height of commercial wind turbines is approximately 80 meters (EIS 2017). In Maine, the approximate average height of turbines that have been constructed is 130 m (MDIFW). The suggested minimum turbine height in the state is around 24 m and the maximum height that has been constructed is approximately 156 m (MDIFW and WEF guidebook). This broad range intersects with 43% of heron flight altitudes we observed within Maine. While turbine height varies across different sites, the average height seems to be increasing. Prior to 2006, the highest wind turbines seen were 80 m tall, but since 2012, that height has become the commercial average (EIS 2017). Increasing turbine height may pose a future risk for herons and other birds if constructed along their flight paths, depending on elevation and the slope of the area they are flying over. The highest height seen on applications for wind energy projects in Maine is 180 m, and so it is likely wind turbines height could increase upwards of 200 m in the near future (MDIFW). Furthermore, studies have shown that migrating birds are able to detect whether or not turbine blades are rotating and alter their flight height or adjust their flight path accordingly (Osborne and Diet et al. 1998). While our study only focused on local foraging flights, herons and other migrating birds may generally be better equipped to deal with obstacles such as turbines, but other bird species, such as residential passerines, may have a greater risk of collision (Osborne and Diet et al. 1998). Other studies that have shown that the presence of wind farms affects the presence and flight paths of birds and could have a negative impact on habitat availability (Marques et al. 2019, Larsen and Guillemette 2007). Our findings indicate that herons may be capable of flying higher to avoid ground obstacles, but limited quantifiable mortality rates in the literature suggest that the birds are more likely to avoid an area with wind turbines or that additional studies on bird mortality due to turbine collision is needed. In practice, additional wind farms in Maine may contribute to reduced habitat availability for great blue herons.

While our results provide insight on what affects the height of a heron during a foraging flight, we acknowledge several limitations in our study. First, we focused exclusively on foraging flights, and our findings should not be extrapolated to migration flight patterns, as these longer flights may occur at different altitudes. Second, we worked with a modest sample size of 5 herons, with a specific spatial distribution in Maine, which may make it difficult to interpret our results as representative of Maine herons more generally. Third, our study area was also restricted to only where these herons have lived and foraged, and did not occur in close proximity with any current operating wind farms. As a result, our findings allow predictions of how the heights of wind turbines may intersect with foraging flights of herons, but are not direct measures of risk. These caveats notwithstanding, the advanced technology used in our study gives us the most informative data on great blue heron foraging and flight behavior in Maine to date, as well as expanding from previous information that only focused on coastal populations. With continued technological advancements, future studies can include a more representative sample size from a greater range of colonies across Maine and examine additional influences on flight height like wind, temperature, and weather, and the energy costs of foraging flights. Further studies can also expand their focus to migration flights and comparing the range of altitudes, speeds, and energy costs during longer flights.

With the expansion of wind energy in the United States, controversy surrounding the construction and design of wind farms will continue to grow at a federal and state level. Maine, being an eco-friendly state located along the coast, can expect continued discussion and legislation concerning growing wind farms. An ecological concern that MDIFW has addressed for the past decade and continues to is the potential impact on the wildlife in Maine, especially the birds and bats (MDFIW). Great blue herons, being a species of special concern and one that travels a variety of distances within and across Maine for foraging and wintering may need to play a role in policy decisions for future wind farm construction. The Maine Department of Inland Fisheries and Wildlife (MDIFW) already has forest management guidelines to minimize disturbances around great blue heron colonies during the breeding season. While we observed that these birds were able to fly higher in response to increased elevation and distances from certain land cover types, the increased flight speed that is associated with higher flight altitudes likely pose additional threats. Visibility and turbulence could become issues if herons need to fly higher in order to avoid increased numbers of wind turbines or taller turbines if turbine heights begin to exceed 156 m in Maine. Our study supports the guidelines issued by MDIFW for forestry practices that ensure minimal disturbance to heron colonies and their habitats, and the similar considerations enforced for wind energy developments. Currently, guidelines promoted by MDIFW are merely suggested and are not enforced for any wind energy development project (MDIFW). While companies or businesses looking to construct a development must submit an application including specific information on wind turbine numbers and dimensions that must be approved, followed by an assessment of the site location, the companies themselves choose the size and dimensions of the turbines and blades and the location of the site without limits being enforced. Greater buffers surrounding wetlands and open water may be needed for wind farm construction to account for lower flight altitudes flying to and from these habitats that could increase collision risk. Our model would allow for the prediction of heron flight altitude at a particular site and therefore could assess collision risk for future construction (Table 2). In order to conserve maximum suitable habitat for herons, considerable buffers between wetlands and other bodies of water are required for any construction of future wind farms.

LITERATURE CITED

Allen FH. Effect of Wind on Flight Speeds. *The Auk* 56: 291–303, 1939.

Aschwanden J, Stark H, Peter D, Steuri T, Schmid B, Liechti F. Bird collisions at wind turbines in a mountainous area related to bird movement intensities measured by radar. *Biological Conservation* 220: 228–236, 2018.

Barrios L, Rodríguez A. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines: Bird mortality at wind power plants. *Journal of Applied Ecology* 41: 72–81, 2004.

Brigham, Mark R, Fenton, Brock M, Aldridge HDJN. Flight Speed of Foraging Common Nighthawks (Chordeiles minor): Does the Measurement Technique Matter? *The American Midland Naturalist* 139: 325–330, 1998.

Brzorad JN, Maccarone AD. An Inexpensive Technique for Capturing Gregarious Wading Birds on their Foraging Grounds. *Waterbirds* 37: 335–339, 2014.

Bureau UC. Census.gov [Online]. [date unknown]. https://www.census.gov/en.html

Chevallier D, Handrich Y, Georges J-Y, Baillon F, Brossault P, Aurouet A, Le Maho Y, Massemin S. Influence of weather conditions on the flight of migrating black storks. *Proc R Soc B* 277: 2755–2764, 2010.

Gibbs JP, Woodward S, Hunter ML, Hutchinson AE. Determinants of Great Blue Heron Colony Distribution in Coastal Maine. *The Auk* 104: 38–47, 1987.

Larsen JK, Guillemette M. Effects of wind turbines on flight behaviour of wintering common eiders: implications for habitat use and collision risk: Wind turbines and wintering common eiders. *Journal of Applied Ecology* 44: 516–522, 2007.

Hedenstrom, Anders, and Thomas Alerstam. "Optimal Flight Speed of Birds," n.d., 18.

Howell, S., Lewington, I., & Russel, W. (2014). *Rare Birds of North America*. Princeton University Press.

Leung DYC, Yang Y. Wind energy development and its environmental impact: A review. *Renewable and Sustainable Energy Reviews* 16: 1031–1039, 2012.

Marques AT, Santos CD, Hanssen F, Muñoz A, Onrubia A, Wikelski M, Moreira F, Palmeirim JM, Silva JP. Wind turbines cause functional habitat loss for migratory soaring birds. *J Anim Ecol* (March 11, 2019).

National Oceanic and Atmospheric Administration [Online]. [date unknown]. https://www.noaa.gov/

Niemuth ND, Walker JA, Gleason JS, Loesch CR, Reynolds RE, Stephens SE, Erickson MA. Influence of Wind Turbines on Presence of Willet, Marbled Godwit, Wilson's Phalarope and Black Tern on Wetlands in the Prairie Pothole Region of North Dakota and South Dakota. *Waterbirds* 36: 263–276, 2013.

Nilsson C, Klaassen RHG, Alerstam T. Differences in Speed and Duration of Bird Migration between Spring and Autumn. *The American Naturalist* 181: 837–845, 2013.

Osborn RG, Dieter CD, Higgins KF, Usgaard RE. Bird Flight Characteristics Near Wind Turbines in Minnesota. *The American Midland Naturalist* 139: 29–38, 1998.

Osborn RG, Higgins KF, Usgaard RE, Dieter CD, Neiger RD. Bird Mortality Associated with Wind Turbines at the Buffalo Ridge Wind Resource Area, Minnesota. *The American Midland Naturalist* 143: 41–52, 2000.

Pearce-Higgins JW, Stephen L, Langston RHW, Bainbridge IP, Bullman R. The distribution of breeding birds around upland wind farms. *Journal of Applied Ecology* (September 2009).

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (n.d.). Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=31032#tab2

USGS.gov | Science for a changing world [Online]. [date unknown]. https://www.usgs.gov/

Wind Energy in Maine. (n.d.). Retrieved from https://windexchange.energy.gov/states/me#capacity

BIBLIOGRAPHY

Acquisto, A. (2019, February 15). Janet Mills Lifts LePage ban on new wind power permits in Maine. *Bangor Daily News*. Retrieved from https://bangordailynews.com/2019/02/15/politics/mills-lifts-lepage-ban-on-new-wind-power-permits-in-maine/

Allen FH. Effect of Wind on Flight Speeds. *The Auk* 56: 291–303, 1939.

Aschwanden J, Stark H, Peter D, Steuri T, Schmid B, Liechti F. Bird collisions at wind turbines in a mountainous area related to bird movement intensities measured by radar. *Biological Conservation* 220: 228–236, 2018.

Barrios L, Rodríguez A. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines: Bird mortality at wind power plants. *Journal of Applied Ecology* 41: 72–81, 2004.

Beaver, D., Osborn, R., & Custer, T. (1980). Nest-Site and Colony Characteristics of Wading Birds in Selected Atlantic Coast Colonies. *The Wilson Bulletin, 92*(2), 200-220.

Brigham, Mark R, Fenton, Brock M, Aldridge HDJN. Flight Speed of Foraging Common Nighthawks (Chordeiles minor): Does the Measurement Technique Matter? *The American Midland Naturalist* 139: 325–330, 1998.

Brzorad JN, Maccarone AD. An Inexpensive Technique for Capturing Gregarious Wading Birds on their Foraging Grounds. *Waterbirds* 37: 335–339, 2014.

Bureau UC. Census.gov [Online]. [date unknown]. https://www.census.gov/en.html

Carpenter FW. An Astronomical Determination of the Heights of Birds during Nocturnal Migration. *The Auk* 23: 210–217, 1906.

Chevallier D, Handrich Y, Georges J-Y, Baillon F, Brossault P, Aurouet A, Le Maho Y, Massemin S. Influence of weather conditions on the flight of migrating black storks. *Proc R Soc B* 277: 2755–2764, 2010.

Erwin, R. (1985). Foraging Decisions, Patch Use, and Seasonality in Egrets (Aves: Ciconiiformes). *Ecology, 66*(3), 837-844.

Gibbs JP, Woodward S, Hunter ML, Hutchinson AE. Determinants of Great Blue Heron Colony Distribution in Coastal Maine. *The Auk* 104: 38–47, 1987.

Grossman, D. (2018, January 30). Governor of Maine Bans All New Wind Farms. *Bangor Daily News*. Retrieved from https://www.popularmechanics.com/technology/infrastructure/a15929521/governor-of-maine-bans-all-new-wind-farms/

Gustafson T, Lindkvist B, Gotborn L, Gyllin R. Altitudes and Flight Times for Swifts Apus apus L. *Ornis Scandinavica* 8: 87, 1977.

Hafner, H. (1997). Ecology of Wading Birds. *Colonial Waterbirds,20*(1), 115-120.

Hedenstrom, Anders, and Thomas Alerstam. "Optimal Flight Speed of Birds," n.d., 18.

Howell, S., Lewington, I., & Russel, W. (2014). *Rare Birds of North America*. Princeton University Press.

Kellett, J. (1990). The Environmental Impact of Wind Energy Developments. *The Town Planning Review, 61*(2), 139-155.

Larsen JK, Guillemette M. Effects of wind turbines on flight behaviour of wintering common eiders: implications for habitat use and collision risk: Wind turbines and wintering common eiders. *Journal of Applied Ecology* 44: 516–522, 2007.

Leung DYC, Yang Y. Wind energy development and its environmental impact: A review. *Renewable and Sustainable Energy Reviews* 16: 1031–1039, 2012.

Maine State Planning Office. Wind Energy Facility Ordinance Guidebook. 2010.

Marques AT, Santos CD, Hanssen F, Muñoz A, Onrubia A, Wikelski M, Moreira F, Palmeirim JM, Silva JP. Wind turbines cause functional habitat loss for migratory soaring birds. *J Anim Ecol* (March 11, 2019).

Myers, J., Morrison, R., Antas, P., Harrington, B., Lovejoy, T., Sallaberry, M., . . . Tarak, A. (1987). Conservation Strategy for Migratory Species. *American Scientist, 75*(1), 18-26.

National Oceanic and Atmospheric Administration [Online]. [date unknown]. https://www.noaa.gov/

Niemuth ND, Walker JA, Gleason JS, Loesch CR, Reynolds RE, Stephens SE, Erickson MA. Influence of Wind Turbines on Presence of Willet, Marbled Godwit, Wilson's Phalarope and Black Tern on Wetlands in the Prairie Pothole Region of North Dakota and South Dakota. *Waterbirds* 36: 263–276, 2013.

Nilsson C, Klaassen RHG, Alerstam T. Differences in Speed and Duration of Bird Migration between Spring and Autumn. *The American Naturalist* 181: 837–845, 2013.

Osborn RG, Dieter CD, Higgins KF, Usgaard RE. Bird Flight Characteristics Near Wind Turbines in Minnesota. *The American Midland Naturalist* 139: 29–38, 1998.

Osborn RG, Higgins KF, Usgaard RE, Dieter CD, Neiger RD. Bird Mortality Associated with Wind Turbines at the Buffalo Ridge Wind Resource Area, Minnesota. *The American Midland Naturalist* 143: 41–52, 2000.

Parris, R., & Grau, G. (1979). Feeding Sites of Great Blue Herons in Southwestern Lake Erie. *Proceedings of the Colonial Waterbird Group, 2*, 110-113.

Pearce-Higgins JW, Stephen L, Langston RHW, Bainbridge IP, Bullman R. The distribution of breeding birds around upland wind farms. *Journal of Applied Ecology* (September 2009).

Pratt, H. (1970). Breeding Biology of Great Blue Herons and Common Egrets in Central California. *The Condor, 72*(4), 407-416.

Smallwood, K., Rugge, L., & Morrison, M. (2009). Influence of Behavior on Bird Mortality in Wind Energy Developments. *The Journal of Wildlife Management, 73*(7), 1082-1098.

Smallwood, K. Shawn. (2013). Introduction: Wind-Energy Development and Wildlife Conservation. *Wildlife Society Bulletin (2011-), 37*(1), 3-4.

Spaar R, Bruderer B. Soaring Migration of Steppe Eagles Aquila nipalensis in Southern Israel: Flight behaviour under Various Wind and Thermal Conditions. *Journal of Avian Biology* 27: 289, 1996.

Stantial ML, Cohen JB. Estimating flight height and flight speed of breeding Piping Plovers: Flight Height and Speed of Breeding Piping Plovers. *J Field Ornithol* 86: 369–377, 2015.

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (n.d.). Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=31032#tab2

USGS.gov | Science for a changing world [Online]. [date unknown]. https://www.usgs.gov/

Wind Energy in Maine. (n.d.). Retrieved from https://windexchange.energy.gov/states/me#capacity

APPENDIX A

Table 1. AIC scores and degrees of freedom for each landscape variable affecting flight height of great blue herons, sampled 2016-2018

Variable	df	AIC	ΔAIC
Speed	4	28596.48	0
Wetlands	4	28641.37	44.89
Low urban development (345m)	4	28645.29	48.81
Low urban development (690m)	4	28648.04	51.56
Low urban development (175m)	4	28648.28	51.80
Low urban development (520m)	4	28649.17	52.69
Variety of land cover types	4	28652.00	55.52
Elevation	4	28656.78	60.30
Slope	4	28660.21	63.73
Null	3	28661.41	64.93
Forest (175m)	4	28662.11	65.63
Open water	4	28662.86	66.38
Forest (345m)	4	28663.10	66.62
Forest (520m)	4	28663.12	66.64
Forest (690m)	4	28663.40	66.92

Table 2. Calculated 95% confidence intervals, beta coefficients, and standard error for each landscape variable affecting flight height of great blue herons, sampled 2016-2018

Variable	Beta Coefficient	Standard Error	Lower Confidence Interval	Upper Confidence Interval
Elevation	1.41	3.25	-4.96	7.78
Speed	17.37	1.94	13.57	21.17
Wetland	9.47	2.33	4.90	14.03
Open water	5.57	2.09	1.47	9.66
Low intensity urban development (345m)	6.70	2.27	2.25	11.14
Forest (345m)	3.03	2.27	-1.42	7.47
Variety of land cover types	6.67	2.36	2.04	11.29

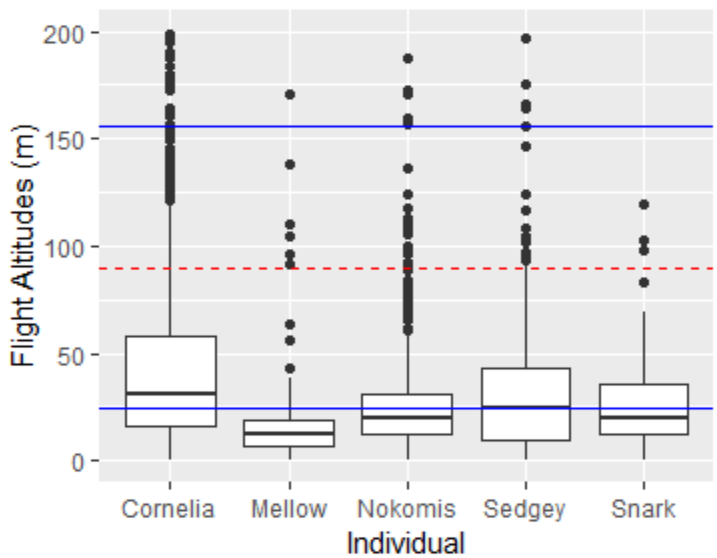

Figure 1. Boxplot of the flight altitudes for each individual great blue heron, sampled in Maine 2016-2018. The blue lines represent the lower and upper range of wind turbine heights, with the average height represented by the red dashed line.

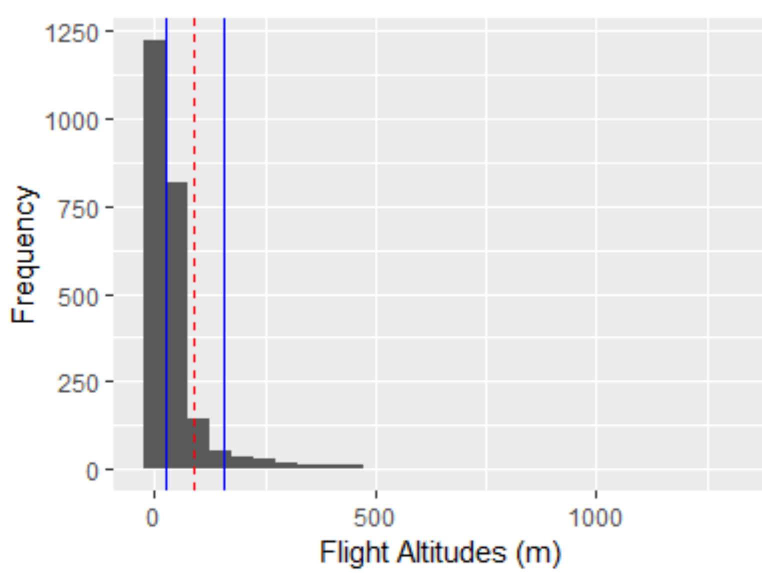

Figure 2. Histogram of the range of flight altitudes of great blue herons sampled in Maine 2016-2018. The blue lines represent the lower and upper range of wind turbine heights, with the average height represented by the red dashed lines.

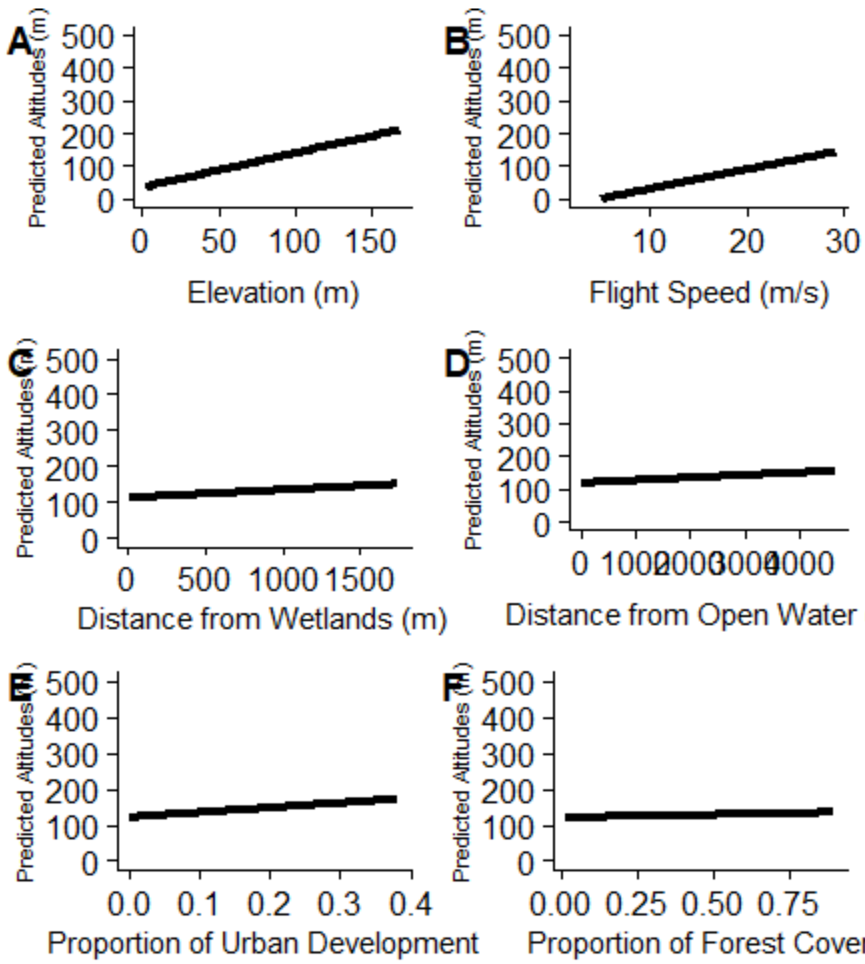

Figure 3. Predicted flight altitudes of great blue herons based on landscape variables, sampled in Maine 2016-2018

AUTHOR'S BIOGRAPHY

Lauren Dolinski was born on December 31, 1996 in Northampton, Massachusetts. She was raised in Easthampton, Massachusetts and graduated from Easthampton High School in 2015. While attending the University of Maine, Lauren majored in Wildlife Ecology with a particular interest in ornithology. She was an active member of the Maine Student Chapter of the Wildlife Society for all four years of her college career.

Upon graduation, Lauren will be spending some time working off the coast of Georgia monitoring sea turtles and shore birds. Later on she hopes to travel to places warmer than Maine working avian technician jobs before pursuing a Master's degree and continuing to follow birds all around the globe.