

Northern Saw-whet Owls:  
Influence of Environmental Factors on Autumn Migration Dynamics

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## Abstract

A portion of the population of the Northern Saw-whet Owl (*Aegolius acadicus*) leaves its breeding range in Canada and the northern United States each fall to winter where lesser snow cover allows easier access to prey. Study of its migratory dynamics is difficult, however, both because of its nocturnal habits and because it does not vocalize readily off of its breeding territory. Since 2002 banding studies in the Lynchburg area have investigated the migration dynamics of this species in central Virginia. However, few studies have examined the influence of environmental factors on capture rates of saw-whets during migration. Data were analyzed for the falls of 2007 and 2012, which were the two years of greatest migration volume in central Virginia, being “irruption years” in this species’ migratory cycle. In both years, nightly owl capture rates were strongly correlated with prevailing wind direction, with highest capture rates occurring during nights in which winds were predominantly out of the northeast quadrant. In 2012, nightly owl capture rates were also strongly negatively correlated with moon illumination, with highest capture rates occurring during nights of least moon illumination. For both years’ data combined, owl capture rates were also weakly negatively correlated with wind speed, Julian date, and temperature. Possible reasons for these relationships are considered.

## Northern Saw-whet Owls:

## Influence of Environmental Factors on Autumn Migration Dynamics

**Introduction**

The Northern Saw-whet Owl (*Aegolius acadicus*) is eastern North America's smallest owl species. Sexual dimorphism is pronounced within this species of owl, with females being larger. Males are an average length of 18-20 cm and average of 75 g, comparable to the weight of a robin (Rasmussen et al. 2008). Females are 25% larger than males weighing about 100g, and they average 20-21.5 cm (Rasmussen et al. 2008). Females also have longer wingspans and tail lengths than males averaging 135-146 mm and 69-73 mm respectively compared to a male's average wingspan of 133.5-139 mm and tail length of 65-70 mm (Johnsgard 2002).

The Northern Saw-whet Owl looks similar to the larger Boreal Owl (*Aegolius funereus*) (Johnsgard 2002). The two owls are distinguished by the presence of white streaking on the crown in saw-whets rather than spots that are present on the crown of the Boreal Owl (Johnsgard 2002). There are no sexual differences displayed in the coloring or patterns of saw-whets, so both sexes are essentially identical in plumage. The saw-whet is a rather short-bodied owl with a large catlike head, a round facial disk, and a black beak. The saw-whet's head is asymmetrical with respects to the location of the ears on the sides of their heads, which allows them to track prey by sound alone (Johnsgard 2002). Unlike some species of owls, saw-whets lack feathered tufts. The tail and legs are short, with heavy feathers extending down to the talons to provide insulation. The claws are black and soles of the feet are yellow (Rasmussen et al. 2008).

There are unique physical characteristics that distinguish adult from juvenile saw-whets. Adult saw-whets have brown upper body parts with thin white lines extend from the facial disk to the nape encompassing the crown (Rasmussen et al. 2008). White surrounds the eyes on the facial disk with streaks of pale and dark brown and stiffened black feathers between the eyes (Rasmussen et al. 2008). Variable white spots cover the backside of the body from the nape to the tail and onto the wings. The undersides are white with broad brown markings running along the chest to the top of the legs. The eyes are consistently golden in adults, but this feature can occasionally be found in juveniles (Rasmussen et al. 2008).

For the first week of a new hatchling's life its natal plumage is an entire coating of white down (Rasmussen et al. 2008). These young weigh about 7.5g, with a wing chord of 11.4 mm (Rasmussen et al. 2008). As the hatchlings grow they develop a buff belly with a solid light brown chest, chin, and throat (Rasmussen et al. 2008). The facial disk is dark brown, and as they mature they acquire white coloring around the eyebrow region and forehead, forming a Y-shaped marking (Rasmussen et al. 2008). The auricular feathers near the ears are develop a deep brown to black color, and the rest of the crown and upper body parts are deep brown (Rasmussen et al. 2008). Juveniles lack the white and brown markings on their backs and chest seen on adults, but they begin to show some white markings on their wings. Juveniles can be distinguished from adults by the presence of a single generation of remiges or wing feathers, whereas adults have two generations of remiges during fall molt (Rasmussen et al. 2008).

There are two subspecies of the Northern Saw-whet Owl: *Aegolius acadicus acadicus* and *Aegolius acadicus brooksi* (Johnsgard 2002). *Aegolius a. acadicus* is a migratory owl, while *A. a. brooksi* is non-migratory resident of Queen Charlotte Islands, British Columbia (Johnsgard 2002). The two are distinguished genetically in mtDNA (Withrow et al. 2014). *Aegolius a. brooksi* is also much darker and smaller than *A. a. acadicus*, and has distinct feeding habits (Rasmussen et al. 2008; Withrow et al. 2014). There is no documented hybridization between these two subspecies (Johnsgard 2002). A related species is the Unspotted Saw-whet Owl, *Aegolius ridgwayi*, distributed throughout Central America (Rasmussen et al. 2008). The adult's plumage looks similar to that of the Northern Saw-whet Owl's juveniles, and they have comparable vocalizations.

The Northern Saw-whet Owl is most vocal during courtship and early breeding season; late winter to early spring (Duncan et al. 2009). They begin singing about one half hour after sunset, and intermediately until sunrise (Rasmussen et al 2008). In the fall and winter the owls remain silent, while in the breeding season these owls will exhibit a wide variety of calls. One of the first calls heard at the beginning of spring is the male advertising call (Rasmussen et al. 2008). This call has been described as a sequence of recurring *whoop* or *kwook* notes at a rate of 1 to 2 notes per second with a mean frequency of 1.1 kHz (Johnsgard 2002). This call may last for hours. Females will respond to the male's advertising call by repeating the male's notes at a faster rate with a lower, softer pitch (Johnsgard 2002). Both male and females may give a *ksew* call which is a high-pitched signal given repeatedly (Rasmussen et al. 2008). This call is believed to

be given when the owl feels threatened. They may also make a clicking sound with their beak when threatened, and produce loud squeaks when encroached on by an intruder. Before and after eating the nestlings will exhibit a begging *tssshk* call (Rasmussen et al. 2008). When the male comes to deliver food to the nest both male and female will perform a duet *tssst* call known as the visiting call (Rasmussen et al. 2008).

The Northern Saw-whet Owl is a forest dweller and most inhabit dense coniferous forests, usually adjacent to river banks (Rasmussen et al. 2008). Although they prefer coniferous forests, they can also be found in mixed forests such as spruce-fir forests. These type of forests provide sufficient coverage year round from predators and dense vegetation for roosting (Rasmussen et al. 2008). Their territories are typically on the southern face of elevated slopes where snow coverage is minimal during the winter months (Rasmussen et al. 2008).

Woodlands provide sufficient perches for the owl to hunt prey as they depend upon the coloring of their feathers for camouflage (Johnsgard 2002). Saw-whets are secretive in nature and can go unnoticed as they rest tamely on low perches while using their keen hearing and low-light vision to allow them to track their prey in total darkness (Rasmussen et al. 2008). The owls pounce on their prey from these low perches, and they can maneuver through heavy vegetation to hunt due to their light wing loading (Johnsgard 2002). Like most owl species, saw-whets catch prey with their feet. They are nocturnal hunters, feeding when their metabolic cycle peaks, from one half hour after sunset to one half hour before sunrise (Rasmussen et al. 2008).

Northern Saw-whet Owls prey principally on small mammals (Bowman et al. 2010). Through pellet analysis, the saw-whet's diet has been found to include wood mice (*Apodemus sylvaticus*) and white-footed mice (*Peromyscus leucopus*) as their primary prey, along with various types of shrews (*Soricidae*), woodland voles (*Microtus pinetorum*), and invertebrates such as beetles (*Coleoptera*) and grasshoppers (*Orthoptera*) (Rasmussen et al. 2008). Birds make up a small portion of this species diet, and are typically consumed during migration. The largest prey that has been observed through pellet analysis are juvenile gophers, chipmunks, and squirrels (Rasmussen et al. 2008).

Saw-whet owls are found breeding in southern Alaska, southern Canada, northern portions of the United States, the mountains of southern California, and the Mexican highlands (Johnsgard 2002). Preferred breeding grounds are in coniferous or mixed deciduous forests within these areas (Speicher et al. 2011). Saw-whets have been observed breeding at an elevation of 1500 meters in spruce-fir forests in the southern Appalachians in the eastern and northeastern parts of the United States (Johnsgard 2002). Some observers have heard saw-whets vocalizing in the coniferous swamps of Maryland, and juveniles have been spotted in mixed forest at lower elevations of the southern Appalachian Mountains in Tennessee (Rasmussen et al. 2008). In the west, breeding grounds occur in low to mid-elevations of mountainous regions (Rasmussen et al. 2008), including Idaho, Wyoming, British Columbia, Santa Cruz Island California, Central Manitoba, Colorado, and semi humid pine forests in Mexico. In Colorado the owls can be found breeding 1900-3000 meters in elevation in the densest portions of spruce forests

(Johnsgard 2002). Much is still unknown about the borders of their breeding grounds; however, since they tend to change from year-to-year and are secretive and nocturnal.

The Northern Saw-whet Owl nests in various types of forests depending on where food is most abundant and if nesting cavities are available (Johnsgard 2002). Having a nesting cavity in an area where food is plentiful can play a role in the success rate of the owl's clutch. Saw-whets are monogamous, but can be polygynous when food sources and nesting sites are abundant (Johnsgard 2002). This species can maintain a nesting cavity throughout the year to increase the chance of breeding again with the same mate the second year, but due to mortality rates of 40-50 percent per year during migration, the chances of a male and female breeding two years in a row is low (Rasmussen et al. 2008). Competition for these favorable breeding areas can cause aggressive behavior between the owls (Rasmussen et al. 2008).

During the breeding season the male will begin courtship by flying around the female 15-20 times before landing (Johnsgard 2002). The male will then attract the female with his advertising call. Once she has drawn near, he shows her the available nesting cavities (Rasmussen et al. 2008). Nesting cavities are typically in vacant woodpecker dwellings. The female then chooses a cavity where she would like to lay her eggs (Rasmussen et al. 2008). The female can be spotted roosting in her nest several days prior to laying the first egg, while the male can be observed bringing food to the nest several days before the first egg is laid. Saw-whets have an average clutch size of four to seven eggs, and it can take one to three days for one egg to be laid (Johnsgard 2002).

Eggs are smooth and white with an average size of 30x25 mm. The eggs are continually laid in intervals of one to three days until completion of the clutch.

The female remains with the eggs for incubation, while only leaving the nest, usually early in the night, to excrete waste (Johnsgard 2002; Rasmussen et al. 2008). The eggs are incubated for 26-28 days, and throughout the female's duration with the eggs and nestling she keeps the nest clean of all parasites and feces (Rasmussen et al. 2008). The hatchlings eyes open in 7-10 days, and they gain 7g of mass a day from the time they are 4 to 14 days old (Rasmussen et al. 2008). When the hatchlings are three to four weeks old their wings start to grow rapidly, their down plumage begins to wear off, and they begin to loose mass (Johnsgard 2002; Rasmussen et al. 2008). At this time the juveniles are getting ready to leave the nest. The male continues to bring food to both the female and the nestlings until the juveniles depart and the female has left to roost in a new area (Rasmussen et al. 2008). The food not consumed is stored for later use. Mortality of young can occur due to starvation, bloodsucking flies (*Carnus hemapterus*), parasites, diseases such as cyathostomiasis, and even car collisions (Rasmussen et al 2008). This species of owl has a short life expectancy of two years on average, but older owls have been recorded. According to Rasmussen et al. (2008), the maximum age reported for this species of owl is 10 years and four months in the wild and 16 years in captivity.

Each autumn saw-whets leave their breeding grounds and migrate south to their wintering grounds, although some choose to winter on their breeding grounds (Brinker et al. 1997; Rasmussen et al. 2008). Those that choose to remain on their breeding grounds are typically in the southernmost part of their range (Bowman et al. 2010). In the winter,

saw-whet's breeding grounds become covered in snow for long periods of time with temperatures remaining below 0 °C (Brinker et al. 1997). It is thought that this owl migrates not to escape the cold weather, but because acquiring prey can be challenging in these harsh, cold weather conditions with snow covering the ground (Brinker et al. 1997). Typically, small-mammals are living in their tunnels under the snow, and most of the small birds have fled south for the winter (Bent 1938). Also, when temperatures fall below freezing, few insect prey are available (Stock et al. 2006). It can therefore be difficult for this species to maintain its body weight (Brinker et al. 1997). Therefore, saw-whets choose to migrate to milder climates where food may be more plentiful.

These owls demonstrate differential migration based on various circumstances. Males tend to remain closer to the breeding grounds than females, and adults remain closer to the breeding grounds than juveniles. Males may remain closer to their breeding grounds so that they can better compete for territories when spring arrives. Social dominance might also play a role in differential migration as males force the females and juveniles to move farther south. Beckett and Proudfoot (2012) have proposed that females may migrate further than males because they are larger than males, and may be more susceptible to winter's limited food supply. Females also need further resources for egg development that are not essential for males (Beckett and Proudfoot 2012).

Northern Saw-whet Owls may not only migrate in order to acquire prey, but to escape their predators as well. Large birds are the primary predators of this species (Rasmussen et al. 2008). They are frequently preyed upon by larger owls such as the Barred Owl (*Strix varia*), Great Horned Owl (*Bubo virginianus*), Eastern Screech-Owl

(*Megascops asio*), and Spotted Owl (*Strix occidentalis*) (Brinker et al. 1997; Rasmussen et al. 2008). Other predators consist of the Broad-winged Hawk (*Buteo platypterus*), Cooper's Hawk (*Accipiter cooperii*), and Peregrine Falcon (*Falco peregrinus*) (Rasmussen et al. 2008). Saw-whets can be more exposed in the deciduous forests in the winter months due to the lack of leaves on the trees. Therefore, migration to coniferous or evergreen forests appeal to this species where they can take cover in the dense shrubs (Brinker et al. 1997). For example, southeastern coniferous forests provide adequate coverage, food, and snow free environments for these owls (Brinker et al. 1997).

These owls migrate on a broad front across North America to their wintering grounds; however, routes of greater concentration in the east appear to be along the Ohio River valley, through the Appalachian Mountains, and along the Atlantic Coast (Rasmussen et al. 2008). Some owls have been found as far south as northern Florida (Brinker et al. 1997). According to Rasmussen et al. (2008), studies have also shown that owls at higher elevations migrate to lower elevations to winter. Routes in the west are still vague due to lack of study, and exact boundaries of the wintering grounds there are generally unclear. But as true of their breeding grounds, their favored wintering habitat usually consists of dense woodlands where they can forage from suitable perches (Rasmussen et al. 2008).

Saw-whets live a secretive life and can be difficult to locate because of their nocturnal habits unless they are vocal. They are most vocal during their breeding season. However, saw-whets infrequently breed in Virginia: thus, when present here during migration and when wintering they are rarely vocal, as they are not defending a breeding

territory (Pagels and Baker 1997). This makes the study of the migration dynamics of the saw-whet difficult.

In Virginia, four primary banding stations have been tracking the migratory patterns of the Northern Saw-whet Owl. One lies in the Coastal Plain region on the lower Delmarva Peninsula, and was the first banding station initiated in Virginia, beginning operations in 1994 (Smith et al. 2013). A second banding operation is located west of Richmond. And a third banding station is operated in the Ridge and Valley region of Virginia on the border of West Virginia in Rockingham County, and began operations in 2001. To fill the geographic gap between these three locations, and to gather data on saw-whet migration in the eastern Piedmont region of central Virginia, a banding project was initiated at Liberty University in 2002. Mist nets and audio lures are used at each of these four banding stations to study the migration dynamic of this owl.

Banding stations have shown that around every four years there is an irruption in the migration cycle of Northern Saw-whet Owls (Beckett and Proudfoot 2011). This results in higher densities of migrating saw-whets outside their normal breeding range (Stock et al. 2006). These years are typically referred to as invasion years. Whalen and Watts (2002) have suggested that this increase in migration volume is due to a decrease in the amount of prey or habitats available per owl, driving more owls to migrate. Trees drop their mast on a cyclical basis every three to five years. Mice populations tend to then fluctuate based on these cycles. If the mast production is high in the fall, that following spring the mice population will increase. Therefore, in the summer the owl population will increase due to the increase in prey. By next fall, the mast production will decrease

along with the mouse population, driving the owls south. It has been proposed that these prey cycles may increase the impact of food shortages because years with few prey may follow years of abundant prey in which the saw-whet populations experienced low mortality along with high productivity (Whalen et al. 1997). An increase in population numbers along with a decrease in prey availability could cause these vast migrations.

As noted earlier, migration dynamics have been investigated in central Virginia since 2002. Much has been learned about the volume and timing of the saw-whet migration, as well as variability among the years. Also, many other similar studies have contributed to our understanding of migration patterns in different regions concerning migration routes, ratios of males and females, and of juvenile and adult birds. However, another significant factor with respect to understanding saw-whet migration dynamics is the influence of weather on both flight activity and capture probabilities. Very few studies have looked at environmental factors correlated with the number of owls netted. The goal of this study was therefore to take a more careful look at this relationship between weather patterns, flight dynamics, and capture probabilities. It is important to understand the flight dynamics themselves along with their possible influence on capture rates, because these factors might introduce the possibility of bias into migration samples, and influence estimates of population trends based on samples of migration by banding.

### **Methods and Materials**

Liberty University's Northern Saw-whet Owl banding project is conducted at Camp Hydaway in Campbell County, Virginia. Commencing in late October, it runs from late November to early December. Trained Liberty University biology students aided in

this project. Teams of students arrived at Camp Hydaway 30 minutes before dusk to hike to the net site some distance back in the woods to open five mist nets that are closed during the day to avoid capturing diurnal birds. Students then set up the audio lure that broadcasts a saw-whet call in order to attract owls into the net. Loud speakers directed the call upward, and were located on the ground in front of the middle of the five nets. A car amplifier boosted the volume of the audio lure, which consisted of an Mp3 player that broadcasted a continuous loop recording of the saw-whet call. The nets were checked every hour from the time they were opened until 11 pm when they were closed. Data recorded by the students included time of net check, number of any owls captured, light of moon if present, and degree of cloud coverage.

Captured owls were carefully removed from net and placed in a breathable cloth bag for transport to the camp buildings for processing. There, the owl's sex was determined by comparing its weight and wing length, using a discriminant function developed by Brinker (2000), as females average heavier and larger than males. Each owl's age was also determined by examining the stage of molting of the wing feathers using molt criteria of Pyle (1997). A black light was used to see if blood was present in the feathers detected by the florescence of the porphyrin proteins in the blood, which indicated that the feathers were new (Weidensaul et al. 2011). New feathers appear pink while old feathers appear white under the black light. Birds with all new feathers were classified as birds of the year ("hatch year") while those showing evidence of molt in the form of a mixture of old and new feathers were classified as "after hatch year" birds.

Once the owl's information had been documented, a U.S. Fish and Wildlife Service aluminum band with a unique identifying number was placed on the owl's leg, allowing the owl to be identified if it were encountered again. The owl was then placed in a cage and its eyes allowed to readjust to the dark before being released. Mist-netting of owls was not attempted during precipitation for the safety of the owls, as their plumage is not effective in repelling water when they are hanging in the mist nets.

A few weather environmental variables were recorded each time nets were checked for owls. These included the relative height of the moon in the sky (none, low, high) and the relative degree of cloudiness (clear, partly cloudy, cloudy). Several other hourly weather variables were obtained from the Lynchburg Regional Airport's historical weather database. These variables were temperature, barometric pressure, humidity, wind direction, wind speed, and degree of cloudiness. The United States Naval Observatory provided information on degree of moon illumination (0-1), and the timing of moon rising and setting was also obtained online.

For most of the environmental variables (moon illumination, wind speed, barometric pressure, temperature, and humidity), a nightly average was obtained simply by averaging the reported hourly numeric values for the hours during which owl banding activities took place for that evening. To obtain a value for nightly sky condition, the following values were assigned: clear = 0, scattered clouds = 0.25, partly cloudy = 0.5, mostly cloudy = 0.75, overcast = 1.0. To obtain a nightly wind direction value, sixteen compass bearings from north and proceeding clockwise NNE, NE, ENE, etc. to NNW were assigned compass bearings values of 0, 22.5, 45.0, 67.5 etc. to 337.5. Any hour with

a calm wind speed value was not included in averages of nightly wind direction. Julian date was used as an additional environmental variable in analyses. Finally, a nightly value of owls per hour was calculated as a measure of owl capture activity.

To explore the possible effect of the environmental variables on magnitude of owl migration, it was desirable not to use data sets reflecting low volumes of owl movement, where the power of the data to detect significant environmental effects would be low and the potential of the data to mask small effects would be high. I therefore restricted my analysis to only years in which the magnitude of owl migration was highest. Highest densities of migrating owls occur in “irruption” years in which owl reproduction has been especially high. Only in 2007 and 2012 did the proportion of young (“hatch year”/HY) owls at this site exceed that of adult (“after hatch year”/AHY) owls, and the highest number of owls were captured in these two years of the study. Therefore, only these two years’ data were analyzed.

Nightly data were analyzed by performing Pearson correlations between owls per hour and each environmental factor, as well as between each pair of environmental factors. A significance level of 0.05 was used to identify significant correlations. Scatterplots and histograms were then used to visualize these different relationships. In order to also consider the possible influence of environmental factors the previous night on a given night’s owl flight, correlations of this nature were also performed.

### **Results**

Considering 2007 first, owl capture rate was only significantly correlated with wind direction (Table 1), with the most favored directions being in the N to ENE

quadrant (Figure 1). Several environmental factors were significantly correlated with one another in 2007, such as temperature with humidity, Julian date with moon illumination, and Julian date with temperature (Table 1).

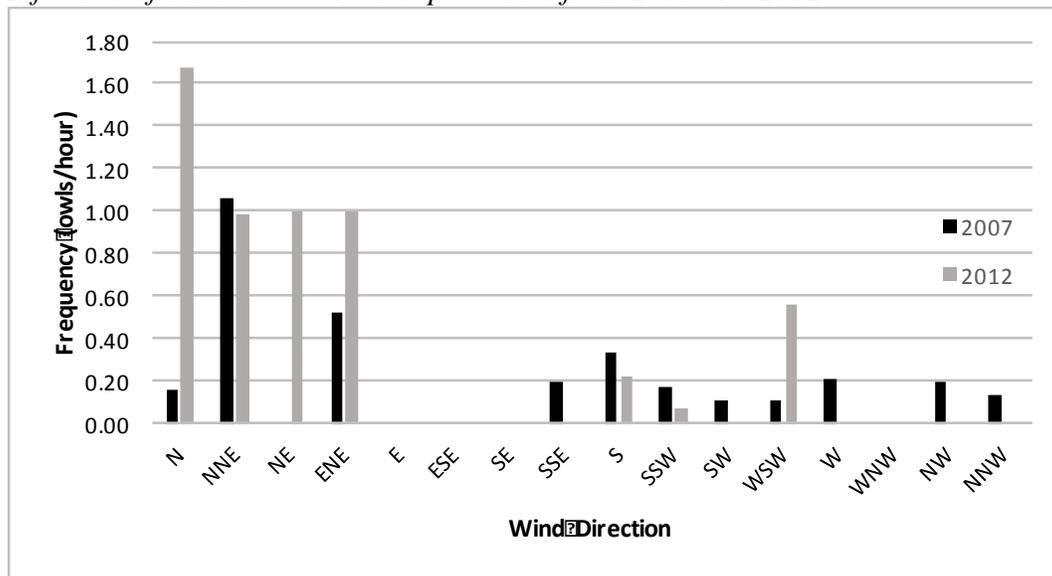
**Table 1**

*Pearson correlations among environmental variables and with owls/hour for 2007. A value of  $r > 0.29$  or  $< -0.29$  is significant except in the case of Wind Direction, where a value of  $r > 0.315$  or  $< -0.315$  is significant because of a smaller sample size due to some calm nights with no wind direction. Significant correlations are in bold.*

2007	Julian	Sky	Moon	WindSP	WindDir	Pressure	Temp	Humidity	Owls/hr
Julian	1								
Sky	0.238437	1							
Moon	<b>-0.37379</b>	-0.2286	1						
WindSP	0.215138	0.190866	-0.116	1					
WindDir	-0.12173	<b>-0.29762</b>	-0.19663	-0.14876	1				
Pressure	0.093545	-0.27888	0.211195	<b>-0.32693</b>	-0.24723	1			
Temp	<b>-0.33882</b>	0.081005	0.205429	0.203387	0.147655	-0.21676	1		
Humidity	-0.06094	<b>0.297898</b>	0.108065	<b>-0.32515</b>	-0.13434	-0.11594	<b>0.392235</b>	1	
Owls/hr	-0.24937	-0.17232	-0.05243	-0.12111	<b>-0.38002</b>	0.201596	-0.19759	0.006304	1

**Figure 1**

*Influence of wind direction on capture rate from 2007 and 2012.*



For 2012, owl capture rate was again significantly correlated with wind direction (Table 2), with the most favored directions being in the N to ENE quadrant (Figure 1).

Owl capture rate was also significantly correlated in 2012 with moon illumination (Table

2), with the lowest moon illumination favoring highest capture rates (Figure 2). Owl capture rate was not correlated with moon illumination in 2007, and a comparison of data on owl capture rate and moon illumination from 2007 (Figure 3) and 2012 (Figure 4) indicates that in 2007, moon illumination began increasing in intensity about four days earlier in the second week of November than in 2012. This time period is during part of the peak time in November when saw-whets are migrating through central Virginia. In 2012, environmental factors were significantly correlated with one another in three cases, including Julian date with temperature as in 2007 (Table 2).

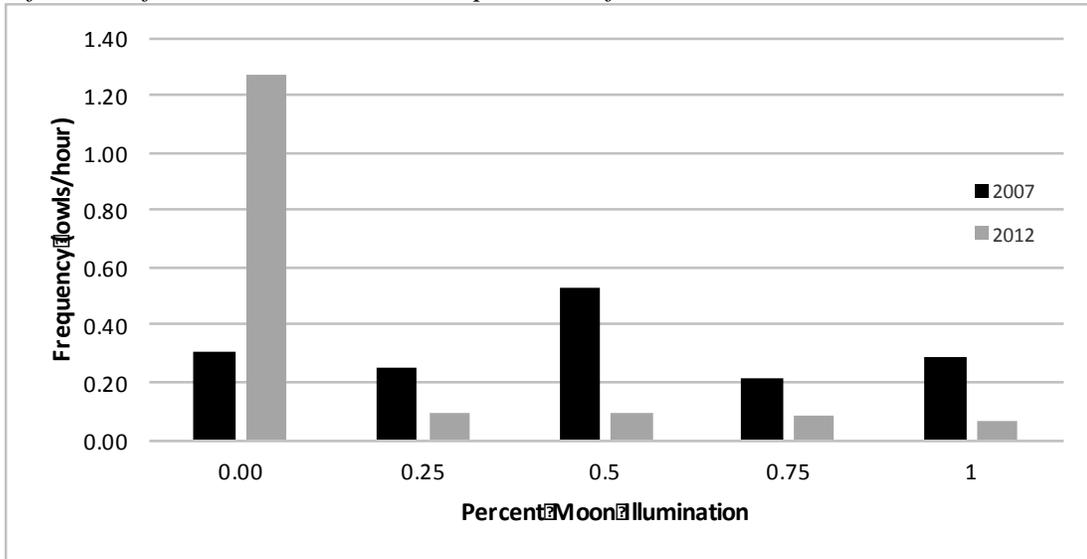
**Table 2**

*Pearson's correlations among environmental variables and with owls/hour for 2012. A value of  $r > 0.325$  or  $< -0.325$  is significant except in the case of Wind Direction, where a value of  $r > 0.385$  or  $< -0.385$  is significant because of a smaller sample size due to some calm nights with no wind direction. Significant correlations are in bold.*

2012	Julian	Sky	Moon	WindSP	WindDir	Pressure	Temp	Humidity	Owls/hr
Julian	1								
Sky	0.217081	1							
Moon	0.015696	-0.17722	1						
WindSP	-0.0162	0.115238	0.027634	1					
WindDir	0.367448	-0.34806	0.358134	0.087861	1				
Pressure	<b>0.420024</b>	-0.09283	-0.26301	-0.078	-0.21673	1			
Temp	<b>-0.42189</b>	-0.04517	0.067778	0.158796	0.010654	-0.18784	1		
Humidity	-0.01309	0.162562	-0.06615	-0.30264	<b>-0.63881</b>	0.116486	0.152428	1	
Owls/hr	-0.27261	-0.01347	<b>-0.57169</b>	-0.28419	<b>-0.4911</b>	0.079813	-0.32116	0.126996	1

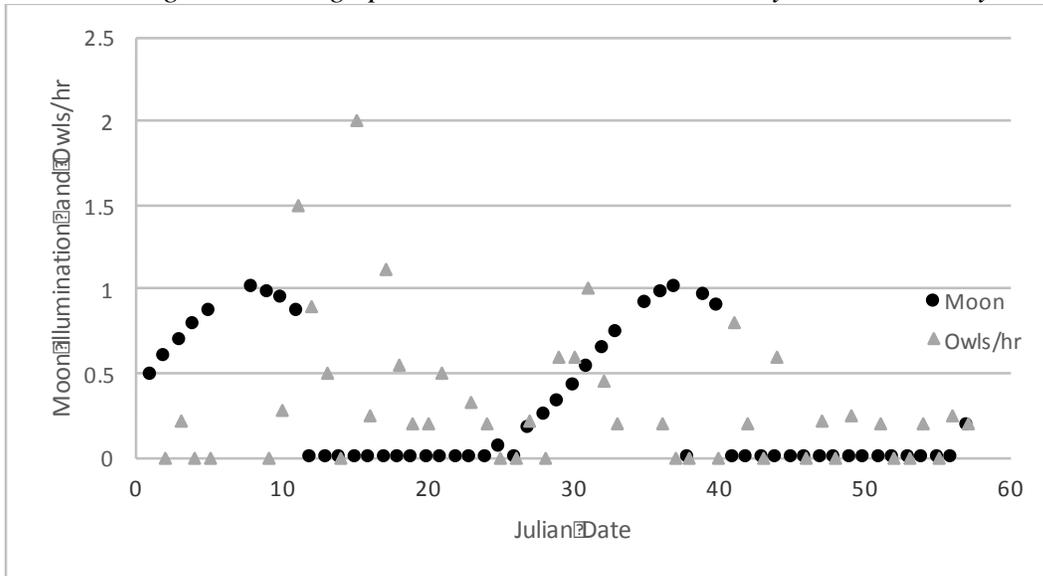
**Figure 2**

*Influence of moon illumination on capture rate for 2007 and 2012.*



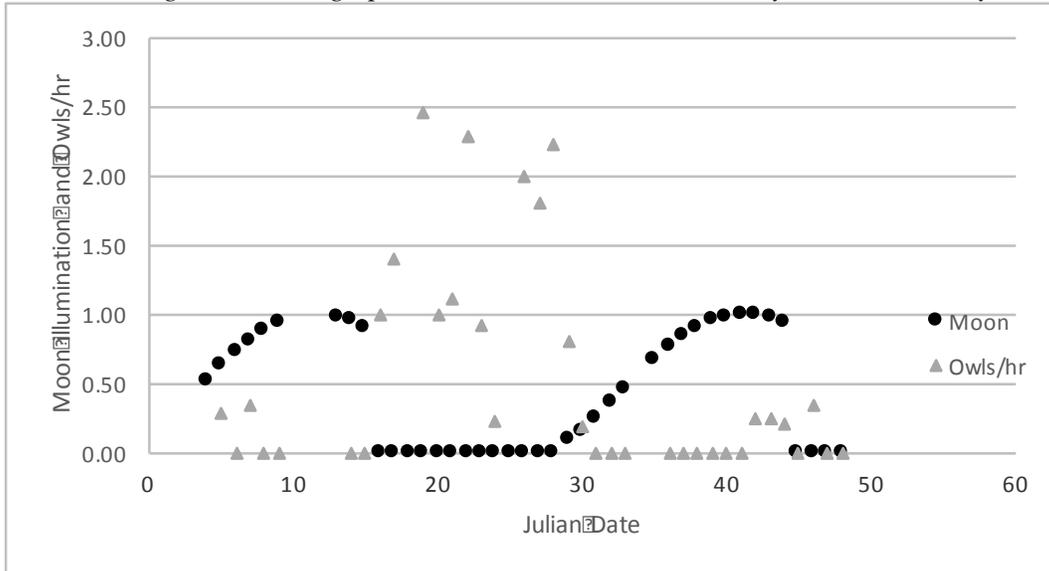
**Figure 3**

*Capture rate (owls/hour) and moon illumination relative to Julian date for 2007. Moon illumination was given a value of zero for all nights during which the moon was not visible during owl banding operations because it had already set or had not yet risen.*



**Figure 4**

*Capture rate (owls/hour) and moon illumination relative to Julian date for 2012. Moon illumination was given a value of zero for all nights during which the moon was not visible during owl banding operations because it had already set or had not yet risen.*



For both years combined, owl capture rates were most closely correlated with wind direction, while the next most significant correlation among the pooled data was capture rate with moon illumination (Table 3). Three other environmental factors were weakly correlated with owl capture rates in the pooled data: temperature, Julian date, and wind speed. Considering the combined influence of the two most highly correlated environmental factors with owl capture rate, nights with northerly wind directions along with lowest moon illumination had the highest capture rate of owls (Figure 5). Of the correlations between the environmental factors with one another, the most significant was that of Julian date with temperature (Table 3), with temperature decreasing with Julian date (Figure 6). Finally, correlations performed on capture rate with respect to environmental factors the previous night were all insignificant, except in the case of

moon illumination and Julian date, which both change by only a small degree from night to night.

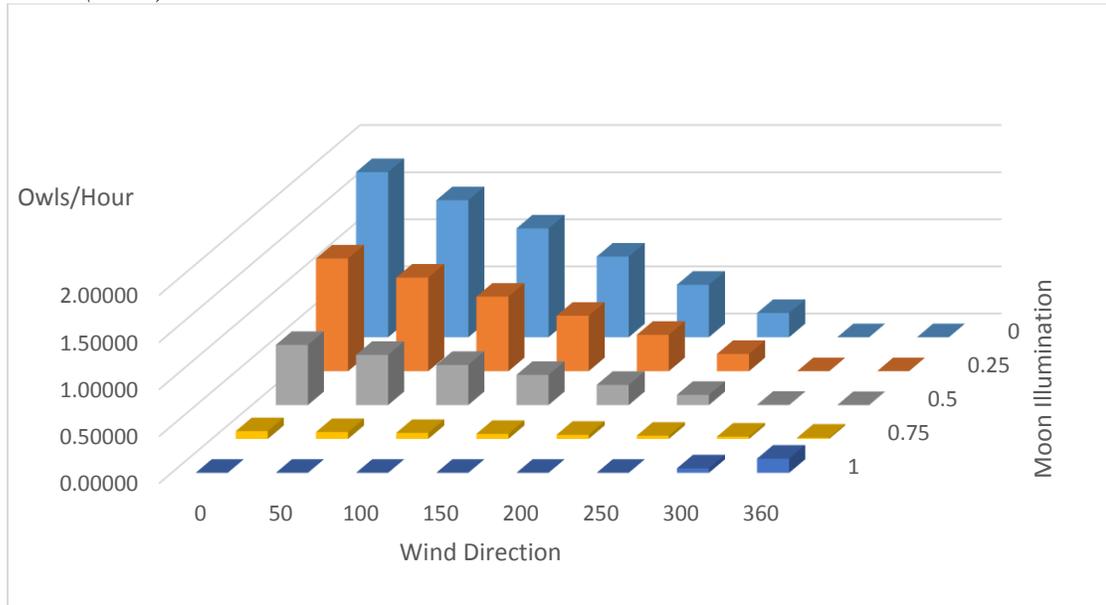
**Table 3**

*Pearson’s correlations among environmental variables and with owls/hour for 2007 and 2012 data pooled. A value of  $r > 0.215$  or  $< -0.215$  is significant except in the case of Wind Direction, where a value of  $r > 0.242$  or  $< -0.242$  is significant because of a smaller sample size due to some calm nights with no wind direction. Significant correlations are in bold.*

07/2012	Julian	Sky	Moon	WindSP	WindDir	Pressure	Temp	Humidity	Owls/hr
Julian	1								
Sky	<b>0.225049</b>	1							
Moon	<b>-0.21596</b>	-0.19594	1						
WindSP	0.119487	0.151053	-0.05496	1					
WindDir	0.091256	<b>-0.31191</b>	0.019718	-0.03442	1				
Pressure	<b>0.214698</b>	-0.19015	-0.00965	-0.20726	-0.23033	1			
Temp	<b>-0.36554</b>	0.02348	0.133169	0.182355	0.128157	-0.20477	1		
Humidity	-0.04006	<b>0.236586</b>	0.018731	<b>-0.30659</b>	<b>-0.30089</b>	-0.02171	<b>0.297632</b>	1	
Owls/hr	<b>-0.24114</b>	-0.05963	<b>-0.32418</b>	<b>-0.23138</b>	<b>-0.47268</b>	0.121525	<b>-0.25128</b>	0.059374	1

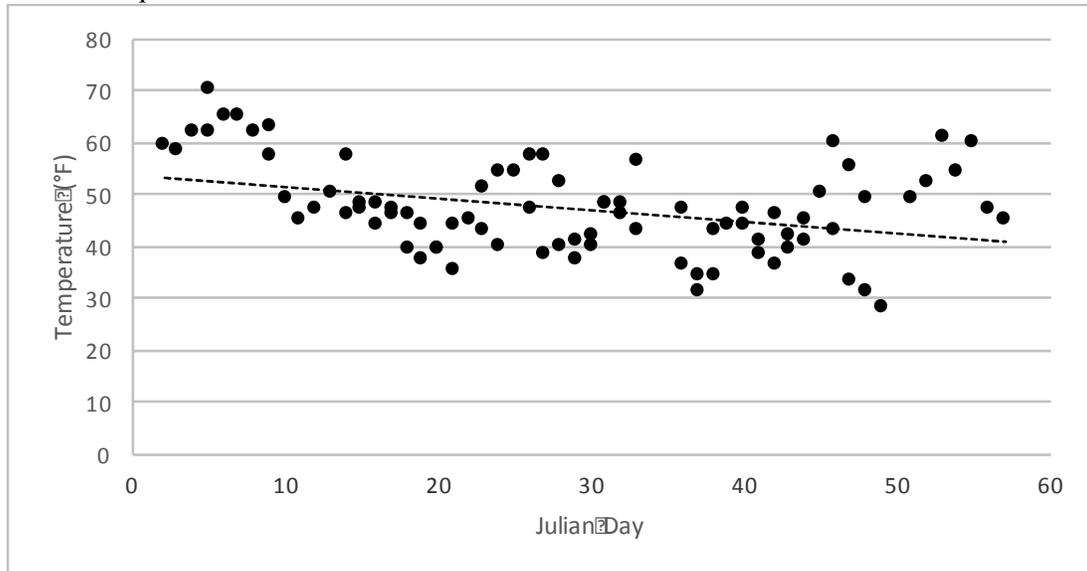
**Figure 5**

*Surface chart of wind direction and moon illumination on capture rate of owls. The chart begins with full moon illumination (1) to no moon illumination (0), and from N (0°) to NNW (360°).*



**Figure 6**

*Temperatures correlation with Julian Date for 2007 and 2012 data pooled. Julian Day one corresponds with October 19<sup>th</sup>.*



### Discussion

For the data of both years analyzed separately and pooled, the environmental factor most strongly associated with high owl capture rates was wind direction, with the heaviest flights associated with wind from the N to ENE quadrant (Figure 1). In general, northerly such winds are conducive to fall migration in birds because tail winds reduce the amount of energy that must be expended while flying. Previous studies of saw-whets, analyzing data from the Great Lakes and Midwest regions, found heavier flights associated with winds from the N to W quadrant (Mueller & Berger 1967, Weir et al. 1980, Brittain et al. 2009) in contrast to our heaviest flights with winds from the N to ENE quadrant. Further analysis of more years of data would be necessary before concluding that NE tailwinds are most favored in saw-whet migration in central Virginia. However, analysis of fall saw-whet same-year recapture data has found that birds in the Great Lakes region generally exhibit more southeast flight trajectories, compared to birds

in the Appalachians to Atlantic seaboard to the St. Lawrence region, which generally exhibit more southwest flight trajectories (Beckett and Proudfoot 2011, Confer et al. 2014). These differences in flight direction in different regions of North America are understandable in light of the fact that many saw-whets migrating from northern regions across Canada and the United States are thought to overwinter in the coniferous forests of southeastern United States (Brinker et al. 1997), and might be related to the apparent difference in wind direction favored for larger owl flight in Virginia compared to more westerly locations. Specifically, birds in Virginia benefit more from NE tailwinds, while birds in the Great Lake and Midwest region might benefit more from NW tailwinds; such tailwinds allow the owls migrating to expend less energy because they do not have to fight crosswind that might blow them off course. Northern Saw-whet Owls have a very low wing loading; that is, their weight is light relative to the wing surface area (Johnson 1997). Light wing loading makes a bird more susceptible to being drifted by crosswinds, so that this species might show a strong preference for the direction of winds under which their heaviest flights take place.

For 2012 and both years pooled, moon illumination had a strong negative correlation with capture rates, with lower capture rates occurring under high moon illumination (Figure 2). Other studies have observed similar results, with capture rate being highest during periods of low moon illumination (Evans 1980, Stock et al. 2006, Frye 2012). Moonlight may cause mist nets to be more visible to the owls, which may help them avoid the nets (Frye 2012). The owls might also be migrating at lower volumes during moon exposure. Speicher et al. (2011) suggested that saw-whets wait for low risk

circumstances under which to migrate and forage. They therefore hypothesized that with a full moon saw-whets are less likely to forage due to predator avoidance. Greater moonlight might expose those small owls to their predators, such as the larger Barred Owl and the Great Horned Owl that are known predators of Northern Saw-whet Owls (Rasmussen et al. 2008). In addition, saw-whet's nocturnal rodent prey may not be as active under greater moonlight, further reducing saw-whet owl activity under greater moonlight. According to Speicher et al (2011), moonlight is an exogenous factor in decreasing the nocturnal activity in prey, and they cite Alvarez-Castaneda et al. (2004) in finding that Barn Owl (*Tyto alba*) pellets showed a decrease in number of rodents taken during a full moon.

Brittain et al (2009), however, observed higher saw-whet capture rates with greater moon illumination. And in 2007, I did not find a significant correlation between moon illumination and capture rates, with more owls captured in that year during times of greater moon illumination than might be expected (Figure 3). Both Brittain et al. (2009) and Frye (2012) suggested that habitat is an important contributor to the amount of light exposure a net site might receive. If nets are surrounded by trees, the canopy of the trees may decrease the amount of moon light in the forests. These trees could therefore provide enough shading to hide the nets, shade for the owls to feel protected from predators, and even enough shading for their nocturnal prey. Evans (1980) and Frye (2012) both had mist nets in low vegetation that did not shade the nets from the moon, which led to the inference that the owls could see the nets, resulting in their finding of a negative effect of

moonlight on capture rate. However, our nets were in a deciduous forest that shaded the nets until leaf fall, which contradicted the idea set forth by Brittain et al (2009).

Brittain et al. (2009) also suggested that comparison of studies might be confounded by whether the moon's influence was assessed simply by gross phase designations (ex. new, quarter, half, full) such as Evans (1980) and Stock et al. (2006), versus a percentage of moon illumination relative to a full moon as he and Frye (2012), as well as this present study used. Cloud coverage is yet another factor that could influence results if not taken into account. For these data moon illumination was classified as zero under full cloud coverage, which of the above cited studies is something only Brittain et al. (2009) did. Also, none of these studies corrected for the height of the moon in the sky during banding hours or even if it had yet risen or already set, which we took into account. All of these factors make interpretation of the varying results of different studies difficult.

A potential explanation for the differences in our results between 2007 and 2012, as well as among other studies, could be the time of month that the full moon falls relative to the peak of saw-whet migration. We observed that the moon had not yet risen above the horizon at night during the peak period of owl migration in 2012, which was also more concentrated in a smaller period of time. In 2007, when there was no correlation with of capture rate with moon illumination, the peak period for owl migration was spread out over a longer timeframe, and overlapped more during periods of greater moon illumination (Figure 3 and 4). In the peak period of migration, the owls might not stop their migration until there is zero moon illumination to continue.

These varying results highlight the interplay of factors that may interact in influencing owl capture rates. To further study the possible influence of moon illumination on saw-whet capture rate, a larger data set under a greater variety of conditions is needed. In addition, we plan to directly measure light levels during nightly operations in the future to better assess its relationship with owl capture rates.

For our pooled data, three other environmental variables were significantly correlated with capture rate of owls: Julian date, temperature, and wind speed. There was a weak negative correlation between Julian date and capture rate of owls, the later in the season, the fewer owls captured. Breckett and Proudfoot (2011) in analyzing fall migration data on Northern Saw-whet Owls in eastern North America from 1999-2008 noted that migration peak times advanced southward over the course of the season suggesting that the owls migrate in distinct fronts rather than in a random seasonal dispersal. Based on studies of this species' fall migration in central Virginia since 2002, the peak time for Northern Saw-whet Owl migration invariably occurs during the first two weeks of November. It can therefore be inferred that fewer owls will be captured later in the season during the second half of November because fewer owls are migrating during that time. Although fewer owls were caught later in the season, that does not mean more owls will be caught early in the season. This banding project always begins just before the number of migratory owls begins to build. If we started earlier in the season, fewer owls would also be caught there, and a correlation of capture rate with Julian date would be eliminated.

Along with Julian date, temperature showed a weak but significant negative correlation with capture rate of owls for pooled data; for cooler temperatures, fewer owls are captured. From October to December, temperatures in central Virginia decrease as winter approaches. Because a greater number of owls are caught early in our banding season with respect to Julian date data when migration is peaking, this explains why more owls are caught under warmer conditions. Temperature's correlation with Julian date thus explains temperature's weak correlation with capture rate.

Finally, wind speed was weakly correlated with capture rate, with fewer owls captured under greater wind speeds. The mist nets are moved when wind speed becomes significant, and probably causes the nets to become more visible to the owls, resulting in a decrease in the number of owls captured because they avoid the nets. Wind speed may also decrease the distance at which the audio lure can be heard (Erdman et al. 1997), and decrease owl captures in that way. As one additional consideration it is possible that these owls might have a more difficult time flying in stronger winds because of their light wing loading, causing them to also expend more energy in flight on nights with greater wind speeds.

Much is still unknown about migration dynamics of the Northern Saw-whet Owl. Studying this species can be difficult due both to its secretive nature and its semi-nomadic movements. Thus, only banding studies such as presented here provide us with understanding of its migratory patterns and wintering distribution. From these studies we are provided with a basic knowledge of this species' natural history, which is necessary to determine possible conservation needs and to implement management practices. Only

by conducting such long-term studies can a species long-term population status be monitored and protected.

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