**Washington College**
**Department of Environmental Science and Studies**

# A Longitudinal Study of the Effect of Lunar Cycles on Migration for Maryland's *Aegolius acadius* Population

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ABSTRACT

This project focuses on the impacts of moon luminance on the migratory behavior of the Northern saw-whet owl throughout Maryland. Data sets from three different research sites throughout Maryland (Assateague Island, Casselman River, and Lambs Knoll) that spanned over 20 years of research were analyzed to study the impacts of moon luminance on saw-whet owl catch rates at the research sites to indicate migratory patterns. This data was analyzed for covariance using ANCOVA statistics programing and tested at both the statewide and site-specific levels for pooled data sets involving all years and data sets for individual years as well. Results indicated that there were individual years of significance ($p<0.05$) on a statewide (4 years of significance) and site-specific level (4 years of significance) but no trials of pooled years were significant for either statewide or site-specific trials. These years of significance mostly fell around years of high owl captures per season, indicating the possibility of their validity being higher due to greater effort values in capturing owls than in other years. These findings may have been biased by different methodology on a site-by-site basis, lack of collection of data on evenings of extreme weather when moon luminance may have most impacted owl migration, cloud cover not having been accounted into the analysis, as well as other potential factors that may have skewed results. Further testing with data that is more controlled and which involves cloud cover analysis should be conducted to assist this study in providing feedback on moon luminance's effect on owl migration in order to design of more efficient sampling programs.

# INTRODUCTION

*Northern Saw-whet Owl Description—Physical and Behavioral*

A common species throughout North America and Canada, the Northern saw-whet owl (*Aegolius acadius*) is one of the smallest owl species in size with males measuring an average 18 to 20 cm in length and about 75 g in mass and females at 20 to 21.5 cm in length with about 100 g in mass. Northern saw-whet owls can be noted by their large golden eyes offsetting white facial disks amid brown-streaked feathers and white crowns and napes as well as spots of white on their tails, wings, and backs. These birds consume small mammals such as deer mice (*Peromyscus*) and meadow voles (*Microtus pennsylvanicus*). Their feeding decisions are influenced by prey size (generally <40g) and habitat as well as space to hide remaining prey item as Northern saw-whet owls only eat half of their prey items at a time. These birds make calls with 9 different known vocalizations, one of which, called the advertising call, is used as audiolure in migratory studies. These owls are usually monogamous in their reproductive behaviors although there are instances of polygamy with this species in seasons of highly available prey. Natural predators of these individuals include larger owls such as the Long-eared Owl (*Asio otus*), Great Horned Owl (*Bubo virginianus*), and Barred Owl (*Strix varia*) (Cannings, 1993).

Northern saw-whet owls nest mostly in coniferous forests and woodland habitats across their range and prefer old growth forests or those with high areas of edge forest habitat versus interior forest habitat (Cannings, 1993). As a species that partakes in hole-nesting throughout various cavities available in a given habitat, the saw-whet is often threatened by habitat destruction from human activity. Breeding site philopatry is not very strong for this species which is likely related to the style of nesting, due to difficulty in finding nests located in such hidden places. The common issue of anthropic activity also causes birds to leave their original breeding sites in search of safer shelter (Cannings, 1993). It has been noted that it is imperative for regions to have thick vegetation that provide habitat for roosting as well as vegetation that provides ledges or perches giving rise to habitat for foraging in order for saw-whets to inhabit the areas (Cannings, 1993). The low species range for saw-whets is, again, likely affected by the high specificity of habitat for the birds as their behavior (roosting/reproduction, hunting, and scavenging) is highly dependent on the topography and biological composition of the regions in which they live. These factors surrounding population levels (species range) and duration of populations present after breeding (breeding site philopatry) in a given site are believed to play a large factor in the species migratory behavior and patterns (Beckett & Proudfoot, 2011).

*Northern Saw-whet Owl Description—Migration*

While the status, which includes the specialization and degradation, of physical elements (such as vegetation and soil composition) of saw-whet Owl habitats play key roles in determining the birds' migratory locations, scientists believe that the largest factor in this species' migration rates and patterns as well as population levels is population size of their prey. A few studies by researchers such as Cannings (1987) have supported the assertion that population size of saw-whet owls has a correlation to the population size of meadow voles and deer mice alike. While not much research has been conducted on the population cycles of the vole and mice species in Maryland, it is widely accepted that a varying 3 or 4 year cycle of vole and mice populations across the country impact the populations of saw-whet owls (Cannings, 1987).

In North America, the northern saw-whet owl was first observed for its migratory behavior in 1906 but did not become widely studied until late into the 20$^{th}$ century (Beckett & Proudfoot, 2011). This is in part due to the subtle and camouflaging coloration of this species' feathering as well as its ability to suspend movement for extended periods of time. In the coniferous forests of North America where they spend much of their time, saw-whets effectively protected themselves and went unnoticed from observation by predators and researchers alike for hundreds of years (Confer et al., 2014). For many years after researchers began to be aware of Saw-whet presence and migration through all of North America, they had trouble following the migratory patterns of these birds (Cannings, 1993). Researchers also had difficulty understanding the drastic fluctuations in the population that are commonly seen in season-by-season migration studies of saw-whet owls (Beckett & Proudfoot, 2011).

Today, saw-whet migration patterns, trends, and paths are still topics that are not fully understood, as there are a few different widely held beliefs about all of them due to their many facets. Scientists have tracked factors that affect both saw-whet small-scale movements and wide spread migratory patterns since the early 1900s (Cannings, 1993). Small movements by the birds include flight that occurs only at night once it is dark; this is so that the birds may avoid predation from larger owls (Erikson & Bowen, 2011). Saw-whets stay as concealed as possible in the brush of habitats which are defined as shrubs, trees, and vines (Rollins, 1997) so that they find refuge from larger birds that cannot make it through such spaces in forests.

Tracking the movement and migration of the saw-whet owl into and out of Maryland only began to be closely monitored by researchers and ornithologists in the early 1990s (Cannings, 1993). There are many different factors involved in tracking these birds that are measured and accounted for at the sites at which they are banded. These factors often involve the specifics of banding and netting practices that can include hours of open netting, evenings in which researchers will open their nets to survey the owls, use of audiolure, and placement of nets around audiolure devices (Project Owlnet, 2015). Other factors that come into play with tracking saw-whet owls are the measurements of sex, age, wing length, weight, fat count, tick count, and deformities present for the birds being banded that are migrating through the area (Project Owlnet, 2015). Finally, factors that are monitored by sites tracking saw-whet owls include the state of the station at which birds are banded which include evening climate, daily climate that might impact it, habitat description, habitat stability, presence of other species, and lunar phase/illumination (Project Owlnet, 2015).

*Lunar Cycles and Anticipated Study Outcomes*

This study will focus on the effects of lunar phase and moon illumination on saw-whet owl migration in Maryland by analyzing covariance of these factors for the individual days of study. Studies have already noted that moon phase appears to impact owls captured by noting that nights with higher luminance values have lower capture values for owls (Project Owlnet, 2015). Both the owl's ability to evade the nets in brighter lights as well as well as reductions in migration due to evasion of brightness have been posited as causes of such a correlation (Project Owlnet, 2015). Viewing saw-whet behavior as it is influenced or not influenced by lunar cycles demonstrates individuals' ability or inability to adjust flight patterns based off of environmental changes.

The anticipated results of the study would support the belief that lunar phases have a significant impact on the migration patterns, behavior, and actions of saw-whet owls in Maryland. Findings from the analysis that show significantly different capture rates are anticipated to indicate this. From the analysis there is expected to be a relationship between lunar phase and luminance that indicates higher owl capture rates at nights within seasons that have a full moon and lower owl capture rates at nights within seasons that have a new moon. Such overall trends are anticipated from all of the 3 sites studied in Maryland over the periods of time that data was collected (52 seasons of data pooled from all 3 locations over 19 years total). Small fluctuations based on region of the site are expected as well. These are not anticipated to make a serious impact on the overall results, however, as moon luminance and lunar cycles are not as likely to fluctuate over regions within a state. Assertions about species ability/inability to adjust flight patterns based off of environmental changes such as shifting moon luminance was posed based off of the results of analysis. Implications for species ability to adjust well to environmental fluctuations was inferred to indicate survival ability in the face of climate change. This study connected its assertions of saw-whet owls' ability to adapt behavior due to environmental fluctuations as seen in moon luminance to the species' ability to adapt behavior due to environmental fluctuations caused by climate change.

## MATERIALS AND METHODS

The first part of this study involved a field survey at Chino Farms' Foreman's Branch Bird Observatory in order to acquire hands-on understanding of owl banding practices as well as the effect of the many factors that are in play during evenings of owl banding. The field survey began on or around October 25, 2015 and lasted for 3 weeks which was long as was suitable until the year's season ended on November 30, 2015. Throughout this window of study, evening banding surveys were completed 2-3 times each week. Duration of each survey in terms of length in hours of net openness on a given evening depended on the suitability of the evening. This specifically took into account climactic or spatial variations on a night-by-night basis (i.e. on exceptionally windy evenings wherein leaving nets open for extended periods of time might be ineffective or likely to cause harm to the birds, banding activities would not commence).

Before each survey physical descriptions of the area of study such as the temperature, wind speed and direction, cloud cover, lunar cycle, and moon illumination level were recorded. Nets for the evening were opened one half hour after sunset and run for no less than 4 hours. Audiolures were played on stereos set up around the nets and they played in the area previously recorded mating sounds of saw-whet owls to attract migrating owls and trap them in the nets. The start time for each night's session was recorded when the nets were opened and the lures began playing. Once the nets were opened they were checked one hour after they are open and hourly for the rest of the evening. Bird processing requires removal of birds from the nets and placement of them into cloth bags for processing immediately thereafter. Processing included collecting data on bird age, sex, wing chord (mm), and mass (g), along with age. All owls that were captured a second time within a session were only processed and recorded once per night, s the individual only counted toward the data for the evening's banding one time. Owls were released by placing them into the shrubs outside of the banding lab or by allowing them to fly off of participants' arms.

Procedures at other locations for past data used in analysis were similar to those used at Foreman's Branch Bird Observatory in the field study, with varying net formations, net areas, dates of net openings, number of weeks of net openings within the season, and hours of opening which were made note of in the analysis. These sites of use for data analysis across Maryland included Assateague Island (19 seasons of data), Casselman River (17 seasons of data), and Lambs Knoll (16 seasons of data) (Figure 1).

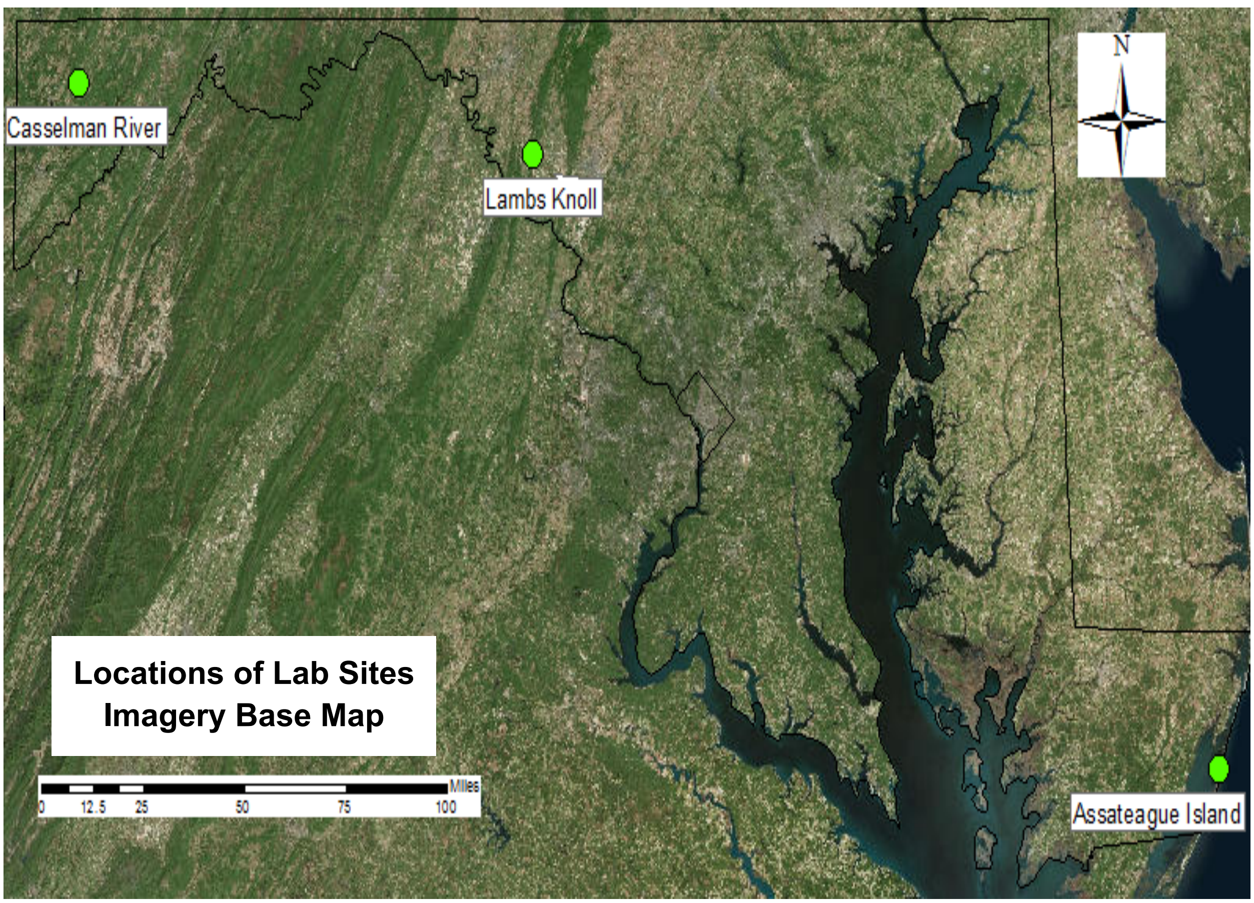


**Figure 1**. Map of locations of study in this project created using ArcMap, a Geographic Information System program.

Project Owlnet protocol standardized the processes between the four sites of interest over the data set of interest more in regards to the effort values which include hours of nets being open, area taken up by the nets, and owl captures per hour (Project Owlnet, 2015). While the banding activities at each site are not identical to those of Foreman's Branch, which are the ones described earlier, they are generally similar to one another. This practice occurs in order to allow for a site to tailor their set-up to that which will allow for them to catch owls at rates that will most accurately reflect the changes and trends within the population (Project Owlnet, 2015). Factors of the protocol that are, however, standardized, are those that encourage surveyors to open nets for at least 75% of the evenings that occur within the timeframe when 95% of saw-whet migrants would normally pass through a site (Project Owlnet, 2015). Although not all sites uphold such a high level of open evenings, all strive to achieve this rate and maintain their sites and staff/volunteer base in order to attempt to reach that outlined goal.

Data assessment for this study sought to track the influence of lunar cycles and moon illumination level on saw-whet owl migration. Rather than assessing covariance by one particular season, this study reviewed the findings of bird banding branches associated with Project Owlnet over many years' worth of recording. David Brinker with the Maryland Department of Natural Resources assisted in creating a plan for data assessment in this study that observes the effects of the moon on saw-whet migration in Maryland. The assessment analyzed covariance using ANOVA testing on SPSS analysis software.

This analysis compared the dependent variable of average owls per hour for each night of data in the study against the fixed factor of moon luminance level for the certain evening. The dependent variable was determined by dividing individual value for owls captured on a single night by the value for hours of nets being open on that same night. Data for the fixed factor in the study was taken from the USGS national website's daily climate and lunar records (USGS, 2015). The covariate used for analysis was determined by identifying the evening of peak catch rate for owls per hour within a season or year of study at the specific location and providing that night with a value of 0. Every night of that season that came before it was provided with a positive number that started at 1 and increased with each additional data point just as every night of the season that came after that peak evening was provided with a negative number that started at -1 and decreased with each additional data point. Data was analyzed at the state-level and pooled across all years, at the state-level for individual years, at the site-level pooled across all years, and at the site-level for individual years.

# RESULTS

Analysis results were based off of a range of about 100-200 hours of net openings per season for Lambs Knoll's site, and about 300-600 hours of net openings per season for both Assateague and Casselman's sites (Figure 2). Area for nets of owl banding varied from about 4-14 units, as these units involved measurement of height of the nets, length of the net, and width of the nets to create an estimate of space open for owl use (Table 1). There is, on average, a three or four year cycle with populations of saw-whet communities where larger population levels are noted based off of birding statistics and then a subsequent three years of lower numbers of catch rates following (Cannings, 1993). Such a four-year trend is seen between 1995 and 1999 in the study at all locations (Figure 2). There is a slight spike again in 2003, 4 years later, with a much greater spike in 2007, 3 years after that. There were high spikes in hours open for most of these years at each site, with high values in Assateague and Casselman in 1995, in all three sites in the year 1999, and again in all three in 2007 (Figure 3). However, these peaks in effort are not as apparent as the peaks in owl capture, even though there is greater effort in some years relative to others. It is noted that effort varies between years based on anticipated number of owls migrating with peak years seeing greater effort values than others.

Site by site methodology also plays a role in the amount of owls captured and their representation of the community present. The longer the hours of net openings, the more likely, in theory, the researchers are to capture at rates that are representative of the bird community present (Project Owlnet, 2015). Yet net area for each year and each site is different, and the amount of hours open can sometimes have less of an impact than the amount of available net area into which birds may fly. Casselman River has consistent high net areas that correlate with consistently high total owl captures, however, Lambs Knoll has both the lowest total hours of net openings and of net area yet after 2006 they mostly lead in highest values for total owls captured (Figures 2-3 and Table 1). The same is true of Assateague Island in 2005 when it has the highest values for hours open, yet the lowest values for owls captured and continues that way until 2011, although it does not have the lowest net area of the three (Figures 2-3 and Table 1). Number of nights open and dates within the season when banding occurs are noted to have some fluctuations (Tables 2-5). These trends and their changes have some effect on the overall values for total owls captured in such banding surveys and have fluctuations within this data set.

There were multiple individual years of significance ($p<0.05$) on both a statewide and site-specific level but no trials of pooled years were significant for either statewide or site-specific trials. These results from the study indicated that moon luminance did not have a significant impact on the number of owls captured per hour at the state-level across all years studied (Table 6) but that it does on a site-level across all years and individual years as well. Data from each of the three sites was pooled together at the state-level, providing a more complete data set that is representative of much larger scale saw-whet owl migration patterns for individual years (Tables 7) and still showed 4 years of significance. Significant values ($p<0.05$) were seen in individual yearly analyses at the state-level in 1993, 1994, 2006, and 2007 (Table 7) and within site-level yearly analyses (Tables 8, 9, and 10). In banding seasons of years when capture rates (1993, 2001, 2007, 2010) are high moon luminance appears to have some effect on migration rates. Moon luminance also had an impact on seasons of years when effort rates (1993, 1994, 2001, 2007, 2009) were highest in this study.

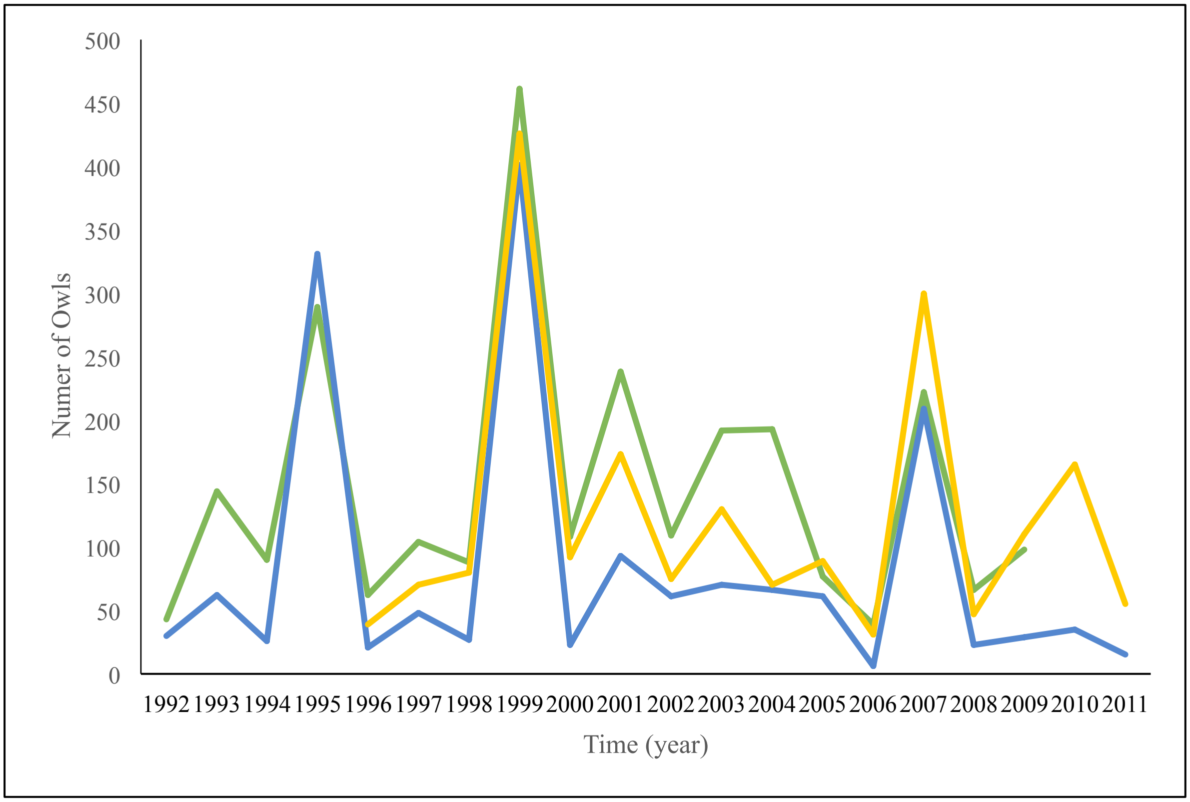


**Figure 2.** Total owls captured for Assateague Island (blue), Casselman River (green), and Lambs Knoll (yellow) banding sites between 1992-2011. Banding at these locations occurred between the winter months of October and December for each year. Data source is David Brinker, DNR, with Project Owlnet.

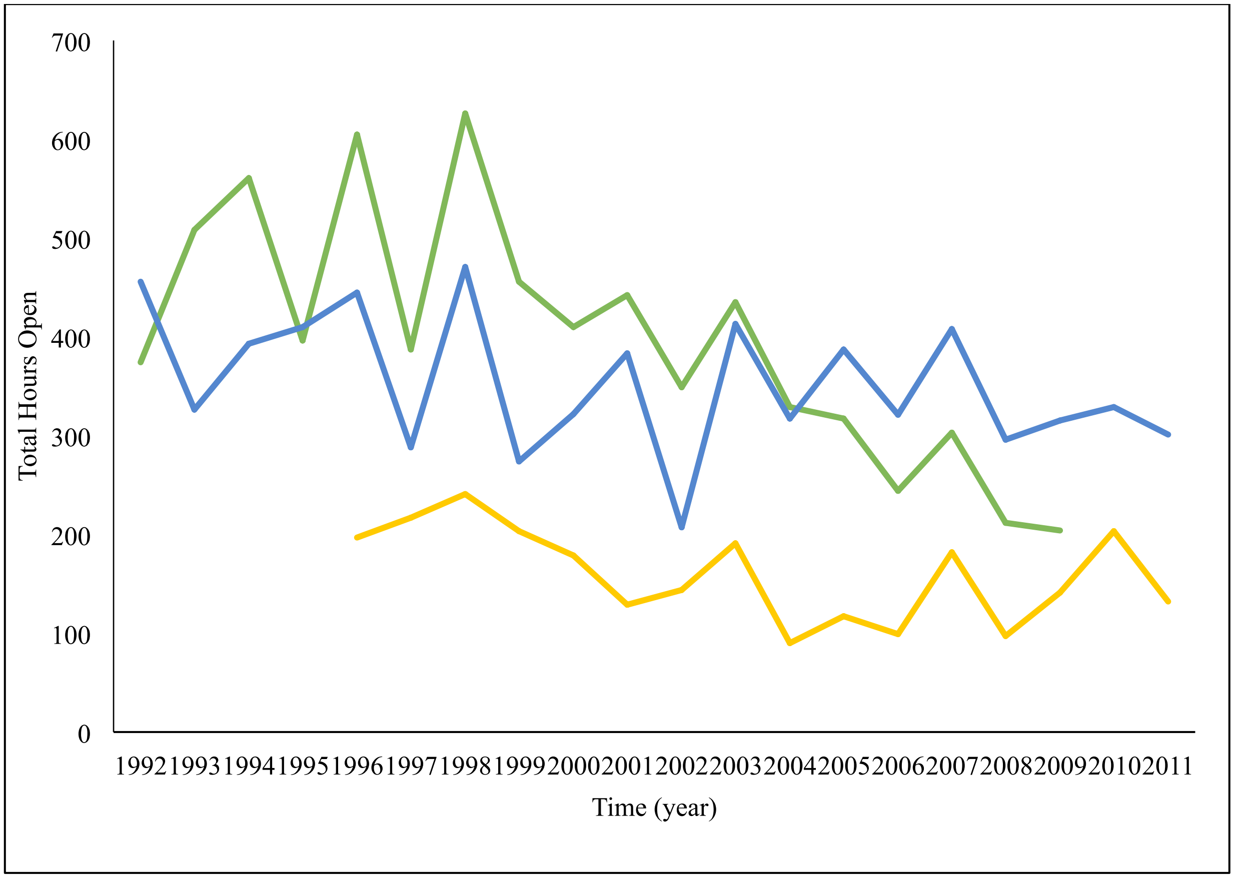


**Figure 3.** Total hours of nets being open to catch birds by year for Assateague Island (blue), Casselman River (green), and Lambs Knoll (yellow) banding sites between 1992-2011. Banding at these locations occurred between the winter months of October and December for each year. Data source is David Brinker, DNR, with Project Owlnet.

**Table 1.** Net area in standard units by year at banding sites between 1992-2011. Banding at these locations occurred between the winter months of October and December for each year. Data source is David Brinker, DNR, with Project Owlnet.

| Year | Assateague | Casselman | Lambs Knoll |
|---|---|---|---|
| 1992 | 12 | 12 | -- |
| 1993 | 12 | 14 | -- |
| 1994 | 12 | 12 | -- |
| 1995 | 12 | 14 | -- |
| 1996 | 12 | 14 | 4 |
| 1997 | 10 | 14 | 4 |
| 1998 | 10 | 14 | 5 |
| 1999 | 10 | 12 | 7 |
| 2000 | 10 | 12 | 7 |
| 2001 | 10 | 12 | 7 |
| 2002 | 10 | 12 | 7 |
| 2003 | 10 | 12 | 7 |
| 2004 | 10 | 12 | 7 |
| 2005 | 10 | 12 | 7 |
| 2006 | 10 | 12 | 7 |
| 2007 | 10 | 12 | 7 |
| 2008 | 10 | 12 | 7 |
| 2009 | 10 | 12 | 7 |
| 2010 | 10 | -- | 7 |
| 2011 | 10 | -- | 7 |

**Table 2.** Opening dates by year for Assateague Island between 1992-2011. Some years of banding, including 2000, 2002, and 2003, were run by only one operator (David Brinker) due to complications. In 1997 there were multiple field assistants on most nights. Data source is David Brinker, DNR, with Project Owlnet.

| Year | Starting Date | Ending Date | Nights Open per Year |
|---|---|---|---|
| 1992 | 10 October | 28 November | 43 |
| 1993 | 28 October | 1 December | 29 |
| 1994 | 22 October | 3 December | 34 |
| 1995 | 22 October | 3 December | 38 |
| 1996 | 21 October | 30 November | 37 |
| 1997 | 21 October | 30 November | 27 |
| 1998 | 19 October | 28 November | 40 |
| 1999 | 15 October | 8 December | 39 |
| 2000 | 25 October | 29 November | 29 |
| 2001 | 20 October | 1 December | 34 |
| 2002 | 28 October | 8 December | 18 |
| 2003 | 20 October | 4 December | 34 |
| 2004 | 26 October | 1 December | 29 |
| 2005 | 23 October | 1 December | 33 |
| 2006 | 25 October | 30 November | 27 |
| 2007 | 20 October | 10 December | 38 |
| 2008 | 20 October | 4 December | 28 |
| 2009 | 21 October | 30 November | 29 |
| 2010 | 17 October | 30 November | 31 |
| 2011 | 23 October | 1 December | 27 |

**Table 3.** Opening dates by year for Casselman River between 1992-2009. Banding surveys are conducted by volunteer students from Garrett College and Frostburg University. Data source is David Brinker, DNR, with Project Owlnet.

| Year | Starting Date | Ending Date | Nights Open per Year |
|---|---|---|---|
| 1992 | 18 October | 1 December | 38 |
| 1993 | 18 October | 14 December | 44 |
| 1994 | 12 October | 9 December | 49 |
| 1995 | 5 October | 27 November | 36 |
| 1996 | 3 October | 15 December | 50 |
| 1997 | 7 October | 2 December | 36 |
| 1998 | 5 October | 10 December | 57 |
| 1999 | 7 October | 7 December | 40 |
| 2000 | 11 October | 25 November | 39 |
| 2001 | 7 October | 3 December | 44 |
| 2002 | 6 October | 6 December | 34 |
| 2003 | 7 October | 10 December | 43 |
| 2004 | 5 October | 5 December | 39 |
| 2005 | 9 October | 26 November | 37 |
| 2006 | 15 October | 3 December | 30 |
| 2007 | 7 October | 30 November | 35 |
| 2008 | 15 October | 23 November | 24 |
| 2009 | 11 October | 13 November | 24 |

**Table 4.** Opening dates by year for Lambs Knoll between 1996-2011. Years with personal problems for operators yielding few open nights included 2004-06. Data source is David Brinker, DNR, with Project Owlnet.

| Year | Starting Date | Ending Date | Nights Open per Year |
|---|---|---|---|
| 1996 | 12 October | 30 November | 26 |
| 1997 | 11 October | 5 December | 31 |
| 1998 | 3 October | 12 December | 30 |
| 1999 | 6 October | 19 December | 31 |
| 2000 | 13 October | 25 November | 26 |
| 2001 | 10 October | 24 November | 21 |
| 2002 | 7 October | 25 November | 21 |
| 2003 | 16 October | 28 December | 27 |
| 2004 | 25 October | 17 November | 11 |
| 2005 | 26 October | 19 November | 13 |
| 2006 | 21 October | 29 November | 13 |
| 2007 | 8 October | 7 December | 22 |
| 2008 | 22 October | 22 November | 12 |
| 2009 | 18 October | 21 November | 17 |
| 2010 | 9 October | 21 November | 19 |
| 2011 | 15 October | 25 November | 14 |

**Table 5.** Average open evenings for all locations between 1992-2011. Data source is David Brinker, DNR, with Project Owlnet.

| | Average Open Evenings per Season | Range of Evenings per Season |
|---|---|---|
| Assateague (1992-2011) | 32.20 | 25 |
| Casselman (1992-2009) | 38.83 | 33 |
| Lambs Knoll (1996-2011) | 20.88 | 20 |

**Table 6**. ANCOVA Analysis results for all sites from SPSS univariate analysis of saw-whet owls per hour against moon luminance levels. Analysis occurred over winter of 2015. Data was provided by David Brinker, DNR.

| | P-Value | df | F-value |
|---|---|---|---|
| Assateague (1992-2011) | 0.214 | 98 | 1.125 |
| Casselman (1992-2009) | 0.139 | 99 | 1.171 |
| Lambs Knoll (1996-2011) | 0.297 | 90 | 1.092 |

**Table 7**. ANCOVA Analysis results for all sites from SPSS univariate analysis of saw-whet owls per hour against moon luminance levels for individual years of significance ($p<0.05$). Years without significant p-values are not listed. Analysis occurred over winter of 2015. Data was provided by David Brinker, DNR.

| Year | P-value | df | F-value |
|---|---|---|---|
| 1993 | 0.006 | 41 | 2.449 |
| 1994 | 0.000 | 43 | 9.836 |
| 2006 | 0.049 | 31 | 1.767 |
| 2007 | 0.048 | 42 | 1.627 |

**Table 8**. ANCOVA Analysis results for Assateague Island site from SPSS univariate analysis of saw-whet owls per hour against moon luminance levels. Analysis occurred over winter of 2015. Data was provided by David Brinker, DNR.

| Year | P-value |
|---|---|
| 2001 | 0.006 |
| 2010 | 0.008 |

**Table 9**. ANCOVA Analysis results for Casselman River site from SPSS univariate analysis of saw-whet owls per hour against moon luminance levels. Analysis occurred over winter of 2015. Data was provided by David Brinker, DNR.

| Year | P-value |
|---|---|
| 1994 | 0.007 |

**Table 10**. ANCOVA Analysis results for Lambs Knoll site from SPSS univariate analysis of saw-whet owls per hour against moon luminance levels. Analysis occurred over winter of 2015. Data was provided by David Brinker, DNR.

| Year | P-value |
|---|---|
| 2009 | 0.014 |

## DISCUSSION

Studies of moon illumination level effects on species have been seen for that of organisms as small as zooplankton migration and behavior (Marques et al., 2009), species classifications as amphibians with attention to reproduction (Grant et al., 2009), and a Nocturnal Pelagic Seabird, the Swallow-Tailed Gull (Cruz et al., 2013). All of these studies and others interested in moon illumination levels focus on the biological and behavioral effects of lunar phase on the species of interest. Such studies have uncovered impacts that range from daily migration in zooplankton (Marques et al., 2009) to biological changes that initiate reproductive activity in amphibians (Grant et al., 2009) to activity and nightly migration in seabirds (Cruz et al., 2013). There is a movement in the biological community to study lunar phase effects on the behavior and activity of animals for the purposes of more accurately surveying their behavior. All of the studies listed previously as well as many others conducted in the fields of ecology and biology within the last ten years have found that the moon's level of light indicated by lunar phase has a significant impact on the behavior of animal species from all different kingdoms of taxonomic ranks. Such study is especially important for owls considering that they are nocturnal creatures.

The data used in this study to test lunar phase's effects on saw-whet migration is not unique to others in the field. This project's results were varied by many factors such as those that were previously stated: net area, hours of net openings, location, number of evenings throughout a season, and specific dates within a season (Project Owlnet, 2015). Despite these variations, significant results were still obtained. Most years of analysis indicated no significance between the independent variable of moon luminance and the dependent variable of owls per hour. This indicates that this factor may not significantly impact the migration rates or that there are too many unaccounted for variables in analysis that prevent the results from being able to indicate accurate population values from which luminance impact can be studied. While not many analyses for statistical significance of covariance between catch rate (owls per hour) and moon luminance supported the conclusion that they do have a relationship, the actual data itself had many factors that complicated the presentation of accurate trends and changes within the population of saw-whets from itself.

The years of statistically significant p-values were years that featured both high catch rates, such as 1993 and 2007, and low catch rates, such as 1994 and 2006. The commonality between these years of significance is that they are in sequence, potentially indicating similar practices by banding sites. All sites have nearly the same net area each year (Figure 3), and net hours open are less than 100 hours different between Casselman and Assateague in 1993 to 1994 (Figure 2). The less than 100 hours difference in net hours open is true of all three sites between 2006 and 2007 (Figure 2). These similar practices were likely derivative of different situations as it was seen in 1994. It was possible that the specifics of the methods used in 1994 were modeled after those from the year before, as there were such high values of owls being captured in 1993. In 2006 it is likely that banding stations decreased effort because of low catch rates early in the season, so the small data set did not have many values to show true significance. However, in 2007 higher catch rates and effort values are shown because it was likely believed to be the peak year in the saw-whet four-year population cycle (as 2003, the assumed next peak year in the cycle, featured similarly moderate catch rates that appeared to be spikes in comparison to 2002) (Cannings, 1993). If it was anticipated that 2007 would be the year of high catch rates, it follows that banding practices would be as ideal as possible, with high effort values, in order to get very accurate data for a largely trafficked year.

Because the significant years were those in which the banding locations performed with highest effort in attempting to catch owls, these are also the years wherein the population of birds in the results would be most representative of the population trends in the area. Results of catch rates of years when nets are open longest and most often are more likely to be exemplary as the attempt to survey accurately is greatest. These years saw high values for a number of nights of banding in the season as well, with such highs at the sites like Assateague Island with 38 nights in 2007, like Casselman River with 49 in 1994, and like Lambs Knoll with 22 in 2007. The years of moon luminance having a significant impact on catch rates are those in which ornithologists attempted the hardest to have nets open often and for long periods of time as they were peak years. Most of these years also saw the highest rates of migration—whether this is due to the peak year in the population cycle or the methods of net-use is not clear. What is clear, however, is that these years are likely to be the most representative of what the populations of saw-whets in the regions actually were, and, thus, were most representative of how lunar cycles and moon luminance could and do impact them.

A facet involved in the inherent uncertainty in surveying practices relates to the amount of evenings in which banding sites are open. Locations used in this study attempted to comply with Project Owlnet's (2015) suggested rates of 75% of evenings open during the 95% migration rate window yet this window does not allow for owls to be caught on evenings of high lunar luminance or on nights with unfavorable wind direction, wind speed, or cloud cover levels. There are likely to have been nights with poor wind direction/speed for owl capture, ones with no cloud cover, or ones with high lunar luminance over the 20 year data set on which surveyors did not open nets to catch owls. However, these evenings would be more likely to show clearly how luminance levels affect capture rates than evenings when surveys were conducted that had favorable and/or little wind, 100% cloud cover, and low lunar luminance. Many evenings of prime importance in looking at this correlation, then, were omitted on necessity by Project Owlnet standards and were unable to be utilized in this analysis. Although cloud cover was not included in analysis for this study, further study involving a comparison between cloud cover on an evening that was omitted alongside that of open net nights might provide insight into this question.

In addition to potential impacts from cloud cover levels, weather variation among sites could have impacted the results as extreme weather could cause owls to delay migration. Weather was not analyzed statistically in this study, however, it likely had an impact on capture rates overall and may have skewed the results so that data could not indicate moon luminance impact on migration because it was already impacted by the alternate factor of weather. There also might be varying weather patterns among locations, as Assateague is located on the Eastern shore of Maryland and the other two sites are located on the mainland of Maryland (Figure 1). At Assateague, high winds might have occurred in a given year, keeping saw-whets in migration from coming near the coast and resulting in decreased catch rates in comparison to the other sites of interest.

Moon rise and set times might impact the survey of owls on a given evening in contrast with another (Beckett & Proudfoot, 2011). It is possible that situations may arise at stations requiring the site to close before the moon sets in the sky, leaving nets closed during a longer span of hours when owls may be flying in a way that is impacted by moon luminance and preventing the station from reporting accurate population values. There is also some slight variation with moon rise/set times that accounts for some potential effect on this study's analysis. A scenario affected by this might be at a point in the season when catch rates are high with a full moon in the sky, however, if the moon rises as late as 2 or 3 AM after a station has been open since sunset, there is a long time period for owls to be caught before high lunar luminance when the full moon rises, compared to nights when the moon is already high in the sky at sunset. This would require night-by-night analysis of the evenings within this study that would factor moon rise and set times in the luminance level variable noted.

Studies of illumination's effects on predatory species like saw-whet owls have revealed such information as the impact that it has on behavior that can inform the results of this project. Moonlight has been seen as increasing predation risk for nocturnal prey species (i.e. small mammals) due to greater activity at night. Although small owls such as the saw-whet are preyed on by Long-eared Owl (*Asio otus*), Great Horned Owl (*Bubo virgi5nianus*), and Barred Owl (*Strix varia*) (Cannings, 1993), saw-whet owls are considered nocturnal predatory species. A study conducted by Prugh and Golden (2014) showed a decrease in hunting activity by such nocturnal predatory species on evenings of high moon illumination. This change in behavior based off of an increase in moonlight is likely attributed to decreased vision for the owl species in the study (Prugh & Golden, 2014). While a decrease in hunting activity is correlated with high moon luminance levels, an increase in hunting activity has been seen to correlate with high meadow vole population spikes that occur every 2-5 years (Sullivan, 1996). This patterned fluctuation in vole population that occurs within Maryland may have played a role in the changing owl population numbers as well.

Other factors to test for in future studies have been listed earlier, yet further research into lunar and weather effects on owl catch rates, especially those of less widely studied owls like the Northern saw-whet, is needed. Such research can assist ornithologists in attempting to better understand the difference between numbers collected from bird banding and the projected populations (and the trends of which over time spans, involving increases and decreases in size) of owls within regions. Continued study of moon illumination levels will afford to ornithologists greater insight into the analysis and even the structure of surveying/sampling programs and testing for such owls so that their data on catch rates to indicate population size in an area is not being misrepresented or skewed. Such continued study will also allow for researchers to propose more informed assertions about species ability/inability to adjust flight patterns based off of environmental changes. As species ability to adapt to changing environments is of special interest to scientists in the face of climate change, continuation of this kind of research on species behavior change

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