East-northeast view from Lookout Road near Altoona, Pennsylvania (public access: 40.56713 N, -78.44014 W). Here, the author observed 26 migrating Golden Eagles on November 30, 2013. Photo by Andrew Dennhardt

# Accounting for Raptors Beyond Our Sight: Modeling Migration and Hawk Count Data to Estimate the Golden Eagle Population in Eastern North America

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## Introduction

We arrive early in the morning soon after dawn. The hike from where we parked to where we will watch is all uphill, to the top of Brush Mountain near Altoona, Pennsylvania. We pass a pair of hunters as they are leaving. They know what we have come to search for. One of them says, "Good luck. We hope that you see a lot of them today." We reach an open area in a break of the tree line and quickly set up our chairs and spotting scope. Facing west-northwest, we enjoy a clear view of the mountainside and the valley below. The winds are blowing hard, upwards of 25 mph. On an overcast late-November day the ambient temperature nears frigid, but we have come prepared this time, wrapped in layers of insulated clothing.

My companion has yet to see a Golden Eagle, and given the high winds and the angle of our lookout, I am skeptical as to whether or not we will actually see any this day. However, within a minute of settling in, my skepticism is immediately silenced. My friend calls out with great enthusiasm, and as I turn around to face the valley, I catch a glimpse of the day's first Golden Eagle. As dawn turns into dusk, we record 11 more Golden Eagles migrating by. Soon after, though, a question arises: how many more eagles are actually out there, beyond our sight?

Such a question is central to understanding how many eagles migrate through the Appalachian Mountains. Estimating population size is essential to species conservation and management. However, demographic estimation is neither simple nor straightforward in practice. Wide-ranging species like raptors are rare, occur at low densities and avoid humans, making them difficult to survey. Despite these challenges, raptors are apex predators that are useful indicators of the health of biological systems; therefore, monitoring their populations is of paramount importance.

The abundant data that HMANA's remarkable network collects have been used for decades to estimate raptor population trends. However, it is far more unusual to use these data to estimate population size. The goal of my research was to do exactly that: to use hawk count data to estimate population size for eastern Golden Eagles and to do so by using tools that can be broadly generalized to other migrant raptor species.

Golden Eagles are uncommon in eastern North America and little is known about their ecology, behavior and demography. There are few of these birds—previous estimates range from 1-5000 individuals—however, no empirical studies have validated those estimates. Eastern Golden Eagles summer

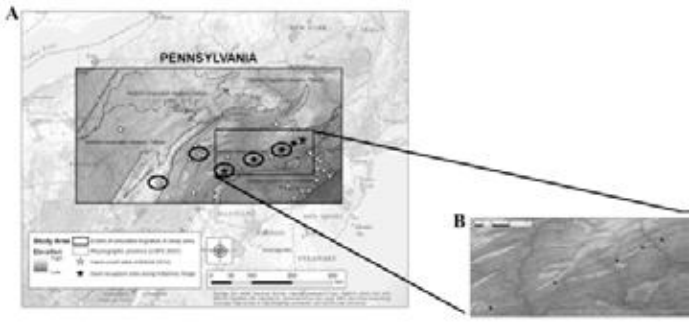


Figure 1. a) Simulation modeling area: the central Appalachian Mountains in Pennsylvania, USA. Here, migration predominantly proceeds in the southwesterly direction each autumn. b) Mark-recapture modeling area: the Kittatinny Ridge. Mark-recapture sites (black stars) are, from northeast to southwest: Little Gap, Bake Oven Knob, Hawk Mountain Sanctuary, Second Mountain, and Waggoner's Gap. Hawk-count sites whose data formed local populations that were summed to obtain a regional estimate (black ellipses) are, from east to west: Hawk Mountain Sanctuary, Second Mountain, Waggoner's Gap, Stone Mountain and Allegheny Front.

throughout eastern Canada, migrate through the Appalachians and Great Lakes in autumn, and overwinter in areas of the upper Midwest and eastern United States. In the course of their migration, they are counted in relatively large numbers at HMANA hawk count sites.

In this research, I used computer models to simulate Golden Eagle migration and combined those simulations with hawk count data to estimate population size. My research was focused on three key questions. First, what proportion of migrating Golden Eagles pass within sight of hawk-count observers (i.e. how available are eagles to be counted)? Second, I asked how frequently do Golden Eagles actually get counted (i.e. what proportion of available eagles are actually detected)? Lastly, by adjusting hawk-counts for rates of availability and detection, how can we estimate the number of Golden Eagles actually out there—eagles within and beyond our sight?

## The Project

I focused this project on a region roughly defined by the state of Pennsylvania (Figure 1a). This area has many hawk count sites, attracts large numbers of migrating Golden Eagles and includes diverse topography that guides eagle migration. The weather is typically dominated by easterly and westerly winds that interact with topography to produce orographic (ridge) uplift. Furthermore, this region includes the Kittatinny Ridge, which is one of few locations worldwide that has multiple hawk-count sites along the same ridgeline (Figure 1b). The proximity of the sites suggests that an individual eagle can be counted and recounted as it goes migrates down the ridge, and that recounting is a critical component of this project.

To better understand eagle movements in Pennsylvania, I first built a computer model that simulates autumn migration of eagles through the region. In this model, eagles generally move along areas where uplift is greatest. I then used this model to assess availability rates of Golden Eagles to observers at sites in Pennsylvania. To do this, I estimated the proportion of simulated eagles that passed within a sighting distance (3 km) of known hawk count sites in the region—those eagles that were available to be counted. I then used a mark-recapture analysis of hawk count data along the Kittatinny Ridge to estimate detection rates for Golden Eagles at sites in Pennsylvania.

This is where the HMANA-archived data became especially important. To estimate detection rates, I used a computer program to identify which eagles seen on the Kittatinny were seen at more than one of the five hawk-count sites (Figure 1b). To do so, the program I wrote had a couple of rules. These were that: 1) Golden Eagles had to be recorded at separate sites on the same day in November during 2002 – 2011; 2) eagles had to be classified to the same age class category by hawk-count observers, whether recorded as an adult or immature bird; and 3) eagles leaving a site upstream on the Kittatinny Ridge had to reach the next consecutive site downstream within an estimated time window based on known eagle flight speeds and distances between sites. Using these matching rules, my computer program generated capture histories representing the track-sequence of individual eagles at sites over time. Each eagle had its own capture history, a sequence of 5 digits—a one when a bird was counted and a zero when it was missed by observers. When enough birds pass through the area, I can then estimate what proportion of available birds are actually detected by hawk count observers.

The last step in the process was to estimate the number of Golden Eagles migrating through Pennsylvania. To do this, I used count data totals from five hawk-count sites: Allegheny Front, Stone Mountain, Waggoner's Gap, Second Mountain and Hawk Mountain Sanctuary (Figure 1a). I then used the following equations to adjust those counts with the availability and detection rates described above:

$$\text{Estimated no. eagles available} = \text{Total no. eagles detected} \times \text{Availability rate} \quad (1)$$

$$\text{Estimated total no. eagles present} = \text{Estimated no. eagles available} \times \text{Detection rate} \quad (2)$$

Finally, after estimating the total number of eagles present at each hawk count site in November for every year, I simply summed the local population size from each site together to estimate the regional population size for a given year.

## Results and Conclusions

My model simulated ~6,000 flight routes for Golden Eagles migrating through Pennsylvania. On average, 24% of eagles passed within 3 km of a hawk-count site. Using HMANA data, I was able to generate 3,069 capture histories of migrating Golden Eagles along the Kittatinny Ridge. Those count data let me estimate that hawk count observers detect ~57% of the eagles that pass within 3 km of their watch site. Adjusting the numbers of eagles counted at each hawk count site by availability and detection rates suggests that on average, around 5,122 Golden Eagles pass through Pennsylvania each autumn.

North-northeast view from a private clearing on the Allegheny Mountains, several miles north of the Allegheny Front hawk-count. Photo by Andrew Dennhardt

If this is accurate, then the true population of eastern Golden Eagles must be even greater than that because it includes both the Pennsylvania migrants as well as others outside of the state. This also suggests that the true population size is larger than previous estimates for the region.

Citizen-science data such as hawk counts are becoming more abundant year-in and year-out. To my knowledge, this is the first case of its kind where these data, integrated with movement models, helped estimate the size of a migratory raptor population. Of course, there are still multiple research needs about eastern Golden Eagles. These include new studies on the species' winter distribution and further population trend analyses. All the while, continued conservation and management of the species is necessary in the wake of increased threats to individual eagles, such as that of lead poisoning and wind energy development.

I have many fond memories of hiking to ridgelines to look for migrating Golden Eagles in the central Appalachians. Some of those mountains hosted established hawk count sites like Allegheny Front, Hawk Mountain and several others. Other areas were more like Brush Mountain, diamonds in the rural rough, visited only by the occasional hunter as well as remarkable numbers of Golden Eagles. In the course of my time counting eagles, it was easy to forget why I was out there and what use the data provided me. However, seeing my models produce results that were both realistic and convincing reminded me of the conservation value of this citizen-science enterprise and, more broadly, of HMANA.

## Acknowledgements

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## Historic Day on Jacks Mountain Hawk Watch October 31, 2014

*By Darrell Smith*

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It was around 12:30 p.m. Eastern Standard Time when I asked Craig Kochel whether he was going to stick around or head back home, which is a little over a two-hour drive for him. He said that he was trying to make up his mind but hadn't decided yet. We talked about the lack of raptors flying when we had a good southeast wind.

But don't let me get ahead of myself. It was around 9:05 a.m. EST on Friday, October 31 when I pulled into the parking lot at the Jacks Mountain Hawk Watch. I saw that Craig Kochel, a professor of geology from Bucknell University, was already on watch. Craig and I have spent many days on Jacks together and I enjoy his company very much. I said hello and asked him if he had seen anything yet. He said that he saw a female Northern Harrier and a Red-tailed Hawk. I spent a few minutes getting some things together and proceeded to get my observation sheet started. The wind was from the southeast at around 6 to 11 miles per hour. I could see approximately 22 kilometers with 100% overcast skies and no precipitation. I put down the harrier and the red-tail and proceeded to watch toward the north with Craig hoping to have a good day.

Fast forward to about 12:50 p.m. since we did not see a single raptor the rest of the morning. Craig and I remarked about how unusual it was that we were not seeing any raptors with a good SE wind, but we know the birds do what they want, when they want. We were both wondering if it was worth spending any more time on watch and then it happened.

We saw a large bird coming from the north that turned out to be an adult Golden Eagle at 12:55 p.m. That bird started a parade of Golden Eagles that would last for over 2½ hours. It was extremely dark at times and overcast all day, which made it hard to identify the maturity of many. In the list below A is for adult, Imm for immature and U for unknown maturity. Here goes as we saw them.

12:55A, 2 at 1:02U, 2 at 1:03U, 1:07A, 1:10A, 1:11A, 1:14U 2 at 1:17A, 1 at 1:17U, 2 at 1:22U, 1:24A, 1:26A, 1:28A, 1:33A, 4 at 1:38A, 4 at 1:38U, 2 at 1:40U, 2 at 1:43U, 2 at 1:46U, 2 at 1:50U, 1:52A, 1:53U, 2 at 2:05U, 2:10A, 2:13A, 2 at 2:19A, 3 at 2:19U, 2 at 2:23A, 2 at 2:31U, 2:59A, 3 at 3:07A, 3:15Imm, 3:31A and 3:35Imm.