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Fall Migration and Winter Habitat Use of Northern Saw-whet Owls (Aegolius acadicus) in the Ozark Highlands

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Saw-whet Owls (*Aegolius acadicus*) in the Ozark Highlands

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ABSTRACT

Studying movement ecology is important not only in understanding the distribution of a species, but in understanding the magnitude of migration through certain regions, as well as explaining regional differences in demographics. The Northern Saw-whet Owl (*Aegolius acadicus*) is a small, migratory forest owl found throughout much of North America. Despite being captured widely during fall migration, the species' movement ecology is poorly understood. Exploratory studies outside the saw-whet owl's normal range have successfully captured the species during fall migration. In the Ozark Highlands ecoregion of the central United States, their status has been considered vagrant during fall and winter. Since 2010, saw-whet owls have been captured successfully in the region, historically considered south of their normal range. We sought to assess fall migration and demographics of 412 saw-whet owls captured at four study sites in the Ozark Highlands of Missouri, northern Arkansas, and eastern Oklahoma. Saw-whet owls were captured from mid-October to early-December in the study region. Capture rate varied by latitude and among sites. Demography of owls travelling through the region varied by migration type, with an increase in captures and proportion of hatch-year individuals during irruption years. In addition to likely being a regular fall migrant through the Ozarks, we documented saw-whet owls wintering in the southwestern Ozarks. During autumn migration of 2016 and 2017, we deployed 27 radio transmitters on saw-whet owls captured at our Arkansas banding site. Detections were obtained from 17 tagged individuals during the following winters. Saw-whet owls remained in the region from 1 to 112 days after release, suggesting the species winters to some extent in northwestern Arkansas. Based on assessment of landscape and habitat variables at diurnal roost sites, the species seems to prefer open shortleaf pine (*Pinus echinata*) habitat. Further study is required to determine the full extent of the saw-

whet owl’s winter range; however, ample pine forest and cedar glades could provide optimal wintering habitat throughout the Ozark Highlands.

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TABLE OF CONTENTS

INTRODUCTION 1

LITERATURE CITED 4

CHAPTER I: MIGRATION AND DEMOGRAPHICS OF NORTHERN SAW-WHET OWL (*AEGOLIUS ACADICUS*) DURING FALL MIGRATION IN THE OZARK HIGHLANDS 5

ABSTRACT 6

INTRODUCTION 7

METHODS 10

RESULTS 14

DISCUSSION 16

LITERATURE CITED 24

FIGURES AND TABLES 26

CHAPTER II: WINTER OCCURRENCE AND ROOSTING BEHAVIOR OF NORTHERN SAW-WHET OWL (*AEGOLIUS ACADICUS*) IN NORTHWESTERN ARKANSAS 35

ABSTRACT 36

INTRODUCTION 37

METHODS 39

RESULTS 43

DISCUSSION 45

LITERATURE CITED 50

FIGURES AND TABLES 52

CONCLUSION 56

LITERATURE CITED 59

APPENDIX A: RESEARCH COMPLIANCE PROTOCOL LETTER 60

INTRODUCTION

The Northern Saw-whet Owl (*Aegolius acadicus*) is a small owl found in forests throughout much of North America. During the breeding season, the saw-whet owl is widespread in northern forests, as well as south into forested highlands of the Appalachian Mountains and in mid-elevation coniferous forests of the Rocky Mountains, into Mexico (Weidensaul 2015). Across most of the continent, the extent of the saw-whet owl's breeding range is well documented. The species can be quite vocal during the breeding season and easily detected using auditory surveys. Until the early 20th-century, the saw-whet owl was considered resident throughout its range, but was occasionally found elsewhere, outside of its normal range. Over a century after its discovery, the saw-whet owl was determined to be migratory, seemingly explaining sporadic records outside what ornithologists believed to be the normal range (Taverner & Swales 1911). Since that time, saw-whet owls have been captured across North America, primarily during fall migration, with most studies occurring in southeastern Canada, along the Atlantic Coast, and the Great Lakes (Project Owlnet 2016). Outside the breeding season, saw-whet owls are largely silent, making detection difficult without capture (Weidensaul 2015).

Migration, especially for a common breeding resident of northern latitudes, allows saw-whet owls to capitalize on prey availability elsewhere in North America during harsh northern winters (Pulido 2007). As most fall migration studies capturing saw-whet owls are concentrated in eastern and north-central North America, the extent of the species' fall migration and winter range is not well known. Further study of the species' movement ecology will be important in understanding what habitats and areas are used during the nonbreeding season, in order to better understand population dynamics and range extents throughout its range (Taylor & Norris 2009).

To further complicate our understanding of the saw-whet owl's movement dynamics, the species is considered irruptive in addition to being a seasonal migrant. Irruptions are irregular movements where large numbers of individuals temporarily move to regions outside their normal range and are typically tied to food availability (Strong et al. 2015). Irruptions in saw-whet owls are characterized by an increase in captures at fall banding sites and an increase in the proportion of hatch-year individuals (Brittain & Jones 2014). For this reason, it is believed the saw-whet owl's irruptive movements occur following years of high prey abundance during the breeding season, leading to high reproductive success (Beckett & Proudfoot 2011). The correlation between saw-whet owl irruptions and prey abundance during the breeding season is further supported by owl irruptions occurring at intervals of three to five years, similar to the three- to seven-year fluctuations observed in boreal small rodent populations (Fryxell et al. 1998). Irruptions tied to boreal small rodent cycles have been observed in a congener of the saw-whet owl, Boreal (Tengmalm's) Owl (*A. funereus*). However, the Boreal Owl has been shown to move outside its normal range during periods of low prey availability (Cheveau et al. 2004). Overall, irruptive movements in the saw-whet owl remain poorly understood.

In the central and eastern United States, the saw-whet owl is known to winter regularly as far south as central Kansas, Missouri, and the Appalachian Mountains of eastern Tennessee and western North Carolina (Rasmussen et al. 2009). Research south of this currently accepted extent has demonstrated that saw-whet owls may winter further south than historically believed. The species has been captured during fall migration in eastern Oklahoma, northwestern Arkansas, northern Mississippi, and northern Alabama (Revels & Bodley unpub. data, Pruitt & Smith 2016, K. Mitchell unpub. data, R. Sargent unpub. data). Additionally, winter records exist for all of the Lower 48 states (Rasmussen et al. 2008).

I sought to assess the status of saw-whet owls in the Ozark Highlands ecoregion during fall migration and winter; two seasons where the species is understudied in the south-central United States. In chapter 1, I analyzed banding data from a collaborative effort among four sites located in Missouri, Arkansas, and Oklahoma. I assessed regional migration trends and demography of saw-whet owls in the Ozark Highlands ecoregion. Prior to this study, the saw-whet owl was considered winter resident in the northern half of Missouri, but only sporadic fall and winter records existed for the remainder of the study area. This study encompasses 8 years of fall banding data, including 2 irruption years. Irruption years were defined using capture data from across eastern North America (Bird Banding Laboratory). I examined trends in migration by site, year, and migration type (irruption, non-irruption). In addition, I assessed variation in sex and age of captures by site, year, and migration type. Finally, using same-season recapture data from central North America, I examined coarse movement patterns in the region. This allowed me to infer migratory pathways used by saw-whet owls captured in the Ozark Highlands. In chapter 2, I used radio telemetry to document the saw-whet owl as a winter resident in northwestern Arkansas. By tracking wintering saw-whet owls, I gathered data at landscape- and microhabitat-scales to determine the species' roost preference and examine habitat around roost sites. Together, these studies greatly improved our knowledge of saw-whet owls in the south-central United States and provide data that help better understand their movement ecology and range in a region where, due to lack of data, they were historically considered vagrant, if not absent.

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Chapter I

Migration and Demographics of Northern Saw-whet Owl (*Aegolius acadicus*) in Autumn in the Ozark Highlands

ABSTRACT

Nearly half of all birds undergo migration, a phenomenon that allows them to satisfy resource demands by moving to different areas seasonally. Studying movement ecology is important not only in understanding the distribution of a species, but understanding the magnitude of migration through certain regions, as well as explaining regional differences in demographics. The Northern Saw-whet Owl (*Aegolius acadicus*) is a small forest owl of northern North America. Each fall, the species is widely captured at banding stations, especially in eastern North America and the Great Lakes region. Many exploratory studies outside the owl's normal range have successfully captured the species during fall migration. In the Ozark Highlands ecoregion of the central United States, their status has been considered vagrant during winter, based on scattered historic records. Since 2010, saw-whet owls have been captured successfully in the northern Ozark Highlands and since 2014 in the southern Ozark Highlands. I sought to assess fall migration and demographics of 412 saw-whet owls captured at four sites in the Ozark Highlands of Missouri, northern Arkansas, and eastern Oklahoma. Saw-whet owls were captured from mid-October to early-December in the study region and capture rate varied among sites, as well as latitudinally. Additionally, irruptive movements were observed during two sampling years, resulting in an increase in captures and a higher proportion of hatch-year owls. Based on same-season recaptures, saw-whet owls primarily arrive in the Ozark Highlands after passing through the western Great Lakes. While fewer saw-whets were captured than at northern banding stations, the species appears to be a regular migrant through the Ozark Highlands during fall.

INTRODUCTION

In order to better understand seasonal variation in populations and habitat use, long-distance movement has long been a source of interest to ornithologists. As many species are difficult to detect outside the breeding season, post-breeding movements are of particular interest to better understand a species more holistically. In nearly half of the Earth's birds, this takes the form of regular seasonal migrations or, in some cases, irregular movements known as irruptions (Berthold 2001). Migration allows birds to capitalize on variation in resource availability in different regions at different times of the year. An example are birds that breed at high latitudes, where food may be abundant during summer months. Many of these northern breeders travel elsewhere for winter, which is more advantageous than remaining where winter is harsh and food availability uncertain (Pulido 2007). Unlike seasonal migration, irruptive movement in birds is irregular. Irruption is characterized by a large number of individuals temporarily moving to regions outside their normal range. A classic example are North American finches, many of which are dependent on boreal seed crops. During masting years with high food availability, they thrive within their usual, northern range. In years with poor food availability, they may travel far outside their normal range (Strong et al. 2015).

Our knowledge of avian movement patterns has expanded substantially in recent years, due to advances in remote tracking technologies and widespread coordinated banding programs (Fiedler 2009). However, knowledge gaps in movement ecology still exist for many species, particularly in difficult to detect, or secretive species. Owls are a classic example of a secretive taxon, containing migrant and irruptive species, whose movement ecology is poorly understood.

The Northern Saw-whet Owl (*Aegolius acadicus*) is a small forest owl and a regular migrant throughout North America, but has irruptive tendencies. The Northern Saw-whet Owl breeds in forests of northern and mountainous North America, following mid-elevation coniferous forest through the Rocky Mountains, into Mexico where its range continues south and east along the Sierra Madre Occidental and Sierra Madre Oriental (Weidensaul 2015). The extent of the saw-whet owl's breeding range is well documented across most of North America. Documenting presence of saw-whet owls during the breeding season is straightforward, as the species regularly vocalizes during this time. The same cannot be said for their migratory and winter ranges, as saw-whet owls are notoriously silent during the nonbreeding season, making them difficult to detect (Brittain 2008).

Once considered a strictly northern species in eastern and central North America, the saw-whet owl's migration was documented in 1911, over a century after the species' discovery, and was not studied extensively until the 1960s (Taverner & Swales 1911, Walkimshaw 1965). Over the past several decades, the saw-whet owl has been widely captured and banded during fall migration in eastern North America and the Great Lakes region. In the east, fall migration occurs from late September in the north to early December in the south (Weidensaul 2015). Its migration west of the Mississippi River is not well documented. Additionally, migration patterns in mountain ranges of the west are muddied by suspected seasonal altitudinal movements (Weidensaul 2015). Spring migration, occurring between late-March and early-May, is even less well-documented than fall migration (Holroyd and Woods 1975).

In addition to being migratory, saw-whet owls are considered irruptive. The species' irruptive movements are not well studied. In boreal forests of eastern Canada, irruptions have been documented in years of increased small rodent abundance during late summer (Côté et al. 2007). As a majority of saw-whet owls banded during irruption years are juveniles, this likely reflects greater breeding productivity due to increased food availability, resulting in an increase in the number of individuals migrating during fall (Whalen & Watts 2002). Northern Saw-whet Owl irruptions occur at intervals of three to five years, similar in scope to the three- to seven-year fluctuations in boreal small rodent populations (Fryxell et al. 1998).

Movement dynamics of saw-whet owls have been studied in eastern North America, primarily through analysis of large banding datasets (Confer et al. 2014). Insufficient data west of the Mississippi River make it difficult to assess migratory movements in the central and southern United States. However, there is strong evidence that saw-whet owls migrate further south than historically believed. Recent banding studies have shown saw-whet owls to occur regularly as far south as Oklahoma, Arkansas, Alabama, and Georgia during fall migration. The region of focus in this study was the Ozark Highlands ecoregion, a > 40,000 km^2 dissected plateau, not exceeding 600 MASL. The Ozark Highlands are characterized by oak-hickory forest, with shortleaf pine (*Pinus echinata*) and eastern red cedar (*Juniperus virginiana*) in areas of shallow soil, disturbance, south-facing, and west-facing slopes (Wiken et al. 2011). Historic records for saw-whet owls exist in the region. In Missouri, the saw-whet owl is considered a winter resident in the northern half of the state. A handful of fall and winter records exist for the southern Missouri Ozarks, 4 of 13 historic records from Arkansas are from the Ozarks, and none of 13 historic records from Oklahoma are from the Ozarks. Because of the few, mostly winter records, the saw-whet owl was historically considered a winter vagrant to the Ozark Highlands.

Our objective was to further investigate saw-whet owl migration in the Ozark Highlands ecoregion. Through a collaborative effort, I explored the species' status in the Ozark Highlands and examined regional trends in migration and demographics. This study includes eight years of banding data, with irruption years in 2012 and 2016, based on capture data across eastern North America (Bird Banding Laboratory). With these data, I examined annual trends in migration and made comparisons between irruption and non-irruption years. Based on previous studies, I expected capture rates to increase during irruption years, captures to be mostly female, and the proportion of hatch-year saw-whet owls to be greater in irruption years (Beckett and Proudfoot 2012, Confer et al. 2014). Additionally, I expected captures to decrease with decreasing latitude and for captures to occur earlier at the more northerly sites (Beckett and Proudfoot 2011). Finally, I examined instances of same-season recapture of banded owls to assess possible migratory pathways for saw-whet owls in the Ozark Highlands and the south-central United States as a whole.

METHODS

Study Areas

This study was a collaborative effort among researchers at University of Arkansas, Fayetteville, Arkansas; Northeastern State University, Tahlequah, Oklahoma; Missouri River Bird Observatory (MRBO), Marshall, Missouri; and World Bird Sanctuary (WBS), St. Louis, Missouri (Figure 1). In 2010, a study to capture and band the Northern Saw-whet Owl during fall migration began at MRBO. Research was conducted at Indian Foothills Park, Marshall, MO and nearby Arrow Rock State Historic Site (for ease, both sites shall be denoted MRBO). A similar study began in 2012 at WBS and in 2014 in northwestern Arkansas. The Arkansas study was conducted primarily at Ozark Natural Science Center, Madison County with some exploratory netting at nearby Hobbs State Park Conservation Area, Benton County (for ease, both sites shall be denoted ONSC). A study began in 2016 in northeastern Oklahoma, at J.T. Nickel Family Nature and Wildlife Preserve (JTNP), Cherokee County. ONSC and JTNP are located in the southwestern portion of the Ozark Highlands ecoregion, and MRBO and WBS are located along the northwestern and northeastern edges, respectively. Habitat varied among sites from primarily deciduous forest at MRBO and WBS, to mixed pine-deciduous with cedar understory and open understory at ONSC and JTNP, respectively.

Capture and Banding

All sites followed standard methods developed by Project Owlnet, a collaboration of researchers studying the saw-whet owl (Project Owlnet 2016). Mist nets of 60 mm mesh size were used at all sites, but netting arrangements varied. MRBO utilized a total of 48 m of mist nets, WBS 57 m from 2012-2016 and 81 m in 2017, ONSC 48 m, and JTNP 90 m. A Cabela's Outfitter Series FoxPro™ predator caller (Lewistown, PA), was placed at the center of each arrangement and used as an audio lure to attract owls to the net area for capture. Audio lures for MRBO and WBS were programmed with a male saw-whet owl's solicitation "*toot*" call. Audio lures for ONSC and JTNP were programmed with 21 sec of a male saw-whet owl's "*toot*" call and 8 sec of the species' "*whine*" call, followed by a 6 sec pause before recycling. The audio lure broadcasts at ~ 100 dB.

Netting occurred from mid-October to early-December at all sites, from approximately 1930 to 0000, for an average of 4.5 hours per night. Netting did not occur on nights with wind >24 kph and/or precipitation. Nets were checked at ~60 min intervals. When a saw-whet owl was captured, basic morphometric measurements were collected and each was banded, sexed and aged. All received a size 4-short aluminum band, provided by the U.S. Geological Survey's Bird Banding Laboratory (BBL). Northern Saw-whet Owls were assigned a sex by comparing mass (g) to closed wing chord (CWC) (mm), using a chart published by Brinker (2000). A saw-whet owl was classified as female if between mass = ≥ 86 g with CWC = ≤ 141 mm and mass = ≥ 93g with CWC = ≥ 120 mm, male if between mass = ≤ 78 g with CWC = ≤ 135 mm and mass = ≤ 88 g with CWC = ≥ 120 mm, unknown sex if measurements fell between these ranges. All saw-whet owls were aged by illuminating the underside of flight feathers (Primaries: P1-P10; Secondaries: S1-S12) with ultraviolet (UV) light. In many owls, feathers contain a porphyrin pigment which fluoresces pink when exposed to UV light. The pigment fades over time, making feather ages conspicuous. In saw-whet owls, new feathers exhibit bright fluorescence, middle-aged feathers light fluorescence, and old feathers little to no fluorescence (Weidensaul et al. 2011). Individuals classified as hatch-year (HY) exhibit even fluorescence across flight feathers, second-year (SY) individuals exhibit two distinct hues of fluorescence, and after second-year (ASY) individuals exhibit 3 or more hues of fluorescence (Weidensaul et al. 2011). Northern Saw-whet Owls cannot be accurately aged beyond ASY unless previously banded. All saw-whet owls were released following processing.

To examine large-scale movements of saw-whet owls in the central United States, same-season recaptures from our study sites were combined with data from a larger dataset provided by the BBL. Same-season recaptures were defined as saw-whet owls that were either banded on the breeding grounds and recaptured the following fall or those banded during fall migration and recaptured in the same season or following winter. I included data from saw-whet owls either captured or recaptured west of the Mississippi River, but east of the Great Plains. Recaptures from Illinois were retained due to close proximity to the WBS site.

Statistical Analyses

Chi-square goodness-of-fit tests, conducted in program R version 3.5.1, were used to compare capture rate among sites, latitudes, and migration types (irruption, non-irruption). The irruption years of 2012 and 2016 were identified by an increase in capture rate and proportion of hatch-year saw-whet owls captured, based on a broader dataset showing patterns in captures across eastern North America (Bird Banding Laboratory, Brittain & Jones 2014). Observed values were raw captures and expected values were calculated based on total effort (net-hours) per year, assuming no difference in capture rate across groups. To test for latitudinal trends, stations were combined into two latitudinal groups, MRBO-WBS and ONSC-JTNP, at approximately 39°N and 36°N, respectively. For temporal comparisons, number of Northern Saw-whet Owls (NSWO) captured (*n*) were standardized for effort using the following equation to obtain a capture rate: n NSWO / (sampling hrs × # 12 m mist nets) × 100 (Ralph 1976).

To examine variation in captures among demographic groups and by migration type, log-linear models with negative binomial distribution were constructed, followed by an information theoretic approach to assess support for each model using package 'MASS' in program R version 3.5.1 (Venables & Ripley 2002). A model set was developed to explain variation in saw-whet owl captures. Individuals of unknown sex (n = 62) were excluded from models. We considered twelve models incorporating three variables: sex, age class (AHY, HY), and migration type (irruption, non-irruption; Table 2). We investigated additive effects, as well as 2- and 3-way interactions between each of the three variables. In all models, effort was included as an offset variable, which are frequently used in count data models to adjust for differential effort or exposure time. We compared models within the set using Akaike's Information Criterion (AIC) and models with ΔAIC values ≤ 2 compared to the top-ranked model were considered good candidates for explaining patterns in captures. When considering nested models within 2 ΔAIC of each other, we chose the simpler model when it differed by one parameter (Burnham & Anderson 2002).

RESULTS

Capture Rate

During this study, a total of 412 saw-whet owls were captured: MRBO = 207, WBS = 85, ONSC = 81, JTNP = 39. Effort varied among stations from 57.1 net hrs at MRBO in 2010 to 1688.0 net hrs at JTNP in 2017 (Table 1). When sites were grouped by latitude, observed number of captures were significantly different from expected capture values ($\chi^2 = 15.92$, $P < 0.01$). Results suggest more saw-whet owls are captured per unit effort at MRBO-WBS, the higher latitude sites, than at ONSC-JTNP, to the south (Figure 2A), however, this varied when considering site alone. Observed number of captures by site were significantly different from expected capture values based on effort alone ($\chi^2 = 246.51$, $P < 0.01$). Results suggest that more saw-whet owls are captured per unit effort at MRBO and ONSC and fewer captured per unit effort at WBS and JTNP (Figure 2B). Generally, lowest capture rates were observed during non-irruption years. Mean capture rate across all stations during non-irruption years was 5.9 NSWO/100 net hrs and ranged from 3.6 NSWO/100 net hrs in 2011 to 19.3 NSWO/100 net hrs in 2010. Mean capture rate across all stations during the two irruption years that occurred during the study was 11.1 NSWO/100 net hrs and ranged from 3.8 NSWO/100 net hrs in 2012 to 14.7 NSWO/100 net hrs in 2016. Observed number of captures by migration type (irruption, non-irruption) were significantly different from expected capture values ($\chi^2 = 39.12$, $P < 0.01$). Results suggest more saw-whet owls are captured per unit effort during irruption years and fewer per unit effort during non-irruption years (Figure 2C).

When examining latitudinal trends in migration, peak in capture rate began during the first week of November at MRBO-WBS and the second week of November at ONSC-JTNP (Figure 3). However, mean banding day was 11 November for both latitudinal groups.

Additionally, the mean date of arrival was one day earlier at ONSC-JTNP (28 October) than MRBO-WBS (29 October) (Figure 3). Last capture of the fall banding season has consistently occurred during the first week of December. The earliest date of capture was 15 October, at MRBO in 2014 and the latest date of capture was 11 December at MRBO. During irruption years, peak capture rates occurred approximately one week earlier (Figure 4).

Demographics and Migration Type

Females (*n* = 310) were most frequently encountered at all study sites and made up 75.4% of total captures, followed by individuals of unknown sex (*n* = 62) (15.1%), and males (*n* = 39) (9.5%; Figure 5). Females exhibited mean weight = 92.9 g (range = 80-109.5 g) and mean CWC =141.1 mm (range = 126-150 mm). Males exhibited mean weight = 79.1 g (range = 72.5-86 g) and mean CWC = 132.6 mm (range = 125-141 mm). Individuals of unknown sex exhibited mean weight = 84.9 g (range = 74.6-97 g) and mean CWC = 136.2 mm (range = 128-145 mm).

All three of the predictor variables were informative in explaining variation in saw-whet owl captures. The top model in the candidate set included interactions between age and migration type, sex and migration type, and age and sex, and received 61% of the weight (Table 2). The second best-supported model contained a 3-way interaction between the variables of interest, but differed from the similar, top model by only one parameter so was not retained for inference. No other models were within < 2 ΔAIC. Within the top model, there was an interaction between age and migration type, whereby captures were higher for both age classes during irruption years than in non-irruption years. However, migration type more strongly affected HY captures, as shown by the steeper slope in Figure 6A. There was also an interaction between sex and migration type (Figure 6B). While migration type clearly influenced the number of females captured—captures were higher during irruption years—there was little change in male captures across irruption and non-irruption years. The final interaction in the top model was between age and sex, whereby age explained some of the variation in female captures, but not for males (Figure 6C).

Band Recoveries

A total of 58 same-season recaptures were mapped for central North America, including 11 from our 4 study sites (Figure 7). Same-season recaptures included one saw-whet owl that was banded on the breeding grounds and recaptured the subsequent fall and 57 banded during fall migration and recaptured in the same season or subsequent winter. Many of the saw-whet owls captured in the central United States appear to pass through the western Great Lakes. Fan-like dispersal patterns from several major banding sites indicate saw-whet owl movement may not be straightforward. A number of interesting recaptures exist regionally, including saw-whet owls banded in central Saskatchewan and recaptured at MRBO, eastern Ontario and recaptured at WBS, and eastern Ontario and recaptured in northern Illinois.

DISCUSSION

I demonstrate the Northern Saw-whet Owl regularly occurs in the Ozark Highlands during fall migration. Individuals captured in the central United States appear to originate in central Canada, passing through the western Great Lakes. However, based on band recoveries, the region hosts saw-whet owls from a larger geographic area than just central Canada. In the Ozark Highlands, saw-whet owls are captured from the third week in October to the first week in December, with peak in captures occurring during the first few weeks of November. Captures per unit effort vary across the study region, with two sites capturing significantly more saw-whet owls per unit effort. As in other studies in eastern North America, saw-whet owls captured were primarily female, suggesting sex-specific migration patterns, with males wintering further north.

Finally, as has been observed in other regions, irruption years result in an increase in total captures and an increase in proportion of HY individuals.

Spatial and Temporal Variation in Capture Rate

Throughout North America, fall capture rates fluctuate based on saw-whet owl breeding success. This has been demonstrated in a number of small-scale studies, as well as a large-scale study examining banding data for the entirety of eastern North America (Whalen & Watts 2002, Brittain et al. 2009, Confer et al. 2014). Irruptive movements have been well-documented in a Northern Saw-whet Owl congener, Boreal (Tengmalm's) Owl (*Aegolius funereus*), in Fennoscandia and are strongly associated with fluctuations in small rodent populations (Korpimaki 1981). In both Europe and North America, Boreal Owls have been shown to irrupt in years with low small rodent abundance, presumably moving outside their normal range in search of food. In contrast, irruptive movements of the saw-whet owl, while poorly understood, appear to occur following a productive breeding season, fueled by high abundance of small rodent prey (Côté et al. 2007). Capture rates during irruption years increase significantly (Confer et al. 2014). Interestingly, irruptive movements in the saw-whet owl do not occur simultaneously across North America and are divided, at the very least, into eastern and western "cycles" (Weidensaul 2015). Even during eastern or western irruption years, timing can vary regionally. For example, at three banding sites near the Great Lakes alone, a study found irruptions to occur at intervals of 1 in 7 years, 4 in 11 years, and 2 in 11 years (Confer et al. 2014). Similarly, not all banding sites in this study experienced an increase in captures during the irruption years of 2012 and 2016. During the 2016 banding season, MRBO captured 47.7 NSWO/100 net hrs at 123.8 net hrs of total effort, while WBS captured 2.1 NSWO/100 net hrs at 631.8 net hrs of total effort. In addition, 2010 was not considered an irruption year, however, capture rate for MRBO was quite high (19.3 NSWO/100 net hrs), as 11 individuals were captured over the course of just 4 nights.

As expected, I observed variation in capture rate by latitude. In eastern North America, fewer saw-whet owls are generally captured with decreasing latitude. This may occur as some individuals reach more northerly wintering sites, following a short migration, rather than continuing to southerly wintering sites (Beckett & Proudfoot 2011). Short-distance migration in saw-whet owls is supported by a study in Colorado, comparing body condition in a long-distance migrant owl (Flammulated Owl) to the saw-whet owl. During fall migration, body condition of the saw-whet owl was variable, mean arrival time later, and migratory passage through the study area longer than the long-distant migrant, which exhibited excellent body condition and had an earlier mean arrival time. Lower body condition of saw-whet owls during fall migration may suggest some individuals are not migrating as far and are obtaining resources *en route* (Stock et al. 2006). While latitudinal variation in captures was expected, a site effect was not. MRBO and ONSC captured more saw-whet owls per unit effort than WBS and JTNP. Habitat at both MRBO and WBS was primarily deciduous forest, while habitat at ONSC and JTNP was mixed pine/deciduous forest; so habitat is unlikely to create the observed variation in capture rate per unit effort among sites. MRBO is largely surrounded by agricultural areas, typically believed to be unsuitable for saw-whet owls. It is possible the forested field site provides an island of habitat to which the owls are attracted in the surrounding agricultural landscape, which could explain high capture rates per unit effort. ONSC is in closer proximity to extensive contiguous forest than any of the other sites, which could explain high capture rates per unit effort. Close proximity of WBS to urban Saint Louis, Missouri, may explain low capture rates per unit effort at this site. Habitat at JTNP is quite similar to ONSC, but perhaps being on the extreme southwestern edge of the forested Ozark Highlands results in lower capture rates per unit effort.

Peak capture of saw-whet owls was expected to occur later at ONSC-JTNP than MRBO-WBS. Latitudinal trends in saw-whet owl migration in eastern North America, suggest mean banding day should be ~3.8 days later for every 1° decrease in latitude (Beckett & Proudfoot 2011). Though peak in captures began approximately one week earlier for the two northerly sites, differences were minimal between the two groups. However, a steep decline in captures was observed for MRBO-WBS after the second week in November. The steep decline may indicate saw-whet owls are migrating through the area, but not stopping to spend winter. The shallower peak in captures and gradual decline observed at ONSC-JTNP could indicate saw-whet owl migration is more spread out, as in the Colorado study, and perhaps individuals are preparing to spend winter in the vast mixed pine-deciduous forests of the southwestern Ozark Highlands. A shared mean banding day between latitudes and earlier mean date of arrival for ONSC-JTNP may suggest sampling at two sites in Missouri is not beginning at a date conducive to capturing the earliest saw-whet owls during migration. During irruption years, an observed peak in captures one week earlier than non-irruption years, as well as a higher proportion of HY individuals was expected. A study in Indiana has demonstrated HY saw-whet owls undergo migration prior to adults. They propose HY individuals migrate first to capitalize on untapped prey resources before adults arrive (Brittain and Jones 2014). Other studies across North America have also demonstrated irruption years to be characterized by an increase in HY individuals following a successful breeding season (Confer et al. 2014). Interestingly, most males captured in this study were HY individuals, while female age proportions were nearly equal, if not somewhat skewed towards AHY. As males are known to winter further north, HY males captured in this study could represent inexperienced individuals.

Demographics and Migration Type

The top-ranked model, describing effects on captures as an interaction among age and migration type, sex and migration type, and age and sex, suggests complexity in migratory movements of the saw-whet owl, driven by no single variable in the model set. Captures were higher in both age classes during irruption years, while there was a steeper decline in HY captures between irruption and non-irruption years, suggesting that adult saw-whet owls are more likely to be captured during non-irruption years. Age and migration type explain variation in female captures, but are uninformative for explaining variation in male captures. The decline in number of females captured from irruption to non-irruption years could be explained by lower capture rates during non-irruption years. A lack of explanation of variation in male captures could be due to low overall capture rates for male saw-whet owls, inaccuracies in methodology, and/or their migration ecology.

As has been demonstrated throughout North America, I expected a large proportion of captures to be female. This is a common pattern that has several explanations, likely acting together. Most simply, a higher proportion of female captures can be explained by audio lure bias. Standard protocol for capturing saw-whet owls calls for the use of the male's breeding advertisement vocalization, which is rarely heard outside the breeding season (Project Owlnet 2016). Few studies have incorporated the species' other vocalizations in audio lures. However, a more even proportion of sexes have been captured when incorporating a female vocalization, which is much quieter and less charismatic than the breeding male vocalization, into the audio lure (Neri et al. 2018). Another factor likely driving unequal sex ratios is that the saw-whet owl exhibits differential migration. In general, males are believed not to migrate as far from breeding grounds as females (Beckett & Proudfoot 2011). As has been demonstrated in Boreal (Tengmalm's) Owls in western Finland, this may be beneficial in allowing males to remain closer to prime breeding territories, where nest cavities are an uncommon resource. Additionally, remaining on a territory year-round may allow familiarity with the territory's resources, making males better providers during the breeding season (Korpimäki 1987).

Finally, sexing technique may also lead to an unbalanced sex ratio. The most widely used sexing method, based on morphometric measurements, leaves room for individuals of moderate mass and CWC to be identified as unknown sex (Brinker 2000). A study that included genetic sexing found 97% of saw-whet owls assigned a sex morphometrically were sexed accurately (n = 592). However, 15% of captures were unable to be sexed morphometrically (n = 92). Of these, 60% were female and 40% were male. Another study determined that, when using morphometric sexing methods, 16% of males were misidentified as female and another 44% of males were categorized as unknown (Beckett & Proudfoot 2012). Though quick and easy to use in the field, morphometric sexing methods may pose a significant problem in reporting accurate sex ratios. Genetic sexing is more accurate, but has not been widely adopted. Morphometric sexing was an issue during irruption years, in particular, when proportion of individuals identified as unknown sex was higher. During irruption years, the unknown sex class was used to describe more HY saw-whet owls, while in non-irruption years, the distinction was used to describe more adults.

Band Recoveries

When plotted on a map, same-season recaptures provide insight into possible migratory pathways used by the Northern Saw-whet Owl. In central North America, these recaptured individuals have primarily originated in the western Great Lakes region or, at least, passed through this region during the beginning of their migration. Additionally, several individuals appear to have originated in central and eastern Canada. Many of the recaptures in central North America form a fanned pattern of dispersal from several major banding sites, demonstrating saw-whet owls travel in a multitude of directions. From one site in Duluth, Minnesota, banded individuals have been recaptured from western Iowa to eastern Indiana. Similarly, Confer et al. (2014) found that individuals banded at northern sites were recaptured broadly by longitude. For example, the study demonstrated saw-whet owls captured in the Northwestern Lake Ontario ecoregion have been recaptured from Wisconsin to New York. Additionally, they demonstrated mean dispersal patterns in a south-southwesterly direction, but found a fan-like dispersal pattern from original banding sites, similar to same-season recaptures in this study. Data provided by the BBL suggests recapture rates for saw-whet owls are extremely low, with a few thousand cases out of several hundred-thousand banding records. Low recapture rates suggest low route fidelity during migration and low site fidelity during winter. Northern Saw-whet Owls exhibit low site fidelity during the breeding season and have been proposed to be nomadic in some parts of their range, but fall/winter dynamics are not well understood (Marks et al. 2015). As a species that is driven by regional prey availability, which varies by year, saw-whet owls are subject to yearly differences in breeding success. Fluctuating breeding success could result in high population turnover, as another probable explanation for low recapture rates. As irruption years are characterized by an increase in proportion of HY individuals, perhaps saw-whet owl populations are dependent on periodic highly successful breeding years that manifest as irruptions.

Our results support many of the known patterns of saw-whet owl migration observed elsewhere in North America. Additionally, I propose the saw-whet owl to be a fall migrant through the Ozark Highlands. Based on a lack of data, this region was once considered outside the species' migratory range. However, from our study I am certain the species is regularly migratory, at least to the southwestern Ozark Highlands, if not further. While there are historic records of saw-whet owls south of the Ozark Highlands, no studies have been conducted there. Additional study is required to better understand movement ecology of this secretive owl, especially south of the known extent of their migratory and winter range.

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Table 1. Effort in 12 m net hours, number of Northern Saw-whet Owls captured, and capture rate per site (NSWO/100 net hrs), by year. Irruptions occurred in 2012 and 2016.

	Missouri River Bird Observatory			World Bird Sanctuary			Ozark Natural Science Center			J.T. Nickel Preserve		
	Effort	NSWO Captured	Capture Rate	Effort	NSWO Captured	Capture Rate	Effort	NSWO Captured	Capture Rate	Effort	NSWO Captured	Capture Rate
2010	57.1	11	19.3	--	--	--	--	--	--	--	--	--
2011	605.8	22	3.6	--	--	--	--	--	--	--	--	--
2012	715.3	43	6.0	434.6	7	1.6	--	--	--	--	--	--
2013	234.5	13	5.5	542.7	15	2.8	--	--	--	--	--	--
2014	203.3	18	8.9	662.6	8	1.2	149.6	2	1.3	--	--	--
2015	99.8	12	12.0	660.3	18	2.7	385.0	22	5.7	--	--	--
2016	123.8	59	47.7	631.8	13	2.1	570.3	36	6.3	664.0	18	2.7
2017	205.8	29	14.1	1510.3	24	1.6	769.8	21	2.7	1688.0	21	1.2
Totals	2245.2	207	9.2	4442.3	85	1.9	1874.7	81	4.3	2352.0	39	1.7

Table 2. Output of Akaike's Information Criterion (AIC) rankings for models used to explore demographic variation in captures of Northern Saw-whet Owls during fall migration in the Ozark Highlands. Includes values for number of model parameters (*K*), ΔAIC, and model weight (*w*).

Model	***K***	**ΔAIC**	***ω***
Age * migration type + sex * migration type + age * sex	8	0	0.61
Age * sex * migration type	9	0.9	0.39
Age * sex	5	42.6	<0.001
Age * migration type + sex * migration type	7	45.5	<0.001
Sex + migration type	4	58.4	<0.001
Sex * migration type	5	59.8	<0.001
Sex	3	83.3	<0.001
Age * migration type	5	343.1	<0.001
Age + migration type	4	349.3	<0.001
Migration type	3	360.8	<0.001
Age	3	363.9	<0.001
Null	2	371.3	<0.001

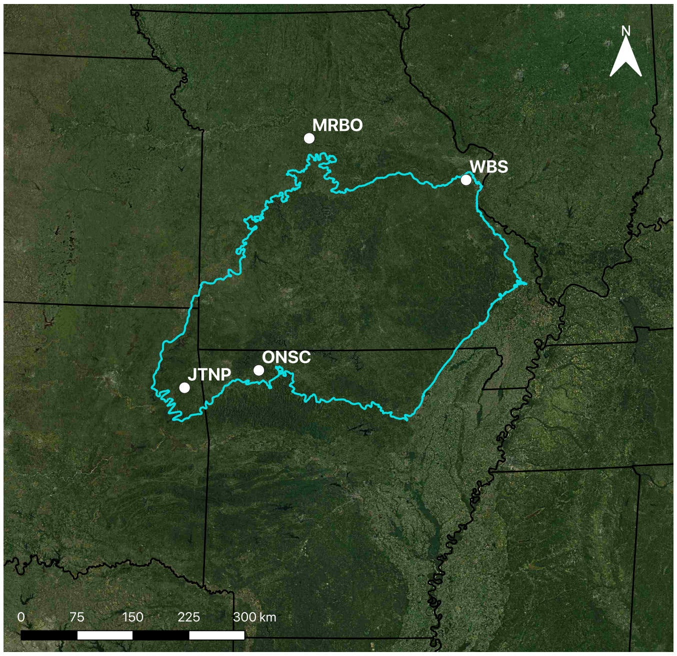

Figure 1. Northern Saw-whet Owl study sites in the Ozark Highlands ecoregion (outlined in blue): Missouri River Bird Observatory (MRBO), World Bird Sanctuary (WBS), Ozark Natural Science Center (ONSC), J.T. Nickel Preserve (JTNP).

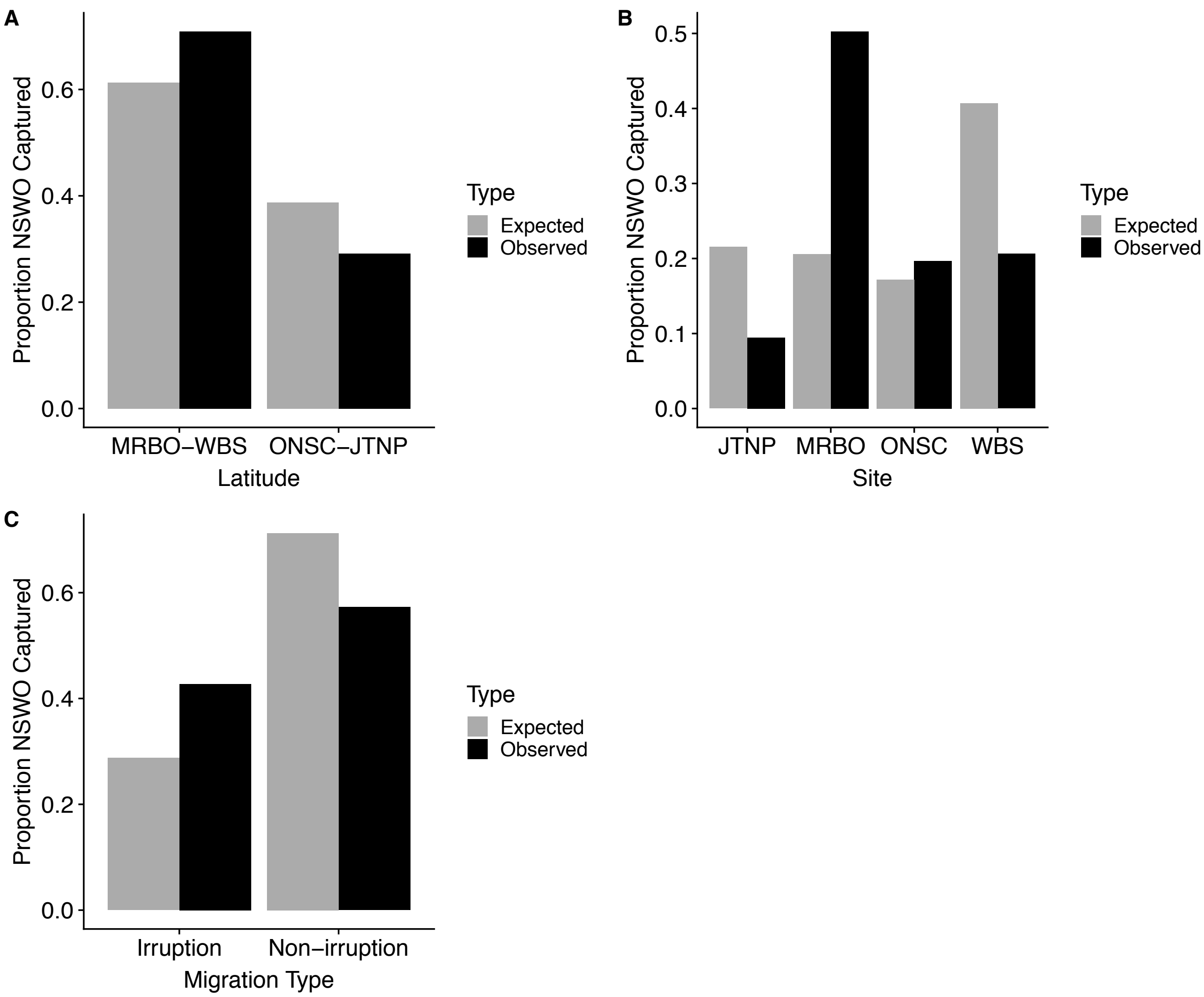

Figure 2. Variation in capture rates of Northern Saw-whet Owl by site and migration type in Arkansas, Missouri, and Oklahoma. A) Observed and expected capture rate by site. B) Observed and expected capture rate by latitude. C) Observed and expected capture rate by migration type.

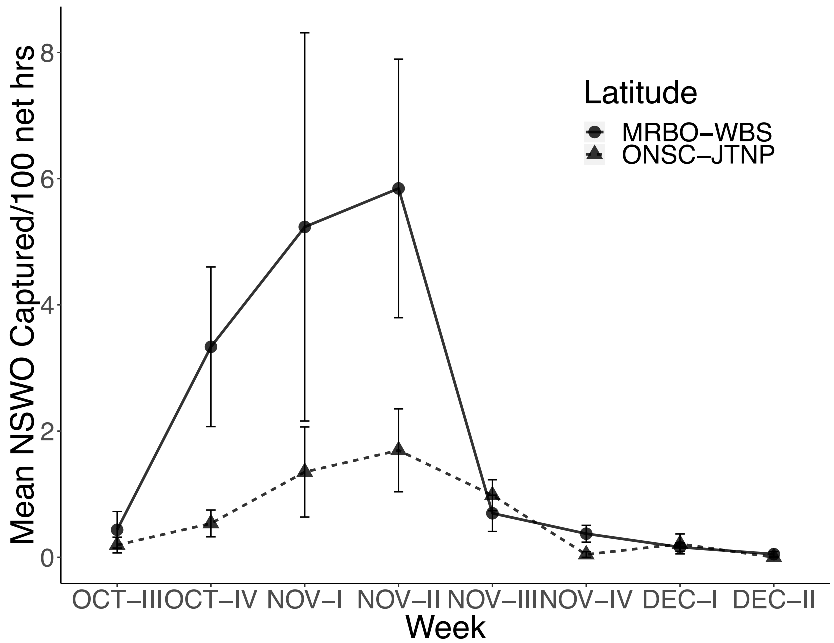

Figure 3. Northern Saw-whet Owls captured/100 net hrs by week at MRBO-WBS and ONSC-JTNP.

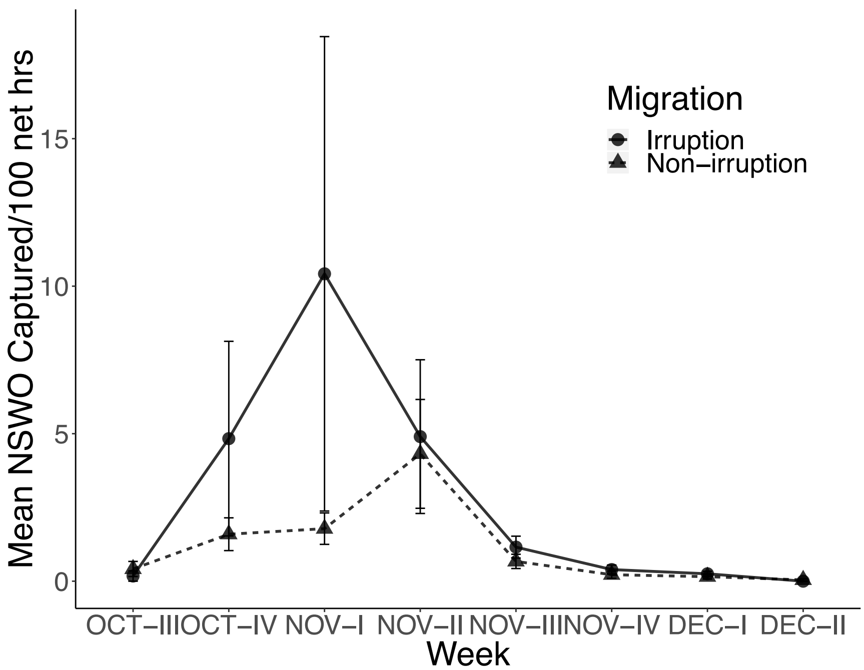

Figure 4. Northern Saw-whet Owls captured/100 net hrs by week and migration type (irruption and non-irruption).

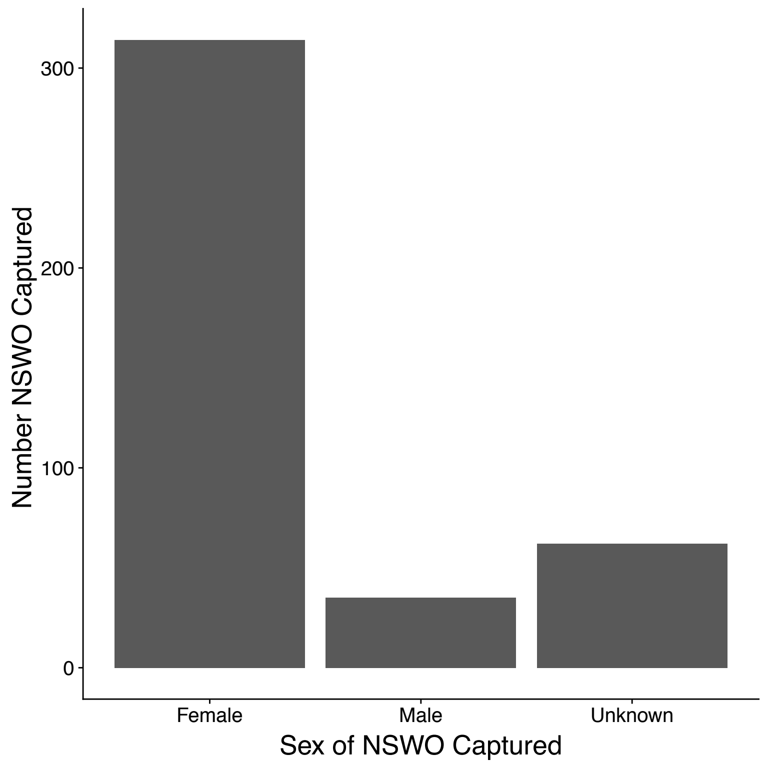

Figure 5. Number of Northern Saw-whet Owls captured by sex class.

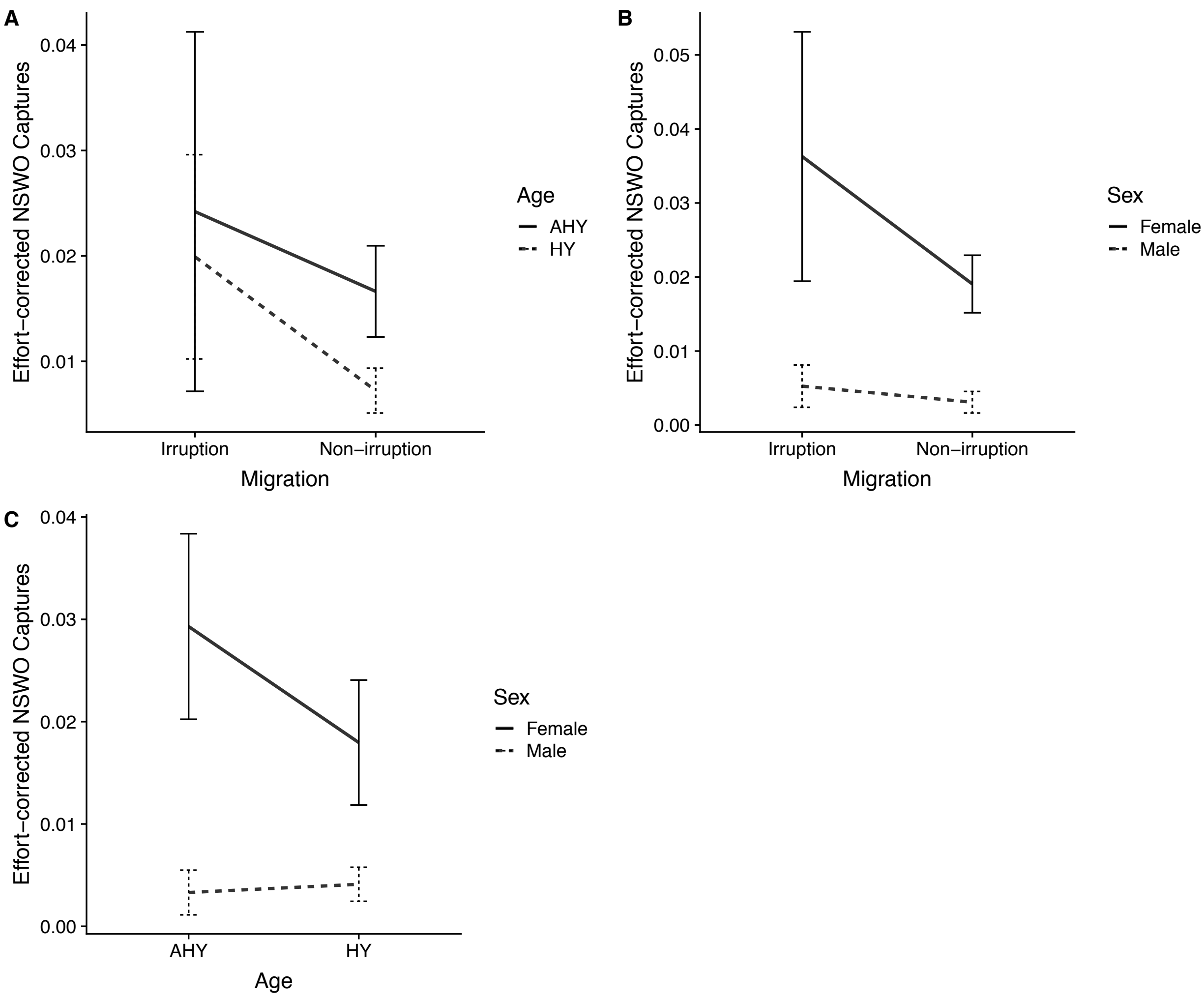

Figure 6. Interaction plots showing variation in effort-corrected mean Northern Saw-whet Owl captures among demographic groups and by migration type with +/- 1 SE bars. A) Interaction between age classes and migration types. B) Interaction between sex classes and migration types. C) Interaction between sex and age classes.

Figure 7. Same-season recaptures of Northern Saw-whet Owl provided by the Bird Banding Lab. Includes recaptures at four Ozark Highlands study sites, in addition to central North America, as a whole.

Chapter II

Winter Occurrence and Roosting Behavior of Northern Saw-whet Owl (*Aegolius acadicus*) in Northwestern Arkansas

ABSTRACT

The Northern Saw-whet Owl (*Aegolius acadicus*) is a well-documented autumn migrant, especially in eastern and central North America. Despite the large number captured each year at autumn banding stations, relatively little is known about where the species spends winter. In the central United States, the saw-whet owl is a well-documented winter residents south to central Kansas, Missouri, and the Appalachian Mountains of eastern Tennessee. However, the species is believed to winter much further south than was historically believed. Northern Saw-whet Owls have only recently been documented migrating through the southwestern Ozark Highlands. These observations, along with sporadic historic records during winter, led us to examine winter occurrence of the species in northwestern Arkansas. During autumn migration of 2016 and 2017, we deployed 27 radio transmitters on saw-whet owls captured at our banding station in Madison County, Arkansas. Detections were obtained from 17 tagged individuals during winter following each migration season and occurred from 1 to 112 days after release, suggesting some saw-whet owls winter in northwestern Arkansas. Locations of 19 roost sites, most in shortleaf pine (*Pinus echinata*), were obtained from 7 individuals. All roost sites were in conifers, in areas characterized by open understory. Landscape-scale habitat characteristics were obtained through GIS analysis of roost sites. Results suggested that saw-whet owls selected roost sites in coniferous trees in areas with more southwesterly mean aspect values. Further study is required to determine the full extent of the saw-whet owl's winter range; however, the abundance of pine and cedar could provide optimal wintering habitat in the Ozark Highlands region.

INTRODUCTION

The Northern Saw-whet Owl (*Aegolius acadicus*) is a small owl that is a widespread breeder in forests of northern and mountainous North America (Weidensaul 2015). Although the extent of the saw-whet owl's breeding range is well documented, the migratory and winter ranges are poorly delineated. The notorious silence and secretive roosting behavior of saw-whet owls renders them difficult to detect during these seasons (Brittain 2008). During autumn migration, saw-whet owls are widely captured from the northeastern United States and Appalachia to the Great Lakes, Midwest, and Pacific Northwest. Once considered a strictly "northern" species in eastern and central North America, recent banding studies have shown them to occur regularly as far south as central Missouri, Oklahoma, Arkansas, Alabama, and Georgia during fall migration (Project Owlnet 2016). The full extent to this migration is not known, beginning in late September in the north and lasting until early December further south (Beckett and Proudfoot 2011). Spring migration is less understood still. During migration, saw-whet owls are captured using audio lures and vocalize occasionally. After migration, response to audio lures decreases drastically, as does rate of vocalization, thus overwintering range and habitat use remains largely unknown.

During winter, saw-whet owls are known to regularly occur in southern Canada, the northeastern U.S., Appalachian Mountains, the Great Lakes region, Upper Midwest, and mountain ranges of the western half of the U.S. (Weidensaul 2015; eBird). The currently accepted extent of winter range in the central U.S. ranges from central Kansas and central Missouri to eastern Tennessee (Rasmussen et al. 2008). Limited research beyond the currently delineated winter range supports the belief that the saw-whet owl's range may extend further south than previously thought. Based on recent banding studies in northeastern Oklahoma, northwestern Arkansas, northern Mississippi, and northern Alabama, saw-whet owls regularly migrate at least that far south (Revels & Bodley unpub. data, Pruitt & Smith 2016, K. Mitchell unpub. data, R. Sargent unpub. data). Additionally, winter records exist for each of the Lower 48 states, including Texas, Louisiana, and Florida, where there are no currently active studies (Rasmussen et al. 2008). To further complicate matters, winter range is likely to expand during irruption years which could explain isolated records from the aforementioned locations. However, a lack of research in the southern U.S. continues to make delineating a more accurate winter range extent difficult.

Low probability of detection, rather than absence, is a likely reason the saw-whet owl has historically been described as vagrant in the south-central and southeastern United States. Current satellite technology remains heavy and expensive, so large-scale movements of the saw-whet owl have not been definitively studied. However, in the central and eastern U.S., several studies have successfully used radio telemetry to examine small scale movement and winter habitat use of the species in Wisconsin, Massachusetts, and Indiana (Swengel & Swengel 1992, Brittain 2008, Churchill et al. 2002). Given a tagged individual remains within range of a receiver, radio telemetry greatly improves the chance of detecting wintering saw-whet owls and allows for identification of roost sites, which is not possible with the use of audio lures and mist nets alone.

In 2014, an exploratory study was initiated to document saw-whet owl migration through the Ozark Highlands of northwestern Arkansas. The goal was to capture and band the species during autumn migration, which had not previously been documented in the region. During November 2014 and October to December 2015, a total of 24 saw-whet owls were captured (2014 = 2, 2015 = 22). During winter 2014-2015, attempts to capture wintering saw-whet owls through February were unsuccessful (Pruitt & Smith 2016). Despite our inability to capture the species in winter, 7 historic winter records exist for Arkansas (Arkansas Audubon Society Bird Records Database, James & Neal 1986). Additionally, the abundance of shortleaf pine and eastern red cedar in the Ozark Highlands, suggested there was ample roosting habitat for wintering saw-whet owls. Furthermore, researchers have successfully captured saw-whet owls in late winter in northern Alabama (R. Sargent unpub. data). Given this information, I hypothesized some individuals were wintering in the southwestern Ozarks. To test our hypothesis, I employed the use of radio telemetry to determine the status of the saw-whet owl in winter, around our field site in Madison County, Arkansas. Additionally, I tracked radio-tagged saw-whet owls to roost sites to assess habitat use at a landscape-scale and immediately around roost sites.

METHODS

Study Area

This study was initiated autumn 2016 as a continuation of a migration banding study that began November 2014 (Pruitt & Smith 2016). Our field site is located at the Ozark Natural Science Center (ONSC), a 160-ha property owned by the Arkansas Natural Heritage Commission, surrounded by 5900-hectare McIlroy Madison County Wildlife Management Area in rural Madison County, Arkansas, approximately 64 km northeast of the city of Fayetteville. The ONSC is located at approximately 400 MASL, in mixed pine/deciduous forest with a cedar understory (Figure 1).

Capture and Marking

Owls were captured over two fall field seasons beginning 20 October 2016 and 20 October 2017 and continuing through early December, when saw-whet owl capture rates decrease dramatically in the region. This study followed standard methods developed by a collaboration of researchers studying saw-whet owls (Project Owlnet 2016). Four 12 m mist nets with 60 mm mesh were erected along a trail through short-leaf pine (*P. echinata*)-deciduous forest with a dense understory of eastern red cedar (*J. virginiana*). An audio lure programmed with saw-whet owl vocalizations was used to attract owls to the net area for capture. Upon capture, basic morphometric measurements were taken and each individual was sexed, aged, and banded (see Chapter 1, *Migration and demographics of Northern Saw-whet Owl (*Aegolius acadicus*) in autumn on the Ozark Plateau*).

After banding and all measurements were collected, owls were fitted with 1.8 g BD-2 radio transmitters (Holohil Systems, Ontario, Canada). No transmitters were attached to individuals of unknown sex. Transmitters were attached using a leg-loop harness made of elastic sewing thread, because it will eventually rot and detach from the owl (Streby et al. 2015). Harness loops were 36- 38 mm in length for females when gently stretched at both sides, and 32-34 mm for males (S. Craik pers. comm.). Transmitters had a specified average life of approximately 14 weeks, sufficient for monitoring through the winter season. They could be detected at 2.0 to 3.0 km on the ground. Radio transmitters were deployed on 27 saw-whet owls, 11 in fall 2016 and 16 in fall 2017. Transmitters were attached to any individual of known sex.

Tracking and Vegetation Surveys

Surveys for radio-tagged saw-whet owls were conducted weekly, using a Yagi antenna attached to a SRX 400 VHF radio receiver (Lotek Wireless, Ontario, Canada). During the first field season, 26 tracking surveys were conducted between 12 November 2016 and 16 March 2017. During the second field season, 28 tracking surveys were conducted between 18 October 2017 and 16 March 2018. Surveys were conducted at least once per week. Detections were not obtained after 16 March during the first field season and 26 February during the second field season. Around this time, saw-whet owls would presumably have begun their return migration. Twelve monitoring sites were established at elevated points along the road system in McIlroy Madison County Wildlife Management Area (Figure 1). Upon detecting a signal from transmitters, roost sites were located by triangulation. Direction of strongest signal was recorded from 3+ locations and plotted on a topographic map in Avenza Maps™ (Avenza Systems Inc, Toronto, Ontario), mapping software for mobile devices. Locating the roost tree involved hiking to point of triangulation and engaging in smaller scale-triangulation, with painstaking surveys around a group of trees to identify the specific roost tree. Identification of a specific tree often took 60+ min, but was usually obvious based on transmitter signal strength. Visual surveys for roosting owls were usually unsuccessful, likely due to the height of foliage in roost trees. Once located, coordinates were recorded for each roost tree. Brief visual surveys for roosting owls followed identification of roost trees. When a saw-whet owl was no longer using a roost site, vegetation surveys were conducted following methodology from James and Shugart (1970). Specifically, at each site, the roost tree was used as a central point for a four-quadrant plot, with an 11-m radius. Parameters measured included average canopy height using a clinometer, average canopy cover, understory stem density (woody vegetation), and species composition of each plot. Trees were classified as having a diameter at breast height (DBH) >8 cm; stems <8 cm were classified as woody vegetation for understory stem density measurement. Trees were categorized into DBH ranges: 8-16 cm, 16-23 cm, 23-31 cm, 31-39 cm, 39-46 cm, 46-54 cm, 54-69 cm, > 69 cm. Three roost sites were located in open pine stands on private property adjacent to the study area. Due to lack of access, these sites were excluded from subsequent vegetation surveys, but they were included in landscape-scale analysis.

Analysis of Roost Sites

In order to assess landscape-scale characteristics associated with saw-whet owl roost site selection, each roost site was paired with 5 random sites. Random sites were obtained by plotting points at a random compass bearing and random distance from each roost site. Random distances were chosen between 11 and 1782 m. The latter value was derived from home range area (mean ha) in a study of winter home range of the saw-whet owl on Haida Gwaii, British Columbia (Waterhouse et al. 2017). Home range size reported in this study served as a proxy in the absence of data for home range size of the species in the Ozark Highlands. There has been limited study of winter home range size of saw-whet owls and the large winter home ranges of the species on Haida Gwaii seemed to best fit my study, based on the anecdotal evidence that tagged owls moved around to a great extent during winter in northwestern Arkansas.

Coordinates for random sites were obtained using program R version 3.5.1 and plotted in ArcGIS. Using GIS; 11 m buffers were generated around each roost and random site and landscape variables were extracted. Data extracted from the buffers, for use in subsequent analyses, included mean elevation, mean slope, and mean aspect. Each point, roost and random, was overlaid on winter imagery and classified as either falling on conifer (pine/cedar) or deciduous. Classification was completed by an outside reviewer that was blind to which sites were roost or random.

To compare landscape attributes of roost sites to random sites, conditional logistic regression for matched-pairs case-control sampling was completed using the Package 'Survival' in program R version 3.5.1 (Yeldell et al. 2017, Therneau and Lumley 2016). For this analysis, roost sites were coded as cases and random sites as controls. We developed ten models incorporating three variables—tree type, mean elevation, and mean aspect—in an attempt to understand what landscape-scale characteristics best predicted selection of roost sites by the saw-whet owl (Table 2). I investigated additive effects, as well as 2- and 3-way interactions between each of the three variables. Models were ranked using Akaike's Information Criterion (AIC), and models having ΔAIC values ≤ 2 were considered to have equivocal support.

RESULTS

Tracking and Selection of Roost Sites

During 54 surveys, 131 detections were obtained from 17 transmitters, at pre-identified monitoring points. Detections occurred on 94% of surveys; only 3 surveys were without any detections. Ten transmitters were not detected after release. Of saw-whet owls detected (n = 17), mean duration of stay was 50.7 days post-banding. Length of stay ranged from 1 to 112 days, excluding transmitters that were not detected following release (Table 1). Of individuals that remained in the region for an extended period, most were not detected on consecutive surveys, with up to 8 unsuccessful surveys between detections.

Roost sites were located 19 times for 7 individuals (Figure 1). Roost sites of individuals with ≥ 2 detections were located up to 5.3 km apart, at a mean distance of 1.6 km apart. All roosts were located in short-leaf pine (n = 15) or eastern red cedar (n = 4). Two individuals were found roosting in cedar, one on 3 occasions. Individuals were visually located 4 times. Three of 4 visual detections were of one SY female with an affinity for cedar. She roosted at a mean height of 5.9 m and mean distance of 0.46 m from the trunk. The other visual detection was of a HY male roosting in a short-leaf pine, 14 m from the ground at 1.5 m from the trunk, in an area of dense foliage.

Four models from the candidate set of landscape variables were equivocally ranked and all contained tree type. The top model was the tree type model (w_i = 0.38; Table 2), suggesting selection of roost site was affected by tree type (conifer or deciduous). Fewer roost trees were classified as conifer at random sites (22.1%) than at roost sites (94.7%; Figure 2A). The next two models carried some weight and were equivocally ranked based on AIC, suggesting roost site was affected by an interaction between tree type and elevation (w_i = 0.17; Table 2) and tree type and mean aspect (w_i = 0.17; Table 2) The fourth model suggested roost site was affected by tree type and elevation (w_i = 0.15; Table 2). Mean elevation was similar between roost and random sites (Figure 2B), but mean aspect at roost sites was southwesterly (201.4° ± 18.2°), whereas random sites were more southerly (173.5° ± 8.1°; Figure 2C). However, as these models were not significantly different from the best model, tree type played the most important role in guiding selection of roost sites by saw-whet owls.

Vegetation Surveys

Roost sites were characterized by mean canopy height of 18.1 m and 10.5 m at pine and cedar sites, respectively. Mean height of roost tree was 20.3 m for pine and 10.5 m for cedar. A mean canopy cover of 41.9% was observed at pine sites and 90.0% at cedar sites. All sites were characterized by having an open understory, with mean understory stem density of 42.7 stems/100 m^2. Pine sites had a greater diversity of tree species (10 species) than cedar sites (6 species) and pine sites had fewer trees per plot (mean = 14.4) than cedar sites (mean = 22). At pine roost sites, the canopy was primarily composed of pine (71.2%), while the understory was primarily composed of deciduous trees (61.4%). At cedar sites, both canopy and understory were primarily composed of cedar (79.2% and 77.5%, respectively). Pine sites were primarily composed of short-leaf pine, post oak (*Quercus stellata*), and eastern red cedar. Cedar sites were primarily composed of eastern red cedar and white oak (*Quercus alba*).

DISCUSSION

Our study expands the documented wintering range of the saw-whet owl into the Ozark Highlands of northwestern Arkansas. Additionally, our findings provide support for their habitat preferences during winter elsewhere in North America. I documented that some saw-whet owls migrating through the area are spending winter, while others appear to continue migration. Those that stay tend to select roost sites in conifers, mostly in tall shortleaf pine. Habitat around roost sites are characterized by relatively open canopy cover and open understory.

While some saw-whet owls were not detected upon release and others wintered in the area, several individuals remained for a few weeks, suggesting a brief stopover period. Possible stopover behavior fits with other birds of prey, which are known for migrating relatively slowly, feeding along the way. Based on banding recapture data, it has been estimated that saw-whet owls may travel an average distance of ~10.5 km per night (Beckett & Proudfoot 2011). In some species, rate of feeding may be high at the onset of migration, lower in the middle, and high again near the end, when they may be sampling a region's prey availability for wintering (Bildstein 2006). Northern Saw-whet Owls are occasionally recaptured locally during fall migration, likely representing individuals that stopover to feed before continuing their migration. Three saw-whet owls were recaptured locally during this study and may represent examples of individuals feeding in the area during migration. Two of these individuals also remained through winter. A HY male first captured 5 November 2016 weighing 86 g, was recaptured 9 November 2016 and weighed 92 g. A SY female first captured 10 November 2016 weighing 85 g, was recaptured 11 November 2016 weighing 94 g. She remained in the study area 107 days, until a final detection 16 February 2017. Finally, a SY female captured 31 October 2017 weighing 85 g, was recaptured 9 November 2017 weighing 90 g. She was recaptured a third time 15 November

2017 weighing 88 g and remained 103 days in the study area, until a final detection 26 February 2018. The SY female was the same individual located visually 3 times, roosting in cedar.

Ten individual saw-whet owls remained in and around the study area for > 1 month, suggesting overwintering, at least in part. From radio tracking data, I cannot definitively demonstrate where each individual was in relation to the study area; it is quite possible some owls I captured overwintered nearby in locations where they could not be detected via radio telemetry. However, weekly surveys demonstrated saw-whet owls that stayed for an extended period moved around to a great extent, not always remaining within detectable range. Detections were obtained on most surveys, but individuals were often not detected on consecutive surveys. Instead, they could be absent from detectable range for up to several weeks at a time. Sporadic detection supports the idea that saw-whet owls may either occupy large home ranges or be highly mobile during winter in northwestern Arkansas. Irregularity of detection in this study could be a result of the terrain, which is not conducive to long-distance radio tracking. However, I found that a very weak signal could be obtained, even from distant individuals. Few studies have examined winter home range size in the saw-whet owl. A study on Assateague Island, Maryland/Virginia, found saw-whet owls occupying 95% fixed kernel home ranges with a mean area of ~104 ha (Churchill et al. 2002). In contrast, a study conducted on Graham Island, Haida Gwaii, British Columbia found 95% fixed kernel home ranges with a mean area of ~997 ha. Radio-tagged saw-whet owls in this study were observed moving distances of >4 km between detections, reflecting the large home range sizes (Waterhouse et al. 2017). Assateague Island is a barrier island along the Atlantic Coast and saw-whet owls wintering there likely occupy home ranges smaller than those found on the mainland. The study on Graham Island, a large island, may provide a more accurate representation of home range size for saw-whet owls wintering in continental North America. In support of this idea, a study in Idaho demonstrated that saw-whet owls are highly mobile in winter, roosting at sites separated by up to 1.8 km on consecutive days (Hayward and Garton 1984).

Coniferous trees seem to be an important component of habitat used by the saw-whet owl in winter (Weidensaul 2015). Conifers may provide the small owls concealment from diurnal predators in addition to protection from the elements. There is evidence that thermal properties of conifers may create warmer microclimates in cold temperatures, affecting roost site selection in birds (Buttemer 1985). Selection of conifers for winter roost sites has been demonstrated in the literature, but varies regionally and presence of conifers themselves, rather than presence of a particular species, seems to be most important (Swengel & Swengel 1992). In this study, saw-whet owls were observed preferentially selecting coniferous roost sites over other sites in the study area, primarily shortleaf pine and occasionally eastern red cedar. In the Assateague Island study, a majority of roosts sites were found in loblolly pine (*P. taeda*), which represented ~6% of the study area. Additionally, aspect appeared to play a role in site selection in this study. Roosting sites had a more southwesterly aspect, while random sites were more southerly. South-facing slopes may retain more heat during winter, which may be beneficial to a roosting saw-whet owl (Chen et al. 1999). Given the path of the sun during winter, southwest-facing slopes may retain even more heat throughout the day than strictly south-facing slopes.

Others have demonstrated the saw-whet owl's preference for roosting in areas with open-understory, providing support for the findings of this study. In Idaho, saw-whet owls preferred to roost in conifers in areas of relatively open understory (Hayward & Garton 1984). Similar results were found in northern Washington (Grove 1985). In the central and eastern U.S., studies assessing winter habitat use in Wisconsin and Indiana identified saw-whet owl roosts in conifers, in areas with relatively open understory (Swengel & Swengel 1992, Brittain 2008). However, preferred species of conifer differed among studies, based on availability.

In most studies, roost location within a tree differed among conifer species, as well as with height and shape of the tree. Roosting saw-whet owls were found at a lower height and closer to the trunk in short, densely-foliated species like eastern red cedar (*Juniperus virginiana*), while roosts were higher and further from the trunk in tall species like red pine (*Pinus resinosa*), where the densest foliage is further from the trunk (Swengel & Swengel 1992). The researchers noted saw-whet owls were difficult to locate visually, as preferred roosts were away from the trunk in thick mats of coniferous vegetation (Hayward & Garton 1984). Roost sites in loblolly pine were in trees that were 7.9 m in height, on average; shorter than shortleaf pine roost trees in this study (Churchill et al. 2000). Other studies in the eastern U.S. observed use of red pine (*P. resinosa*), Scots pine (*P. sylvestris*), jack pine (*P. banksiana*), white spruce (*Picea glauca*), Norway spruce (*P. abies*), and eastern red cedar (Randle & Austing 1952, Swengel & Swengel 1992). Studies in the western U.S. have observed the use of ponderosa pine (*P. ponderosa*), lodgepole pine (*P. contorta*), and Douglas fir (*Pseudotsuga menziesii*). Location of roosting saw-whet owls within a tree varied by species, usually located where foliage was densest. Roosts are closer to the trunk in cedar and spruce and farther from the trunk in pine. In this study, the few roosts located visually fit with these findings: higher and farther from the trunk in shortleaf pine and lower and closer to the trunk in cedar.

Although I documented saw-whet owls apparently wintering at one site in northwestern Arkansas, winter status in the region as a whole was outside the scope of this study. However, the Ozark Highlands are characterized by oak-hickory forest, interspersed with shortleaf pine and eastern red cedar, which could provide wintering habitat throughout northern Arkansas (Wiken et al. 2011). Similar upland pine habitat in the Ouachita Mountains to the south, as well as vast pine plantations in southern Arkansas may also provide acceptable habitat for wintering saw-whet owls. Further afield, pine is an important habitat component throughout the south-central and southeastern United States. Further study is required to determine the full extent of the saw-whet owl's winter range and to explore whether or not this southern pine habitat supports the species during wintering.

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FIGURES AND TABLES

Table 1. Radio transmitters detected ≥1 times, sorted by total days between first and last detection (HY: hatch-year, SY: second-year, ASY: after second-year).

Identifier	Last Detection	Total Days	Sex	Age
173.221	3/4/17	112	F	HY
173.982	3/16/17	107	F	HY
173.171	2/16/17	107	F	SY
173.642	2/26/18	103	F	SY
173.400	1/19/18	81	M	SY
173.442	2/7/17	79	F	ASY
173.822	1/29/18	72	F	SY
173.082	1/2/17	53	F	SY
173.189	12/31/16	49	F	ASY
173.482	12/27/17	47	F	SY
173.783	12/4/17	19	F	ASY
173.841	11/1/17	15	F	SY
173.340	12/4/16	14	F	HY
173.040	11/3/17	1	F	HY
173.270	11/20/16	1	F	SY
173.101	11/5/17	1	F	SY
173.861	11/20/17	1	F	HY

Table 2. Output of Akaike's Information Criterion (AIC) for models used to examine selection of roost sites by Northern Saw-whet Owls in northwestern Arkansas. Includes values for number of model parameters (*K*), AIC, ΔAIC, model weight (ω), and log-likelihood (LL).

Model	***K***	**AIC**	**ΔAIC**	ω	**LL**
Tree type	1	33.76	0.00	0.38	-15.88
Tree type * mean elevation	3	35.31	1.55	0.17	-14.65
Tree type + mean aspect	2	35.38	1.62	0.17	-15.69
Tree type + mean elevation	2	35.58	1.82	0.15	-15.79
Tree type + mean elevation + mean aspect	3	37.20	3.44	0.07	-15.60
Tree type * mean aspect	3	37.30	3.53	0.06	-15.65
Mean aspect	1	67.90	34.14	0.00	-32.95
Null	0	68.09	34.33	0.00	-34.04
Mean elevation	1	70.06	36.30	0.00	-34.03

Figure 1. Map of study area depicting banding site (Ozark Natural Science Center; ONSC), telemetry monitoring points and Northern Saw-whet Owl roost sites.

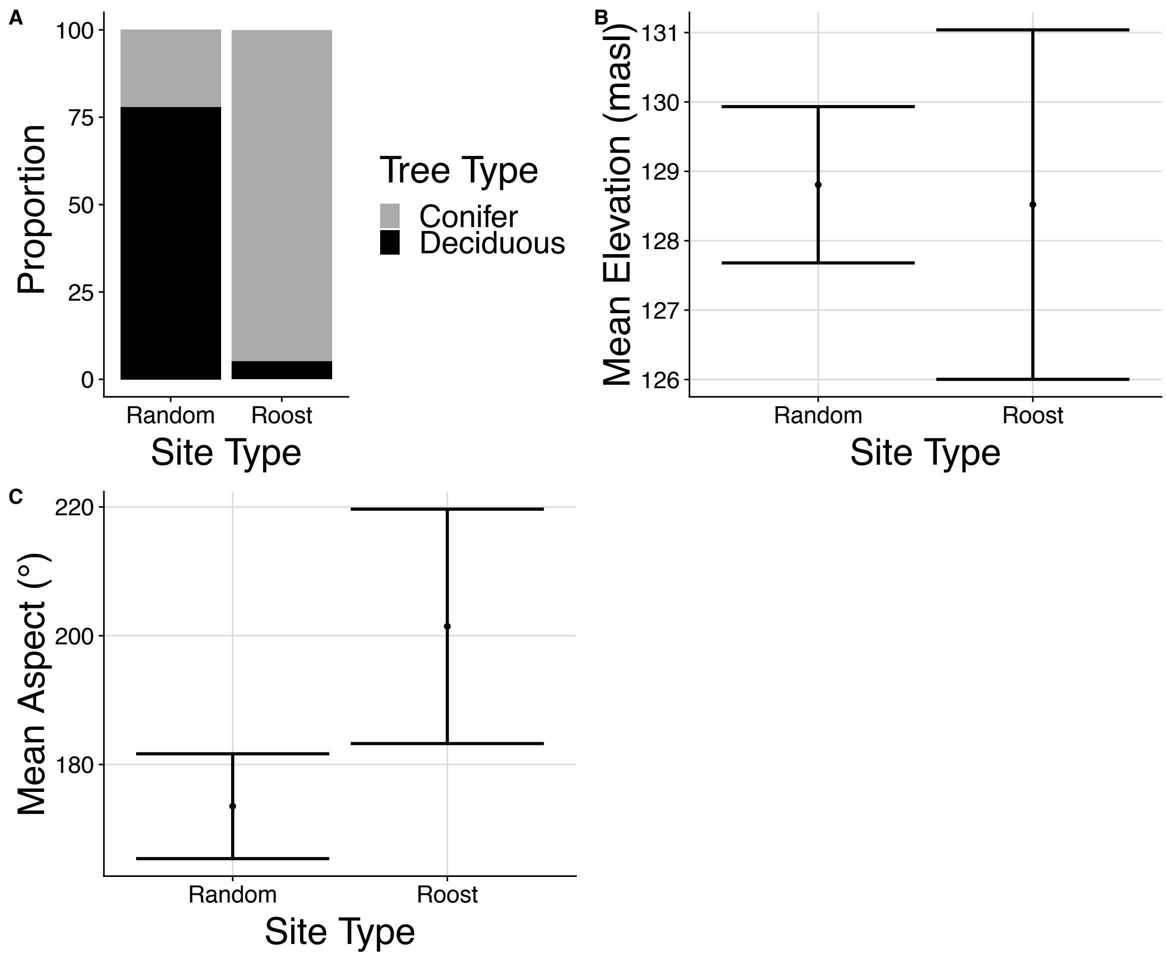

Figure 2. A) Proportion of roost tree type (conifer, deciduous) for roost trees at roost and random sites. B) Mean elevation (meters above sea level) for roost and random sites. C) Mean aspect (°) for roost and random sites.

CONCLUSION

The Northern Saw-whet Owl (*Aegolius acadicus*) has been widely studied across North America, yet its movement ecology is poorly understood, especially south of its currently accepted range. Fall and winter records exist for all of the Lower 48 states, suggesting saw-whet owls may not be uncommon during fall migration and/or winter south of the currently accepted range (Rasmussen et al. 2008). A better understanding of the movement ecology of the saw-whet owl is important in identifying the scope of the species' range, as well as assessing habitat use in regions where saw-whet owls have been little studied. A fuller understanding of this forest owl's life history will also allow for informed conservation decisions in an ever-changing forested landscape. Using data collected at four fall banding sites in the Ozark Highlands ecoregion, I studied trends in the migration and demography of saw-whet owls travelling through the region. Additionally, I used same-season recapture data from banded individuals to infer movement patterns in central North America.

Eight years of banding data from four stations demonstrated that saw-whet owls occur regularly in the Ozark Highlands during fall migration. From same-season recapture data, I can infer that saw-whet owls travelling through the study region originate in or, at least, pass through the western Great Lakes region. Though the western Great Lakes appears to be a high-use migratory pathway, recaptures from the Ozark Highlands have ranged from central Saskatchewan to eastern Ontario. Migration of saw-whet owls in the Ozark Highlands occurs from mid-October to early-December, with little difference latitudinally. Number of captures per unit effort varied among the 4 study sites, with 2 sites capturing significantly more owls per unit effort. An explanation for the differences remains unclear, but could relate to habitat at the landscape or local scale. Demographics of saw-whet owls captured show strong female-bias;

likely a mixed result of audio lure bias, differential migration, and morphometric sexing technique. Periodic irruptions of saw-whet owls into the study region affect captures during certain years, resulting in an increase in total owls captured, as well as an increase in HY individuals.

During the fall migration banding seasons of 2016 and 2017, I deployed 27 radio transmitters on saw-whet owls in northwestern Arkansas. Through the use of radio transmitters, I identified the saw-whet owl as a likely winter resident in the area, previously considered outside the species' normal winter range. Seventeen saw-whet owls were detected after transmitter deployment and these individuals remained in the study area 1-112 days. Mean duration of stay was 50.7 days, suggesting overwintering by some individuals. The remaining 10 tagged individuals were not detected after release, suggesting some saw-whet owls may continue migration after passing through northwestern Arkansas. Based on the location of 19 roost sites, we were able to study roosting behavior and habitat use of the saw-whet owls that remained in the study area. Roost site selection was most affected by tree type, specifically the presence of coniferous trees. Roost sites were located in shortleaf pine (n = 15) and eastern red cedar (n = 4). Mean roost tree height was 20.3 m at pine sites and 10.5 m at cedar sites. Canopy cover differed from 41.9% at pine sites to 90.0% at cedar sites. All sites had a relatively open understory, with mean stem density of 42.7 stems/100 m^2. Overall, pine sites were characterized by a tall, relatively open canopy and open understory, while cedar sites were characterized by a comparatively short, closed canopy and open understory.

My research demonstrates that the saw-whet owl is a regular fall migrant through the Ozark Highlands and a winter resident in northwestern Arkansas. The abundance of shortleaf pine and eastern red cedar throughout the Ozark Highlands ecoregion could provide ample wintering habitat for saw-whet owls, as the species is likely to winter more widely in the region than northwestern Arkansas (Wiken et al. 2011). Similar open pine habitat can be found throughout the south-central and southeastern United States and may also provide acceptable wintering habitat for the species. Certainly, further study during both fall migration and winter is required to better understand the saw-whet owl's movement ecology as a whole. Results from this study can be used to make comparisons with migration magnitude and demographics elsewhere in central and eastern North America, as well as provide baseline data on winter habitat use by saw-whet owls in a region largely devoid of data for the species. If as many saw-whet owls winter in the southern United States as suspected, further study is required to better understand their role in the open pine habitat they prefer. Continued study will allow informed conservation decisions for the future of this understudied owl.

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APPENDIX A: RESEARCH COMPLIANCE PROTOCOL LETTER

UNIVERSITY OF ARKANSAS

Office of Research Compliance

To:	Kimberly Smith
Fr:	Craig Coon
Date:	October 12th, 2017
Subject:	IACUC Approval
Expiration Date:	October 11th, 2020

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your protocol # **18033:** *Occurrence of Northern Saw-whet Owls and Long-eared Owls in fall and winter in northwestern Arkansas*.

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond October 11th, 2020 you must submit a newly drafted protocol prior to that date to avoid any interruption. By policy the IACUC cannot approve a study for more than 3 years at a time.

The following individuals are approved to work on this study: Mitchell Pruitt and Kimberly Smith. Please submit personnel additions to this protocol via the modification form prior to their start of work.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/tmp

18033