BARN OWLS (*TYTO ALBA*) CROSSING THE ROAD - EXAMINING THE INTERPLAY AMONG OCCUPANCY, BEHAVIOR, HABITAT SELECTION, AND ROADWAY MORTALITY IN SOUTHERN IDAHO

by

Tempe Regan

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Tempe Regan

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The following individuals read and discussed the thesis submitted by student Tempe Regan, and they evaluated her presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

James R. Belthoff, Ph.D.	Chair, Supervisory Committee
Jesse R. Barber, Ph.D.	Member, Supervisory Committee
Julie Heath, Ph.D.	Member, Supervisory Committee
Christopher J. McClure, Ph.D.	Member, Supervisory Committee

The final reading approval of the thesis was granted by James R. Belthoff, Ph.D., Chair of the Supervisory Committee. The thesis was approved by the Graduate College.

DEDICATION

To Mom and Dad, for letting me play in the peeper ponds, run around the hills, and wade across the creek to the woods alone: for taking me hunting, fishing, hiking, huckleberry picking and firewood-getting: for showing me how to put stones back in their place after checking under them for treasures, for teaching me that creation matters and showing me how to be a good steward of it. This is where my journey started.

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ABSTRACT

Barn Owls (*Tyto alba*) are killed by vehicle collisions in greater numbers than any other North American bird of prey. Interstate-84 (I-84) in southern Idaho, USA has among the world's highest known rates of Barn Owl-vehicle collisions. Little is known about Barn Owl occupancy in this region, so it is unclear if owls are killed in proportion to their abundance, or if they are equally abundant in segments with lower mortality and somehow escape collisions. Furthermore, studies of Barn Owl movements and behavior are limited. I was interested in understanding (1) factors that affect Barn Owl occupancy in two seasons: early- and post-breeding, (2) Barn Owl colonization of sites from early-breeding to post-breeding season, (3) examining the relationship between model-predicted occupancy, based on the factors I assessed, and roadway mortality established from observed Barn Owl mortality locations, and (4) examining Barn Owl behavior, movements and habitat selection, particularly in relation to I-84. I conducted nighttime point counts for Barn Owls in southern Idaho during the early- and post-breeding seasons (Jan – Mar and Sept – Nov 2014, respectively). I detected Barn Owls during 52 of 666 (7.8 %) point counts and at 39 of 222 (17.6 %) locations in the early-breeding season and during 50 of 201 (24.8 %) point counts and at 31 of 67 (46.3 %) locations in the post-breeding season. During the early-breeding season, probability of Barn Owl detection was 0.32 ± 0.06 (SE). Detection increased with playback of Barn Owl calls and with increasing Julian date, percent moon illumination, and cloud cover. Barn Owl occupancy increased with increased proportion of crops and presence of trees, and it decreased as

background noise level (dBA) increased. Probability of detection of Barn Owls was higher in the post-breeding season (0.45 ± 0.07). Detection increased with playback of Barn Owl vocalizations, increasing Julian date, and decreasing background noise. During the post-breeding season, Barn Owl occupancy was positively related to stream length and negatively related to proportion development and increasing distance from the Snake River. Of the potential models I assessed to describe colonization between seasons, there were two top models. The first model indicated that colonization of sites from the early- to post-breeding season declined with increasing terrain roughness while the second suggested that colonization increased with increasing cumulative stream length but decreased with distance to the Snake River and proportion development. Understanding factors influencing occupancy of Barn Owls will facilitate more effective conservation of this species in southern Idaho, especially in light of potential population declines related to roadway mortality.

Using data from standardized roadkill surveys, I compared road mortality locations of Barn Owls to model-predicted occupancy estimates to understand how occupancy may be influencing mortality along I-84. Using the previously created occupancy models, I generated predicted occupancy at point-count locations which I then paired with the nearest interstate segment (1- and 5-km lengths) to examine the potential effects of occupancy and season on the likelihood of dead Barn Owls. The likelihood that 1-km segments near point count locations included a dead Barn Owl increased with occupancy and was greater during the early-breeding season. For 5-km segments, there was an interaction between occupancy and season, with occupancy having a greater positive effect on mortality during the early-breeding season than in the post-breeding season. However, a substantial proportion of variation in roadway mortality at both scales (96 % and 56% at 1 and 5 km scale respectively) was not explained by occupancy and season, so factors such as geometric roadway features, traffic patterns, fluctuations in small mammal abundance, and owl behavior near the interstate likely also influence mortality rates and locations.

Finally, to address questions of Barn Owl behavior and movements in relation to I-84, as well as habitat use I studied four adult male Barn Owls that were tending nests during February 2015. Two of these nests were within 3 km of the interstate, whereas the other two were more than 25 km away. I examined the efficacy of GPS data loggers for tracking Barn Owls and assessed six recapture methods to retrieve the data loggers. I obtained location data that spanned approximately two weeks of activity for each owl during the nesting season. I recaptured all instrumented males and found that manual- or laser-break triggered trap doors mounted on the nest box were most effective for recapturing Barn Owls. Within home ranges, the probability a Barn Owl used a site was higher near trees and minor roads and lower as distance from the nearest stream and the nearest major road increased. Barn Owl use of areas also increased as terrain roughness increased. Relative use of development, hay/pasture, and sage steppe land cover were less than for cultivated crops, while owls used grassland/herbaceous and wetland land cover more than cultivated crops. The two male Barn Owls that nested within 3 km of the interstate never moved closer than 1 km even though their maximum movements ranged up to 3 km. Thus, it is possible major roadways function as barriers to adult owl movements during the breeding season because they avoid roads, but they remain susceptible to road mortality in their more rare attempts to cross.

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LIST OF ABBREVIATIONS

BSU	Boise State University
I-84	Interstate-84
I-84/86	Interstate-84/86
USA	United States of America

GENERAL INTRODUCTION

This thesis consists of three chapters describing my research on Barn Owl (*Tyto alba*) occupancy, behavior, and movements in relation to the high rates of roadway mortality Barn Owls suffer along Interstate 84/86 (I-84/86) in southern Idaho, USA. During the early- and post-breeding seasons of Barn Owls, I conducted nighttime point counts to collect data relating to Barn Owl detection and occupancy. I also attached GPS data loggers to four adult male Barn Owls to collect fine scale movement and behavioral data. I was interested in understanding (1) factors that affect Barn Owl occupancy in two seasons: early- and post-breeding, (2) patterns of Barn Owl colonization of sites from early-breeding to post-breeding season, (3) the potential relationship between occupancy and roadway mortality using model-based predicted occupancy compared with actual Barn Owl mortality locations to assess whether Barn Owl mortality occurred in proportion to occupancy, and (4) Barn Owl behavior, movements and habitat selection, particularly in relation to I-84.

Information described in this thesis contributes to the general body of knowledge regarding Barn Owl biology and provides information to wildlife management agencies and other stakeholders interested in mitigating the high rates of Barn Owl roadway mortality observed along I-84/86 in southern Idaho. Furthermore, Barn Owl roadway mortality is a common phenomenon across much of their worldwide range, and my studies are among the first in the United States to examine occupancy, movements, and behavior in relation to roadway mortality.

Study Species

Barn Owls (*Tyto alba*) are one of the most widely distributed species of owl in the world (Taylor 2004; Marti et al. 2005; Grilo et al. 2012) and occur on every continent except Antarctica (Marti et al. 2005). There are 32 recognized subspecies worldwide (Dickinson 2003). *Tyto alba pratincola* is the North American subspecies of Barn Owl (Marti et al. 2005). They occur throughout much of the United States but typically are not found in northern states with colder winters and high snowfall (Marti et al. 2005). Barn Owls commonly inhabit open grassland, rangeland, or agricultural areas rather than mountainous or heavily forested areas (Marti et al. 2005). Once Barn Owls establish a nesting territory, they typically exhibit high site fidelity and do not disperse or migrate, especially in lower latitudes (Marti 1999; Marti et al. 2005).

Barn Owls are medium-sized owls with long legs in proportion to their body and are characterized by a striking heart-shaped facial disc, no ear tufts, and dark eyes (Marti et al. 2005). Barn Owl plumage coloration varies from white to dark reddish (pheomelanin) with varying amounts and patterns of black (eumelanin) spotting (Roulin et al. 2001). Barn Owls are sexually dimorphic; in general, females are larger than males, male owls are typically lighter in color with fewer black spots, and females can be darker reddish-brown with heavier black spotting (Roulin 1999; Marti et al. 2005). A typical North American Barn Owl male measures 32 – 39 cm in length and weighs 400 – 560 g, while a female is 33 – 40 cm long and weighs 420 – 700 g (Marti 1990). Wingspan varies from 100 – 125 cm (Marti 1990).

Barn Owls often make use of tree cavities, human structures such as old barns and church steeples, hay bales, river banks, rock outcrops, and caves for nests (Marti et al.

2005). They tend to reuse the same nest site for as long as they live (Marti 1999). Barn Owls can breed during their first year of life (Marti 1997) or at least at one year of age (Colvin 1985; Marti et al. 2005) and are usually monogamous within breeding seasons (but see Roulin and Marti 2002). Barn Owls breed almost year-round in lower latitudes; for example, in Texas breeding has been documented in all but November and December (Otteni et al. 1972). In higher latitudes, it is more common for owls to initiate nesting beginning in early to mid-March (Marti 1994). Timing of breeding is likely tied to food availability and climate rather than day length (Taylor 2004). In general, Barn Owls in higher latitudes lay one clutch per breeding season (Marti et al. 2005), but in lower latitudes a second clutch is more common (Marti 1994). Clutch size can be as large as 10 but typically averages closer to five to seven (Marti et al. 2005). Barn Owls lay one egg roughly every two days, and females begin incubation with the first egg which results in asynchronous hatching (Keith 1964; Smith et al. 1974). The male is the sole provider of food for the first three weeks while the female broods and feeds the young (Marti et al. 2005). When the oldest nestlings are large enough to thermoregulate and feed themselves, the female joins the male in provisioning the brood, and both adults may roost away from the nest during the day (Marti et al. 2005). Young spend 8 – 10 weeks in the nest before fledging (Smith et al. 1974). After they fledge, young typically continue to depend on adults for food for another 3 – 5 weeks (Marti et al. 2005) before initiating dispersal in late summer to early fall. Dispersal movements can be in any direction from the nest and range from 1 – > 1500 km in distance (Marti 1999). Life expectancy is relatively short. For instance, Marti et al. (2005) reported that the “mean age of death of 572 Barn Owls banded across North America and reported to the Bird Banding Laboratory was 20.9

months.” Barn Owls typically have high first-year mortality with 65 – 75% Barn Owl fledglings dying before reaching one year of age (Taylor 2004).

Barn Owls are active almost exclusively at night (Marti 1974; Colvin 1985). They search for prey with low, slow flight about 1 – 4 m above the ground and hunt from the wing more often than from perches (Bunn et al. 1982). Barn Owls specialize in capturing small mammals, especially voles (*Microtus* spp.) and mice (*Peromyscus* spp.), as well as pocket gophers (Geomyoidae), rats (*Rattus* spp.), moles (Talpidae), and shrews (Soricidae) in smaller amounts (Herrera and Jaksić 1980; Taylor 2004; Marti et al. 2005; Marti 2010). A 15-year study on Barn Owl diet in Utah found that 93.6% of prey items were voles and mice (Marti 2010). Barn Owls also eat bats, rabbits, birds, reptiles, amphibians, and arthropods (Otteni et al. 1972; Herrera and Jaksić 1980). Barn Owls detect and capture prey using their excellent low-light vision, acute hearing, and long legs (Marti 1974; Marti et al. 2005). Indeed, the hearing ability of Barn Owls is among the most precise of any animal species tested (Knudsen 1981), and Barn Owls can detect prey in complete darkness using hearing alone (Payne 1971).

Barn Owls are not suited for colder climates and need sheltered places to roost for thermal cover (Johnson 1974). Deaths from freezing or starvation occur under periods of prolonged snow cover and extended cold temperatures in North American and more commonly in Europe (Marti and Wagner 1985). The insulating quality of Barn Owl feathers is lower, and their thermo-neutral zone is much narrower, than other owl species; thus a Barn Owl must expend more energy to maintain its body temperature, and this requires the owl to consume more food (Johnson 1974). Deep snow hindersBarn Owls from locating and/or capturing prey to obtain energy required for thermoregulation (Marti and Wagner 1985; Altwegg et al. 2006). Altwegg et al. (2006) estimated Barn Owl survival in Switzerland over 70 years and found that prolonged winter snow cover reduced Barn Owl populations because their main prey became unavailable under the snow. During two of the most extreme winters, both juvenile and adult numbers were reduced so much that it resulted in a population crash (Altwegg et al. 2006).

Barn Owls are one of the most widely distributed species of owl (Taylor 2004; Marti et al. 2005). Despite this wide geographic range, populations are in decline in many areas (Colvin 1985; Toms et al. 2001). These declines are attributed to three main things. First, the loss of grasslands in some areas has reduced small rodent populations and subsequent hunting opportunities for Barn Owls (Colvin 1985; Taylor 2004). Second, conversion of open barns and other old structures into more modern, closed steel buildings, and the cutting of old trees for agricultural field expansion have effectively removed roost and nest sites (Ramsden 1998; Taylor 2004). Finally, the number of roads and traffic volume has increased resulting in a concomitant increase in Barn Owl roadway mortality from collisions with vehicles and a decrease in owl persistence (Ramsden 2003; Hindmarch et al. 2012).

Barn Owls in Great Britain have been in decline over the last 100 years and experienced a serious 50% reduction from 1991 – 1996 (Ramsden 2003). In central Spain, the Barn Owl population has declined 70% in a 10-year period (Fajardo and Pividal 1994). Barn Owl populations in British Columbia, Canada received a "Threatened" status in 2010 and those in Ontario are considered Endangered, and these are the only two remaining provinces where they currently breed (COSEWIC 2010). Barn Owls have declined in some Midwestern states (Colvin 1985). For example, Connecticut, Illinois, Indiana, Iowa, Michigan, Missouri, and Ohio have listed Barn Owls as threatened or endangered and nine other states list Barn Owls as species of special concern.

Overview of Chapters One, Two and Three

In Chapter One, to help shed light on correlates of Barn Owl occurrence, I conducted a field study within a 10,200 km^2 swath of southern Idaho with Interstate-84/86 as the central feature to collect data on factors potentially related to Barn Owl occupancy. I examined variables that influenced detection of Barn Owls and created single-season occupancy models, accounting for imperfect detection, to predict Barn Owl occupancy during the early-breeding (January – March) and post-breeding seasons (September – November) at two spatial scales, 1- and 5-km.

In both seasons, the models created at a 1-km scale performed better at representing patterns of occupancy than those at the 5-km scale. In the early-breeding season, probability of Barn Owl detection was 0.32 ± 0.06 (SE), and detection increased with playback of Barn Owl calls, increasing date, moon illumination, and percent cloud cover. Early-breeding season occupancy of Barn Owls was related to three variables: occupancy increased with proportion crops, presence of trees, and decreased as background noise level (dBA) increased. In the post-breeding season, Barn Owl detection was 0.45 ± 0.07 (SE), and detection increased with playback of Barn Owl vocalizations, increasing date, and decreasing background noise. Post-breeding Barn Owl occupancy was positively related to stream length and negatively related to increasing proportion development and increasing distance from the Snake River.

The seasonal differences that I detected in both detection and occupancy of Barn Owls suggest that season is an important factor to consider when studying Barn Owls. Studies conducted only during the breeding season may not capture important variations in Barn Owl populations that occur during other time periods. Additionally, scale was also important. Land cover variables measured at a 1-km radius around a point-count location, rather than a 5-km radius, were most suitable for examining Barn Owl occupancy in the contexts I studied.

In Chapter Two, I used both early- and post-breeding season occupancy models created in Chapter One to examine the potential relationship between occupancy and season on observed mortality along Interstate-84/86 in 1- and 5-km interstate segments. Occupancy models were used to predict Barn Owl occupancy at point-count locations < 5-km from Interstate-84/86, and then I paired each point-count location with its nearest 1- and 5-km interstate segment to examine the potential influence of occupancy on mortality by season. In so doing, I evaluated whether road mortality occurred in proportion to occupancy, i.e., road segments with the highest mortality were those in areas of the highest barn owl occupancy.

Both the 1- and 5-km analyses resulted in similar conclusions about the role of occupancy on mortality but differed with the relationship to season. At the 1-km scale, both season and occupancy affected mortality. More owls were killed during the early-breeding season than during the post-breeding season, and as Barn Owl occupancy increased so did the probability of road mortality. In the 5-km analysis, there was a significant interaction between season and occupancy and suggested that occupancy had a greater effect on probability of mortality during the early-breeding season. Model results suggested that if predicted occupancy was 0.25 or higher, there was 100% probability of finding a dead Barn Owl in the nearest 5-km interstate segment. Thus, even at fairly low predicted occupancy levels, probability of mortality had the potential to be very high. Effects of season on mortality at both spatial scales supports previous research demonstrating winter peaks in Barn Owl mortality, both in southern Idaho (Boves and Belthoff 2012), and across other regions where they experience road mortality (Bourquin 1983; Newton et al. 1997; Massemin and Zorn 1998; Fajardo 2001; Ramsden 2003). However, a large proportion (96%) and a moderate proportion (56%) of the variation in road mortality were not explained by owl occupancy at the 1 km scale and 5 km scale respectively. Thus other factors such as geometric features of the roadway, traffic patterns, fluctuations in rodent abundance, and owl behavior near I-84/86, which my study did not address, also potentially influence mortality rates and locations.

In Chapter Three, I conducted a radio-tracking study of four adult male Barn Owls that were each tending nests but at varying distances from Interstate-84 to evaluate the efficacy of using GPS data loggers to record owl movements, examine habitat selection of Barn Owls during the breeding season in southern Idaho using a resource selection function, and help understand how behavior and movements may influence mortality along the interstate. Backpack GPS data loggers captured fine scale location and movement data on Barn Owls. I was able to recapture all four instrumented owls to retrieve the data from the loggers. Manual and laser-break triggered trap doors seemed to be the two best methods of recapturing adult Barn Owls at nest boxes.

The resource selection function showed that probability a site was used in comparison to available sites decreased with increasing distance from the nearest tree and increasing distance from the nearest minor road. Use was positively associated with increasing distance from the nearest stream, increasing distance from major roads, and terrain roughness. Proportion development, proportion hay/pasture, and proportion sage steppe were all used less than cultivated crops while grassland/herbaceous land cover and wetlands were used more than cultivated crops.

Maximum movements away from the nest box for all four owls were > 3 km. The 95 % isopleth home range size varied from 0.93 – 3.48 km^2. Two of the four owls had home ranges that overlapped, which is consistent with previous studies suggesting that Barn Owls are relatively non-territorial and often occur with other Barn Owls nesting nearby (Marti et al. 2005).

Two of the males were from nest boxes < 3 km from I-84, while two were > 30 km from the interstate. The two males nesting closest to I-84 showed consistent movements in directions away from the interstate, never moved closer than 1 km, and did not cross the interstate. This may indicate the interstate is functioning as a barrier to owl movement, at least for owls that are nesting nearby and/or during this particular time of the year. How owls move in relationship to the interstate during other times of the year, e.g., during winter when road mortality is at its highest, remains to be determined.

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CHAPTER ONE: BARN OWL OCCUPANCY IN SOUTHERN IDAHO: CHARACTERSITICS OF HABITAT AND PATTERNS OF SEASONAL CHANGE

Abstract

Barn Owls (*Tyto alba*) are secretive, nocturnal owls that are often difficult to detect during surveys because they do not produce typical owl hoots. Therefore, little is known about patterns of occupancy, and it is unclear what land cover and anthropogenic factors affect Barn Owl occurrence. I was interested in understanding factors that affect (1) Barn Owl occupancy in two seasons: early- and post-breeding, (2) Barn Owl colonization of sites from early-breeding season to post-breeding season, and (3) efficacy of using broadcast of conspecific vocalizations as a method of surveying for Barn Owls. I conducted nighttime point counts for Barn Owls at 222 randomly selected locations (3 times each, 666 total surveys) in southern Idaho, USA during the early-breeding season (Jan – Mar 2014). I revisited 67 locations during the post-breeding season (Sept – Nov 2014) and conducted the same survey protocol (3 times each, 201 total surveys). Each 16-min point count included silent listening as well as broadcast of Barn Owl vocalizations. Spotlights were used to improve visual detection of owls at night. I detected Barn Owls during 52/666 (7.8 %) point counts and at 39/222 (17.6 %) locations in the early-breeding season and during 50/201 (24.8 %) point counts and at 31/67 (46.3 %) locations in the post-breeding season. During the early-breeding season, probability of Barn Owl detection was 0.32 ± 0.06 (SE). Detection increased with playback of Barn Owl calls and with increasing Julian date, percent moon illumination, and percent cloud cover. Barn

Owl occupancy increased with increased proportion of crops and presence of trees and decreased as background noise level (dBA) increased. Probability of detection of Barn Owls was higher in the post-breeding season (0.45 ± 0.07). Detection increased with playback of Barn Owl vocalizations, increasing Julian date, and decreasing background noise. During the post-breeding season, Barn Owl occupancy was positively related to stream length and negatively related to proportion development and increasing distance from the Snake River. Of the potential models I assessed to describe colonization between seasons, there were two that were well-supported. A terrain roughness model indicated that colonization of sites by Barn Owls from the early- to post-breeding season declined with increasing terrain roughness. The second most-supported model suggested that colonization of sites from early- to post-breeding season increased with cumulative stream length but decreased with distance to the Snake River and as proportion development increased. Understanding factors influencing occupancy of Barn Owls will hopefully facilitate more effective conservation of this species in southern Idaho, especially in light of population pressures related to roadway mortality.

Introduction

Wildlife populations are closely tied to habitat characteristics that increase fitness by facilitating occupancy, survival, and reproduction. Understanding how animals use aspects of their habitat is vital to conservation efforts (McClure et al. 2012). Occupancy, or the presence of a focal species in a specific area, can be a way to understand habitat quality (MacKenzie 2005) because occupancy can indicate which areas are more valuable to a species (Sergio and Newton 2003). While understanding occupancy, which is a static state, is important, factors affecting occupancy dynamics such as colonization help elucidate what attracts an animal to a site and promotes occupancy once a site is colonized (Lee et al. 2012; Yackulic et al. 2014). However, features underlying both occupancy and colonization can be challenging to determine depending on characteristics of the life history of a species.

One taxonomic group that is often difficult to study is owls. Information about owl distribution, abundance, occupancy and habitat use is limited because of their nocturnal habits, inconspicuous behavior and, at times, rarity (Takats et al. 2001). While factors influencing occupancy of Spotted (*Strix occidentalis*), Barred (*Strix varia*), Flammulated (*Psiloscops flammeolus*), and Northern Saw-whet Owls (*Aegolius acadicus*) have been identified (Olson et al. 2005; Bailey et al. 2009; Groce and Morrison 2010; Scholer et al. 2014), occupancy of Barn Owls (*Tyto alba*) remains poorly understood. Barn Owls nest in a variety of substrates (trees, haystacks, rock cliffs, open barns and abandoned buildings) and inhabit areas that support small mammal prey such as open grasslands, rangelands, or agricultural areas in temperate climates (Bunn et al. 1982; Marti et al. 2005). But, how specific land cover types and other biotic and spatial features influence occupancy of Barn Owls throughout different seasons of the year is not known. While it is clear that Barn Owls frequently associate with agricultural landscapes (Colvin 1985; Taylor 2004; Marti et al. 2005), responses of Barn Owls to disturbance associated with agriculture are not well studied. Dairy farms harbor high small mammal populations (Rowe et al. 1983), but whether Barn Owls occur more often near dairies is not known. Additionally, the potential effects of variations in terrain, distance from and extent of trees, roads, and bodies of water, on occupancy are not completely understood.

Questions of abundance, distribution, habitat use, and occupancy can often be addressed for diurnal birds with data from standard visual/listening point counts (Rosenstock et al. 2002). However, when applied to nocturnal owl species, the almost complete loss of any visual information during point counts leads to imperfect detection (Kissling et al. 2010). To increase detection, researchers often use broadcasts of conspecific vocalizations to elicit vocal responses from focal owl species (Fuller and Mosher 1987; Hardy and Morrison 2000; Takets et al. 2001; Shawyer 2011). Indeed, broadcast surveys improve detection of Barred, Great Horned (*Bubo virginianus*), Flammulated, and Northern Saw-whet Owls (Tackets et al. 2001; Barnes and Belthoff 2008). Although broadcast surveys for owls are common, some consider it ineffective for surveying Barn Owls (Sara and Zanca 1989; Shawyer 1994) because Barn Owls do not defend a well-defined territory, do not "hoot" in the fashion of other owl species, and are often quiet outside the breeding season (Bunn et al. 1982; Marti et al. 2005; Shawyer 2011).

Understanding factors that influence Barn Owl occupancy and colonization is important, in part, because Barn Owl populations are in decline in many portions of their range (Colvin 1985; Toms et al. 2001). For instance, the population of Barn Owls in Britain has been in decline over the last 100 years (Ramsden 2003). In some areas of central Spain, Barn Owl populations have declined by 70 % in a 10-year period (Fajardo and Pividal 1994). In Canada, Barn Owls now only breed in two provinces and are listed as Threatened in British Columbia and Endangered in Ontario. Barn Owls have declined in some Midwestern states (Colvin 1985). For example, Connecticut, Illinois, Indiana, Iowa, Michigan, Missouri, and Ohio have listed Barn Owls as threatened or endangered, and nine other states list Barn Owls as species of special concern. Barn Owls are also common victims of road mortality (Ramsden 2003; Boves and Belthoff 2012; Grilo et al. 2012; Borda-de Água et al. 2014) which in some cases further imperils their populations (Ramsden 2003; Hindmarch et al. 2012; Borda-de Água et al. 2014).

My main objective was to examine factors related to Barn Owl occupancy using data collected from nighttime point counts in relation to measurements of land cover variables. To understand occupancy, I first examined environmental, temporal, and biological factors that influenced detectability of Barn Owls, including whether use of broadcast calls improved detection. I then used occupancy models, adjusted for imperfect detection, to understand the factors related to Barn Owl occurrence in two seasons: the early- and post-breeding seasons. The early-breeding season represents a period during which time Barn Owl activity is frequently centered at the nest or otherwise focused in breeding territories, whereas the post-breeding season may be a more transitional period during which juveniles undergo natal dispersal and adults are less tied to a nest site (Marti 1999). Finally, I examined what factors influenced Barn Owl colonization of sites between the early- and post-breeding seasons.

Study Area and Methods

Study Area

I studied Barn Owls in southern Idaho, USA between Boise (Ada County, 43°37’N, 116°12’W) and Burley (Cassia County, 42°32’N, 113°47’W) within the Snake River Plain ecoregion (McMahon et al. 2001). Elevation in the study area ranged from 820 m above sea level near Boise to 1330 m just east of Burley. Predominant land cover types were shrub steppe/disturbed grasslands and irrigated agriculture, in addition to a few primarily rural municipalities. Shrub-steppe lands consisted of a mix of native plants such as sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), green rabbitbrush (*Chrysothamnus viscidiflorus*), and bunch grasses often combined with invasive species such as cheat grass (*Bromus tectorum*), tumble mustard (*Sisymbrium altissimum*), and Russian thistle (*Salsola kali*). The main cultivated crops in agricultural areas during my study were sugar beets (*Beta vulgaris*), potatoes (*Solanum* spp.), corn (*Zea mays*), wheat (*Triticum* spp.), barley (*Hordeum* spp.), alfalfa (*Medicago sativa*), and soy beans (*Glycine max*). Agricultural lands contained numerous irrigation ditches, isolated groves of trees, and human structures (barns, grain silos, and abandoned buildings). Approximately 322 dairy farms were scattered throughout the study area, where dairies were defined as "any land, place or premises where milking cows, sheep, or goats are kept, and from which all or a portion of the milk produced thereon is delivered, sold or offered for sale for human consumption" (Idaho Office of the Administrative Rules Coordinator 2014).

Portions of my research also occurred in the Morley Nelson Snake River Birds of Prey National Conservation Area, which is home to some of the highest nesting densities of breeding raptors in the world. The Snake River Canyon, which is one of the widest and deepest canyons in the United States, was one of the main geologic features. This canyon is characterized by vertical walls of volcanic rock which, in addition to Barn Owls, provide nest and roost sites for many raptor species, such as Prairie Falcons (*Falco mexicanus*), Golden Eagles (*Aquila chrysaetos*), and Great Horned Owls.

The Snake River Plain ecoregion has a semiarid climate (Maupin 1995). In the winter (December – February), monthly mean temperature ranges from -11.9 – 10 °C

(Western Regional Climate Center 2015). Monthly mean temperatures in summer average around 21 °C, but daily maximum temperature can be as high as 40 °C (Western Regional Climate Center 2015). During the autumn (October – November), mean monthly temperature ranges from 4.1 – 21 °C (Western Regional Climate Center 2015). Precipitation of 25 – 27 cm falls on the Snake River Basin annually, with most occurring in winter and spring (Maret 1997; Western Regional Climate Center 2015).

Barn Owl Occupancy Surveys

To determine patterns of Barn Owl occupancy, I conducted nighttime point count surveys. Using Arc GIS (ESRI 2013, ArcMap 10.1) I generated random point count locations within a 10,200 km^2 portion of southern Idaho (Figure 1.1). The study area contained a > 250-km long stretch of Interstate-84 as a portion of my study was on occupancy of Barn Owls in relation to roadway mortality (see Chapter 2). Random points were relocated to the nearest public road so that all surveys were conducted from public roads; however, none were surveyed directly from I-84 itself. Distance between points was restricted to >1 km, which reduced the chance of double counting an individual owl at multiple survey locations in one night. Thus, I considered point count locations to be independent of one another.

Point Count Protocol

An assumption of occupancy modeling is that sites are closed to changes in occupancy for the entire survey period. Conducting repeat surveys in quick succession is one way to help meet this assumption (MacKenzie and Royle 2005). Therefore, I spent 16 min at each point-count location conducting three successive surveys. At each location, I used a combination of silent listening for aural detection of owls, spotlighting for visual detection of owls, and call broadcast to help elicit vocalizations from Barn Owls. Survey 1 began with 5 min of silent listening and spotlighting. This was followed by Survey 2 and Survey 3, which each included 30 sec of broadcast calling followed by 5 min of silent listening and spotlighting (Figure 1.2).

For broadcast of Barn Owl vocalizations during point counts, I used a FoxPro (FX3) game caller with pre-recorded Barn Owl vocalizations (Stokes and Stokes 2010) broadcasted at 16 screeches/min at 105 dB measured 1 m from the speaker (Mosher and Fuller 1996; Kissling et al. 2010). During each 30-sec broadcast, I directed the speaker in the four cardinal directions for approximately 7.5 sec each.

Because some literature suggested that Barn Owls may not consistently respond to playback (e.g., Shawyer 2011), I combined broadcasts of Barn Owl vocalizations with spotlighting (Condon et al. 2005) to increase the chances of detecting Barn Owls that were present but not vocalizing. During point counts two observers used high power spotlights (Streamlight Waypoint, 300 lumens) to scan for Barn Owls. I recorded Barn Owls observed within ~250 m of the point-count location (visual detection) and when heard (aural detection) irrespective of distance.

Barn Owls are primarily nocturnal and can be active during all hours of the night (Marti et al. 2005). Thus, I conducted point counts between 0.5 h after sunset and 0.5 h before sunrise. I avoided surveying in heavy rain, dense fog, or when winds exceeded a score of 6 on the Beaufort scale (~ 40-50 km/h), because these conditions could reduce both owl activity and my ability to detect owls (Takats et al. 2001; Condon et al. 2005). When possible, I also avoided surveying within busy residential or developed areas because of the noise associated with these areas and to avoid disturbing people in nearby residences.

Number and Timing of Point Counts

I conducted point counts at 222 locations from January – March 2014, which corresponded with the early-breeding season period for Barn Owls. During these months, Barn Owls typically engage in establishing pair bonds, defending nesting territories, and egg-laying and incubation; for instance, mean date of clutch initiation in nearby Utah is 13 March ± 5.9 (SD) days (Marti 1994). I randomly selected and revisited 67 of the 222 point-count locations to survey for Barn Owls during the post-breeding season (October – November 2014) to examine changes in occupancy and patterns of colonization. During this time most juvenile owls have likely fledged and are initiating their natal dispersal (Marti et al. 2005).

Detection and Occupancy Covariates

When an owl was detected, I recorded time of detection, type of detection (aural, visual, or both), number and species of owl detected, and number and types of vocal responses. For each point count, I also recorded Julian date, time of sunset, and start and stop time of the 16 min spent at each location. Fog was ranked visually into none, low (no effect on visibility), medium (visibility several hundred meters), and high (visibility ≤ 50 m). I measured wind speed (km/h) and temperature (°C) using a handheld weather meter (Kestrel 4000, Nielsen-Kellerman Co., Birmingham, MI). Wind speed was measured once per survey (3 times per point-count location) and then averaged for the 16- min period, and temperature was measured in the middle of the second survey. I used the mobile phone app “Phases of the Moon” (Allaverdiev and Cain 2014) to estimate the percent of moon illumination for a survey night. I divided the sky into four quadrants, visually estimated the percent cloud cover in each quadrant, where 25% was maximum cloud cover per quadrant, and then summed the quadrants to derive percent cloud cover. I measured background noise intensity in A-weighted decibels (dBA) twice per survey (6 times per point-count location) in the range 31.5 – 8000 Hz using a sound level meter (EXTECH, # G3991644) accurate to ±1.5 dB and then averaged noise at each location. Noise type was categorized as road traffic, stream, wind, airplane, train, or other. Presence of above-ground powerlines, fence posts, and trees were also recorded as these represent potential perching, roosting or, in the case of trees, nesting sites for Barn Owls.

To examine correlates of occupancy, I quantified proportion land cover type, cumulative stream length, cumulative road length and terrain roughness using Arc GIS (ESRI 2013, ArcMap 10.1) within 1- and 5-km radius buffers centered on each point-count location. A 1-km radius around a nesting or roosting site often corresponds to average nightly foraging movements of Barn Owls, and 5-km corresponds to maximum estimated movements of Barn Owls (Ramsden 2003; Marti et al. 2005; Chapter 3). To determine the effect of distance from biotic and abiotic features on occupancy, I calculated distance from the point-count location to the nearest dairy, the Snake River, Interstate-84, and other major roads. To examine potential effects of land cover type on occupancy, I determined proportion of cultivated crops, development, grassland/herbaceous, hay/pasture, sage steppe, and water within each 1- and 5-km radius buffer using the National Land Cover Database 2011 (Homer et al. 2015).

<u>Data Analysis - Probability of Detection</u>

Prior to formulating either detection or occupancy models, I examined variables for multicollinearity, redundancy, and lack of variation. I also removed from analysis variables that ultimately caused estimation issues in analyses. I created a detection history from the three repeat surveys conducted at each point-count location and evaluated the potential effects of Julian date, sunset time, cloud cover, percent moon illumination, background noise, broadcast call, fog, observer, wind speed, and temperature on Barn Owl detection. I used a forward-stepwise variable selection procedure (Schuster and Arcese 2013) and retained covariates that lowered Akaike's Information Criterion (AIC, Akaike 1974). I generated detection models for both the early- and post-breeding seasons and calculated probability of detection (p) for Barn Owls. Occupancy (Ψ), the probability a species is present, was held constant during all detection analyses (MacKenzie et al. 2006).

Data Analysis - Occupancy

Occupancy variables included noise level and type (road traffic, stream, wind, airplane, train, or other), distance to nearest dairy, presence of fences and powerlines, distance to Interstate-84, distance to other major roads, cumulative road length, presence of trees, terrain roughness, distance from the Snake River, and cumulative stream length. Land cover variables that I assessed included proportion water, development, cultivated crops, grassland, hay/pasture, and sage steppe (Table 1.1).

I used single season models (MacKenzie et al. 2006) to estimate occupancy of Barn Owls separately in the early- and post-breeding seasons. I used the same stepwise variable selection procedures described above for detection to develop the model best predicting occupancy. I developed models for variables measured at two scales (1- and 5-

km). I then compared the top occupancy models at each scale, where top models were determined by the lowest AIC value, to determine the spatial scale that best predicted Barn Owl occupancy.

Multiseason Occupancy Analysis

I was also interested in assessing whether the same suite of variables from the single season occupancy analyses might be associated with *change* in occupancy at sites between seasons, i.e., factors associated with colonization of sites by Barn Owls. While I was also interested in examining factors associated with extinction between seasons, I ultimately did not have enough surveys in the second season (post-breeding) overall, and especially with extinction events. I used a multiseason modeling approach as outlined in McKenzie et al. (2006). To create a detection model, I combined variables from the early- and post-breeding season detection models: season, Julian date, broadcast call, percent cloud cover, percent moon illumination, and noise level. Next, detection was held constant, and I created a model for occupancy in the first season using variables from the early-breeding season occupancy model: proportion crops, tree presence, and background noise. Then, I held detection and first-season occupancy constant while I tested *a priori* models constructed from different combinations of spatial and biotic covariates with models parameterized to assess Barn Owl colonization from the early- to post-breeding season (Table 1.2). I evaluated models using AIC and considered the most parsimonious model the one with the lowest AIC value.

Model Performance

I evaluated the performance of the early- and post-breeding season occupancy models by calculating the area under the receiver operator characteristic curve (AUC).

Models with AUC values between 0.5 and 0.7 have a poor ability to distinguish between an occupied and unoccupied site, models with values > 0.7 are thought to be useful, those > 0.8 are considered good, and models with AUC > 0.9 are deemed excellent in their ability to discriminate between an occupied and unoccupied site (Pearce and Ferrier 2000). As I used the same data to fit occupancy models and to calculate AUC, AUC values in my case are best viewed as measures of model fit rather than true measures of predictive ability.

Statistical Analysis

All statistical analyses were conducted in R (3.0.1, R Core Team 2015). I used the unmarked package (Fiske and Chandler 2011) for occupancy modeling and the ROCR package for model performance evaluation and calculation of AUC (Sing et al. 2005). Means are given with standard errors unless otherwise noted.

Results

Early-Breeding Season

During the early-breeding season, I detected Barn Owls during 52 of 666 (7.9 %) surveys and at 37of 222 (16.7 %) point-count locations. Most detections, 92.3 % (48 of 52), occurred during silent listening periods. Only 7.7 % of detections (4 of 52) occurred during the 30-sec broadcast periods (n = 3 and n = 1 during the first and second broadcast periods, respectively). Of the 52 Barn Owl detections, 35 (67.3 %) were aural, eight (15.4 %) were visual, and nine (17.3 %) were a combination of visual and aural. Eight detections occurred in Survey 1 (1.2 % of surveys and 3.6 % of point-count locations), 22 detections occurred during Survey 2 (3.3 % of surveys and 9.9 % of point-count locations), and 23 Barn Owl detections occurred during Survey 3 (3.4 % of surveys and 10.4 % of point-count locations).

For 44 detections, I heard 110 individual vocalizations by Barn Owls. Most of these vocalizations ($n = 106$, 96.3 %) were the screech call. Owls uttered 1.9 ± 0.2 screeches per response (range: 1 – 7). The other four responses (3.6 %) were high-pitched chittering or twittering “kewick” calls (Bunn et al. 1982). These chittering calls only occurred when I detected multiple Barn Owls at a point-count location, although there were other times when I detected multiple owls and did not hear chittering calls. I detected >1 Barn Owl at 7 of 222 (3.2 %) point-count locations; six times there were two owls, and once there were at least three different owls. I also detected Great Horned Owls (54 of 666 surveys, 37 of 222 point-count locations), Northern Saw-whet Owls (4 of 666 surveys, 3 of 222 point-count locations) and Western Screech-Owls (*Megascops kennicottii*, 1 of 666 surveys, 1 of 222 point-count locations).

Detection

Detection increased with playback of Barn Owl calls, and with increasing Julian date, percent moon illumination, and percent cloud cover (Table 1.3). The odds of detecting a Barn Owl were 4.3 times higher with broadcast of Barn Owl vocalizations. For every one unit increase in Julian date, percent moon illumination and percent cloud cover, the odds of detecting a Barn Owl increased by 1 – 3% each (Table 1.3). Ultimately, probability of Barn Owl detection during the early-breeding season was 0.32 $\pm$ 0.06.

Sources of Noise

Background noise at point-count locations (n = 222) was 42.6 ± 0.3 dB(A) [range: 34.3 – 81.2 dB(A)]. Road traffic was the most common noise source, recorded at 192 of 222 point-count locations (86.5%). ‘Other’ noise, which included dairy farm/agricultural infrastructure and air traffic, was recorded at 74 of 222 point-count locations (33.3%). Lastly wind noise was recorded at 24 of 222 point-count locations (10.8%), Point-count locations frequently had multiple sources of noise which is why occurrences sum to more than the number of point-count locations.

Scale Selection

Occupancy models at the 1-km scale had lower AIC values than those from land cover, anthropogenic, and road-related variables measured at a 5-km scale (Table 1.5). Thus, I selected the 1-km scale for examining correlates of Barn Owl occupancy in southern Idaho during the early-breeding season.

Occupancy

In the early-breeding season, Barn Owl occupancy increased with proportion crops and presence of trees, and it decreased as background noise increased (Table 1.5). The odds of an owl occupying an area increased by 42.9 times with every one unit increase in proportion cultivated crops, and by 3.8 times with presence of trees. For every one unit increase in background noise, the odds of occupancy were just 0.9 of what they were at the previous level. Model performance was moderate with AUC = 0.73.

<u>Post-Breeding Season</u>

During the post-breeding season, I detected Barn Owls during 50 of 201 (24.8%) individual surveys and at 31 of 67 (46.3%) point-count locations. Similar to the early-breeding season, most detections (86%, 43 of 50) occurred during the silent listening periods. Only 8% (4 of 50) of detections occurred during the 30-second broadcast periods (n = 1 and n = 3 during the first and second broadcast periods, respectively). I detected Barn Owls in both the playback and silent listening periods 6% of the time (3 of 50). Of the 50 total detections, 54% (27 of 50) were aural, 22% (11 of 50) were visual, and 24% (12 of 50) were both visual and aural. Six detections occurred in Survey 1 (3.0% of surveys and 9.0% of point-count locations), 20 detections occurred in Survey 2 (10% of surveys and 30% of point-count locations), and 24 detections occurred in Survey 3 (11.9% of surveys and 35.8% of point-count locations).

For 39 detections, I heard Barn Owl vocalizations (n = 70). Most vocal responses (n = 69, 98.5%) were the screech call, and owls uttered 1.9 ± 0.3 screeches per response (range 1 – 10). I only heard the high pitched chittering “kewick” (Bunn et al. 1982) call as a vocal response once during the post-breeding period, and it was when there were multiple owls detected. I detected multiple Barn Owls at 9 of 67 (13.4%) point-count locations, with the number of owls detected ranging from 2 – 4 individuals in these instances (n = 6 observations of two owls, n = 1 observation of three owls, and n = 2 observations of four owls).

In addition to Barn Owls, I detected Great Horned Owls at 11 of 201 surveys and 8 of 67 point-count locations. Unlike during the early-breeding season, I did not detect Northern Saw-whet Owls or Western Screech-Owls during post-breeding season point counts.

Detection

Detection during the post-breeding season increased with playback of Barn Owl vocalizations, increasing Julian date, and decreasing background noise (Table 1.4). The odds of detecting a Barn Owl were 9.2 times higher with broadcast of Barn Owl vocalizations. With one unit increases in Julian date and background noise, the odds of detecting a Barn Owl increased by 1.1 and decreased by 0.4 times, respectively. Barn Owl detection probability (0.45 ± 0.07) was greater than during the early-breeding season.

Sources of Noise

Average background noise during point-counts (n = 67) was 42.7 ± 0.5 dB(A) and ranged from 35.4 to 79.0 dB(A). The main sources of background noise were road traffic (57 of 67 point-count locations), dairy farm/agricultural infrastructure (9 of 67 point-count locations), and air traffic (8 of 67 point-count locations).

Scale Selection

Similar to during the early-breeding season, models at a 1-km scale had lower AIC values than those from land cover, anthropogenic, and road-related variables measured at a 5-km scale (Table 1.5). Thus, I selected 1-km as the best scale for accurately estimating Barn Owl occupancy during the post-breeding season.

Occupancy

During the post-breeding season (Sept – Nov), Barn Owl occupancy was positively related to stream length and negatively related to proportion development and increasing distance from the Snake River (Table 1.5). For every one unit increase in stream length, the odds of a Barn Owl occupying an area increased by 1.6 times. With one unit increases in proportion development and distance from the Snake River odds of occupancy were 1×10^{-13} and 0.9 of what they were at the previous level, respectively. Model performance was good with an AUC = 0.87.

<u>Multiseason Occupancy Models - Colonization</u>

Of the potential models I assessed to describe colonization between seasons (Table 1.2), there were two top models. The model with the lowest AIC was the terrain roughness model, and the second best model was the fall model (Table 1.6). The terrain roughness model had only one covariate (slope) and indicated that Barn Owl colonization of sites from the early- to post-breeding season declined with increasing terrain roughness (Table 1.6). The fall model had an AIC value within 2 of the top model and had three covariates that were synonymous with those of the top occupancy model in the post-breeding season: stream length, distance from Snake River, and proportion development. Thus, this model highlighted that Barn Owl colonization of sites from early- to post-breeding season increased with increasing cumulative stream length but decreased with distance to the Snake River and proportion development (Table 1.6).

Discussion

The overarching goal of my study was to determine seasonal correlates of Barn Owl occupancy and detection in southern Idaho from data collected through nighttime point-count surveys, spatial data gleaned from land cover data bases, and measurements within point count locations. I found that detection probability varied by season and was greater during the post-breeding season. Across both the early- and post-breeding seasons, detection increased with playback of Barn Owl vocalizations. Occupancy estimates and variables correlated with occupancy also varied by season. In both seasons, a 1-km spatial scale, for the variables assessed, described occupancy best because 1-km models had lower AIC values when compared to assessments at a 5-km scale. Occupancy during the early-breeding season increased with proportion crops and tree presence, and decreased with background noise. Occupancy during the post-breeding season was higher than the early-breeding season and increased with stream length but decreased with distance from the Snake River and proportion development. Additionally, I examined colonization and found two top models: one that indicated terrain roughness or percent slope was important (i.e., owls tended to colonize areas with reduced topography), and one that indicated stream length, distance to Snake River, and development were important correlates of colonization.

Detection: Early-Breeding Season

Roadway mortality and harsh winter conditions might work synergistically to reduce population size and indirectly result in the lower detection rates that I observed during the early-breeding season. In southern Idaho, Barn Owls suffer from the highest recorded rate of roadway mortality with potentially > 1,500 owls killed annually along a ~300-km stretch of Interstate-84 (Boves and Belthoff 2012). Higher road mortality is observed during winter (Boves and Belthoff 2012), which is a time period that corresponds to the early-breeding season when I conducted my point-count surveys. High mortality of Barn Owls related to freezing and starvation has been noted under periods of prolonged snow cover and extended cold temperatures in North America and Europe (Marti and Wagner 1985; Altwegg et al. 2006). Reduced population size may result in fewer Barn Owl encounters and reduced detection rates because they are spread more sparsely across the landscape. Finally, it is possible that Barn Owls respond less to broadcast of conspecific vocalizations because competition pressure for territories and mates might be relaxed or reduced in such depressed populations.

In contrast, Zuberogoitia and Campos (1998) reported the highest rate of detection for Barn Owls in Biscay, Spain was during the breeding season. It is possible that the difference in detection rates between our respective studies was a result of differences in activity levels. The climate in southern Idaho is colder than in Biscay, Spain and Barn Owls, which are limited in their ability to thermoregulate, perhaps reduce activity in extremely cold, windy, or other inclement weather conditions (Johnson 1974; Zuberogoitia and Campos 1998). These weather conditions regularly occurred in southern Idaho during my surveys. Additionally, differences in survey timing could have contributed. My early-breeding surveys captured the time period leading up to the peak breeding season (Jan – Mar) while Zuberogoitia and Campos's (1998) breeding season surveys encompassed a longer period (March – July) and likely captured peak breeding season activity. The positive effect of Julian date on detection that I observed potentially corresponded to increases in breeding season activities such as vocalization, courtship, and establishing and defending territories (Johnsgard 1988). Thus, detectability of Barn Owls might increase until peak-breeding season and then decline as Barn Owls become focused on brood-rearing in late spring – early summer, when vocalizations are less common (Johnsgard 1988). Barn Owls also may be more active and easier to detect on cloudy nights because they are less susceptible to Great Horned Owl predation. For instance, Morrell et al. (1991) found Great Horned Owls to be more active on nights with ≤ 5% cloud cover.

The activity schedules of some nocturnal owl species are related to moonlight levels. For example, Elf Owl (*Micrathene whitneyi*) singing behavior varies with phases of the moon, with more activity under brighter phases (Hardy and Morrison 2000). Great

Horned, Boreal (*Aegolius funereus*), and Northern Saw-whet Owls have greater detection rates under bright, moonlit nights (Armstrong 1973; Morrell et al. 1991), and Eagle Owls (*Bubo bubo*) call and display a white throat patch more frequently on moonlit nights compared to darker nights when silence is more common (Penteriani et al. 2010). Barn Owls may be more active on nights with greater percent moon illumination potentially because they can efficiently visually locate and capture prey, similar to Short-eared Owls (*Asio flammeus*) which have more success locating and capturing prey when moonlight is intense, i.e. under a full moon (Clarke 1983). If Barn Owls are more active while hunting on moonlit nights it could explain the greater detection probabilities I observed. Additionally, the ability of observers to visually detect Barn Owls likely improves on moonlit nights as well. Finally, it is possible that intraspecific communication increases under higher moon illumination which results in greater detection rates.

<u>Detection: Post-Breeding Season</u>

The post-breeding season corresponds to the time period when juvenile Barn Owls are initiating natal dispersal, and dispersal movements result in an influx of young Barn Owls into the population (Taylor 2004; Marti 1999; Marti et al. 2005). Juvenile owls may not be well established on home ranges and therefore likely spend considerable time moving longer distances each night compared to adults with established territories (Taylor 2004). Additionally, because young of the year may be settling into territories, vocal behavior of both juveniles and previously established adult owls may increase at this time of year (e.g., Ritchison et al. 1988). Although vocalizations of different life history stages of Barn Owls are not well studied, the greater detection probability I recorded during the post-breeding period may be a product of a population augmented by more abundant and/or mobile, vocal juveniles. The detection model showed that a progression in Julian date coincided with increased detection rates which is also potentially driven by increased numbers of juvenile owls across the landscape as the fledging season progressed (Marti et al. 2005).

Detection of Western Screech-Owls, Northern Saw-whet Owls (Kissling et al. 2010) and Flammulated Owls (Scholer et al. 2014) is lower under high-noise conditions. Noise may interfere with the ability of owls to communicate vocally with each other and reduce vocalization rates. For instance, Scobie et al. (2014) suggest that one reason Burrowing Owls avoid roads is that high traffic noise impedes vocal communication between mates and between adults and their offspring. If Barn Owls were vocalizing less frequently in noisy areas, this would have reduced the detection rate. Noise may also decrease the ability of observers to detect owls (Morrell et al. 1991). Ortega and Francis (2012) showed that gas-well compressor noise significantly reduced their ability to detect birds and suggested that a background noise level of ~45 dBA reduced the ability of human observers to detect birds within 60 m of a survey site.

Effect of Broadcast Vocalizations on Detection

Effects of using broadcast calls on detection of other species such as Barred, Great Horned, Flammulated, and Northern Saw-whet Owls has been well documented (Tackets et al. 2001; Barnes and Belthoff 2008). Previous literature suggested that unlike the aforementioned ‘typical owls,’ Barn Owls tend to be unresponsive; thus broadcast surveys for Barn Owls have not always been recommended (Sara and Zanca 1989; Shawyer 2011). However, evidence to the contrary appears to be mounting. My results indicated clearly that Barn Owl detection improved with broadcast during both the early-and post-breeding periods. Similarly, Wingert (2015), working in Illinois, found that detectability of Barn Owls increased with call broadcast during surveys conducted during the peak of the breeding season and within 250 m of known nesting owls. On the island of La Gomera, Spain, where Barn Owls occur at very low densities, broadcasted vocalizations also elicited vocal responses from Barn Owls three times out of 65 surveys, and Siverio et al. (1999) suggest these owls would have gone undetected without stimulation from the broadcast calls.

Occupancy: Early-Breeding Season

During the early breeding period, Barn Owl occupancy was higher at sites with greater proportion crops, presence of trees, and low background noise within a 1-km radius. These relationships may have been driven by availability of suitable nesting and hunting habitat provided by agricultural lands and disturbance causing owls to occupy noisier areas less frequently.

Small mammals, which are the primary prey of Barn Owls, are plentiful in agricultural landscapes; in general, Barn Owls are common in these areas as well (Bunn et al. 1982; Taylor 2004; Marti et al. 2005). Indeed, occupancy was higher with greater proportions of cultivated crops in my study. Furthermore, in the shrub steppe dominated landscape of southern Idaho, agricultural lands are among the few areas with trees, which were often located near human structures and along irritation ditches (pers. observ.). Nest site availability limits Barn Owl populations because they are cavity nesting raptors (Bunn et al. 1982; Taylor 2004; Marti et al. 2005). That Barn Owls in southern Idaho had a positive association with croplands and trees supports other studies linking declines in occupancy and breeding success of Barn Owls to modernization of agricultural practices and loss of nest and roost sites (Colvin 1985; Bunn et al. 1982; Percival 1992; Taylor 2004; Hindmarch et al. 2012). For example, urbanization of historical agricultural fields, conversion of open wooden barns to modern, steel buildings, and tree removal led to loss of habitat for Barn Owls in British Columbia, Canada (Hindmarch et al. 2012). Furthermore, I found trees and crops most strongly affected occupancy during the early-breeding season, which is a time when owls must gain access to nesting cavities and prey resources to meet energetic requirements of breeding (Taylor 2004; Bond et al. 2005).

Although previous studies indicate that noise negatively affects *detection* of other owl species (Kissling et al. 2010; Scholer et al. 2014), noise was not found to affect occupancy. The negative effect of noise from road traffic, dairy farm infrastructure, and air traffic on Barn Owl occupancy that I observed is of import because we are currently learning more about the way animals may respond negatively to noisy environments (McClure et al. 2013; Ware et al. 2015; Mason et al. 2016). Barn Owls can hunt using only the information provided by prey-movement sounds (Payne 1971), and their hearing is some of the most sensitive tested (Knudsen 1981; Marti et al. 2005). Thus, Barn Owls may be especially sensitive to anthropogenic noise. Northern Saw-whet Owls were unwilling to hunt or unable to capture mice under loud [61 dB(A)] noise when their prey capture ability was tested under different levels of noise produced by gas well compressors (Mason et al. 2016). Interestingly, this sound intensity level of 61 dB(A) coincides with the level where Barn Owl occupancy dropped to zero in my study.

Occupancy: Post-Breeding Season

The tendency for Barn Owl occupancy to increase near the Snake River, in less developed areas, and in sites with more streams during the post-breeding season may have been driven by nest site and prey availability. Barn Owls prefer less exposed nest and roost sites; e.g., far back in crevices or in areas with low visibility and high cover (Rudolph 1978). The Snake River canyon provides this habitat to Barn Owls (Marti 1988; Boves and Belthoff 2012) because of numerous cavities and crevices in cliffs along the canyon. Development reduces habitat for small mammals and decreases hunting opportunities for Barn Owls. For instance, Hindmarch et al. (2014) found higher percentages of urban land cover within a 1-km radius of breeding Barn Owls reduced fledging success. While Barn Owls that nested in urban areas did not lay fewer eggs, their nests were less productive and fewer young survived to fledge, which was likely a result of reduced prey availability in urbanized landscapes (Hindmarch et al. 2014).

Nest sites are often a limiting factor for Barn Owls (Colvin 1985; Taylor 2004). As such, trees limited to streams in the shrub steppe of southern Idaho provide important nest and roost sites and might explain the positive association between streams and Barn Owl occupancy in my study. Additionally, undisturbed strips of land along streams are habitat for small mammals, especially in an agricultural matrix where croplands receive intense and regular disturbance via repeated cycles of plowing, cultivation, harvest, and tilling. Chapman and Ribic (2002) examined small mammal abundance along untreated stream buffers and surrounding crop fields and found abundances were two to three times greater near the stream regardless of the type of farming practice. They also found meadow voles (*Microtus pennsylvanicus*) to be the most common species within the stream buffers (Chapman and Ribic 2002). Voles frequently are the primary prey of Barn Owls, so Barn Owls appear to be vole specialists (Bunn et al. 1982; Campbell et al. 1987; Taylor 2004; Marti et al. 2005; Marti 2010). Furthermore, breeding success often increases with greater proportions of voles in the diet (Gubanyi et al. 1992; Taylor 2004). Thus, Barn Owls may occupy home ranges in areas with greater stream densities because of abundant nest and roost sites and robust small mammal populations.

Multiseason Occupancy: Colonization

Scholer et al. (2014) found a negative relationship between terrain roughness and Northern Saw-Whet Owl occupancy and suggested that rugged terrain may create sub-optimal conditions for aurally locating prey because uneven landscapes interfere with sound waves. As Barn Owls also rely on hearing for hunting, this could also underlie the negative relationship between increasing terrain roughness and colonization I observed. When colonizing an area, Barn Owls moved into relatively flat landscapes compared with those where the terrain varied or was more “rough”. In southern Idaho, flat topography is also usually associated with agriculture, grassland, and pasture areas that provide suitable habitat for small mammals rather than the more dynamic and hilly terrain often covered by shrub steppe, lava outcrops, and buttes.

The fall model suggested that colonization was negatively associated with increasing distance from the Snake River and development and positively related to increasing stream lengths. These are patterns similar to those shown when related to single season occupancy in the post-breeding season where it was the top model. Thus colonization is likely related to these factors along the same lines (see above). Similar to those relationships, Spotted Owl colonization of sites is driven by greater amounts of old growth forest, likely because the trees provide critical nest and roost sites for owls and habitat for their prey (Yackulic et al. 2014).

Results of colonization models likely relate to juvenile owl activity more than adults because I assessed colonization from early- to post-breeding seasons. Juveniles are dispersing in the post-breeding season and searching for hunting opportunities and available territories (Marti et al. 2005). In contrast, adults are philopatric and typically stay within 1.5 km of an established nest site during the breeding season and within 5 km during other times of the year (Marti et al. 2005); thus adult Barn Owls typically do not move to colonize new areas. Indeed, Marti (1999) found that only 3.8% of breeding Barn Owls underwent a breeding dispersal from one season to the next.

Conclusions

My study indicates that point-count surveys for Barn Owls should incorporate broadcast of Barn Owl vocalizations irrespective of whether the counts occur in the early- or post-breeding periods. Broadcast surveys allow for a large geographic area to be covered (Zuberogoitia and Campos 1998) and provide a way of improving detection of Barn Owls. However, even with broadcast of conspecific vocalizations, Barn Owl detection probability appears to be lower than for some other species of owls. For instance, probability of detection during broadcast surveys for Flammulated Owls was close to 1.0 (Barnes and Belthoff 2008; Scholer et al. 2014), detection of Northern Saw-Whet Owls was 0.77 (Scholar et al. 2014), and detection of Barred Owls was 0.54 (Kissling et al. 2010).

Because of seasonal differences in both detection and occupancy, my study also suggests that season should be considered when studying Barn Owls, as studies limited to the breeding season may not capture variations in Barn Owl populations occurring during other time periods. My study also suggests understanding the influence of landscape level factors, both natural and anthropogenic, on colonization of unoccupied sites is critical because colonization is the precursor to site occupancy (Lee et al. 2012). Indeed, features that attract a focal species to a site during colonization may differ from those that promote long-term occupancy. Additionally, I found that spatial scale affected model performance, and a 1-km rather than 5-km radius around point-count locations was most suitable for assessing and predicting Barn Owl occupancy. Thus, multi-season and multi-scale approaches, as well as those that assess occupancy dynamics such as colonization and extinction (Lee et al. 2012), will be important for gaining a holistic understanding of Barn Owl conservation approaches.

Overall, Barn Owl *occupancy* during the early-breeding season and Barn Owl *detection* during the post-breeding season were negatively associated with the intensity of background noise. This suggests that Barn Owls may avoid areas with high noise levels, although the potential mechanisms underlying this relationship are not known. My nighttime surveys attributed background noise to road traffic, dairy farm infrastructure, and air traffic, and I encountered traffic noise at most point-count locations in both the early- and post-breeding seasons. These results therefore indicate that anthropogenic noise is almost ubiquitous across the southern Idaho landscape in which I worked. The effect of different noise types on occupancy and behavior of Barn Owls is not known, so future work should examine if, and how, anthropogenic noise affects breeding and dispersing Barn Owls. Finally background noise levels now should be recognized as a factor that also reduces detection rates in Barn Owl surveys (see also Ortega and Francis 2012).

Understanding what land cover, spatial, and biotic features of the southern Idaho landscape Barn Owls require to achieve maximum fitness is necessary to manage a stable population. Barn Owls are in decline in much of their worldwide range (Colvin 1985; Toms et al. 2001), and habitat loss and road mortality are two of the main causes. In southern Idaho, road mortality accounts for large numbers of dead Barn Owls (Boves and Belthoff 2012). It is unclear if owls are simply killed in proportion to their occupancy, or if other patterns between occupancy and mortality occur such that roads may function as an ecological trap or barrier to owl movements. Using these occupancy models to spatially predict occupancy across southern Idaho and then examine the relationship between occupancy and mortality was the focus of Chapter 2 of this thesis. Once the link between occupancy and mortality is well understood, we will have better options to reduce Barn Owl mortality along roads in Idaho.

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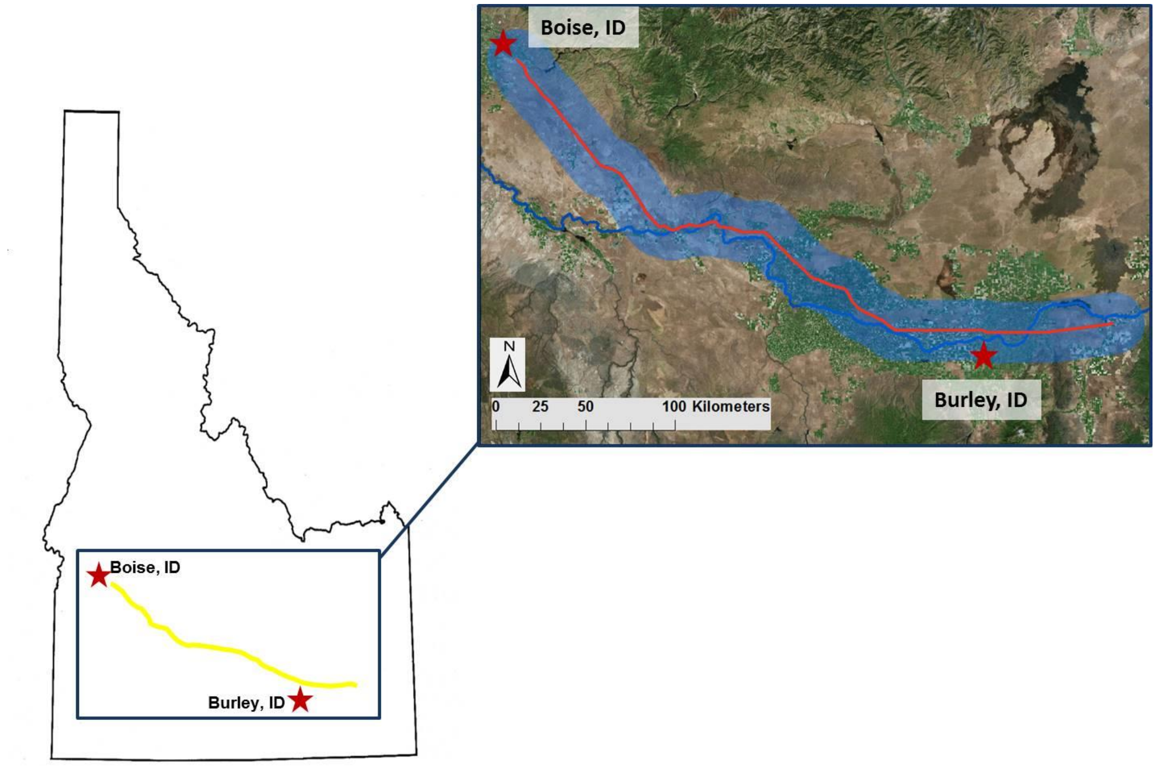

Figure 1.1. Study area map showing the location of my 10,200 km^2 study area (blue) and Interstate 84 (red), where I surveyed for Barn Owls during the early- and post-breeding seasons of 2014.

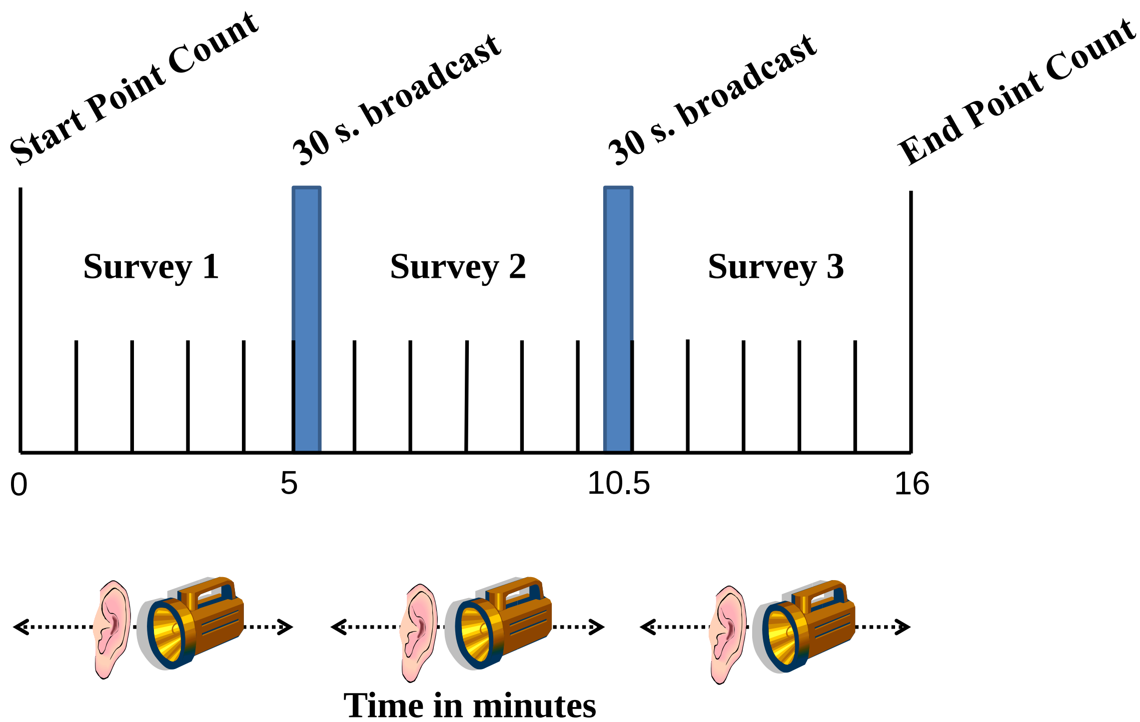

Figure 1.2. **Broadcast sequence for Barn Owl surveys in s. Idaho during the early- and post-breeding seasons, 2014. Point counts consisted of three repeat surveys conducted over 16 min. Survey 1 included 5 min of silent listening, Survey 2 began with 30 sec. of broadcast of Barn Owl vocalizations followed by 5 min of silent listening, and Survey 3 was the same format as Survey 2.**

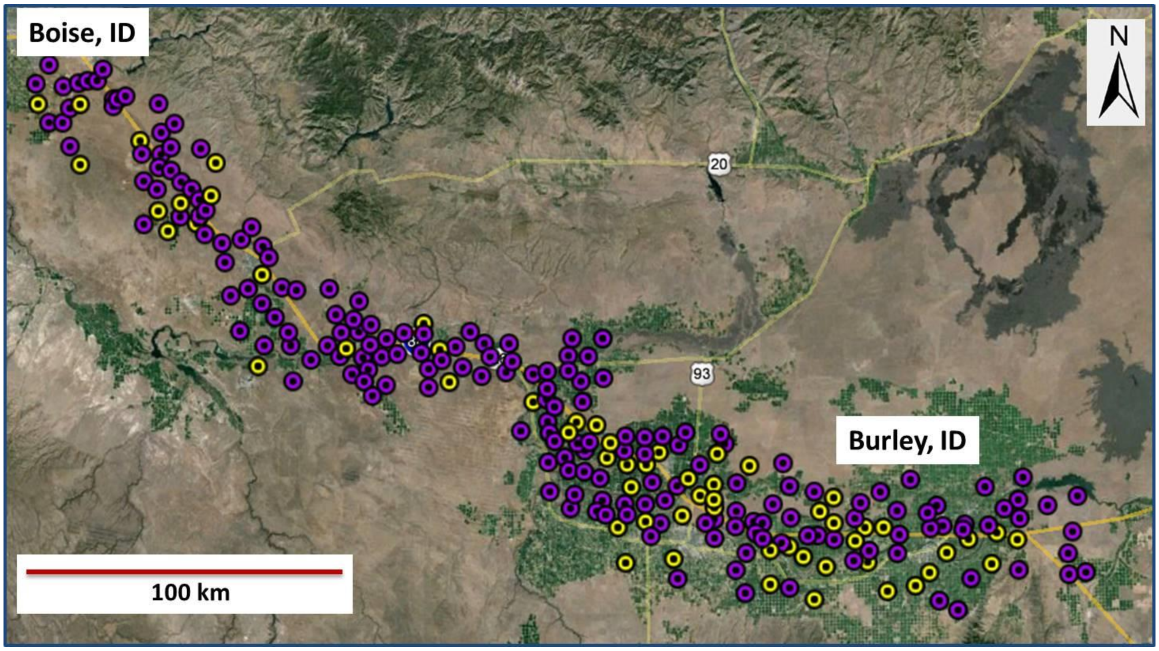

Figure 1.3. Point-count locations (n = 222) surveyed for Barn Owls in early- and post-breeding seasons, 2014 in s. Idaho. Yellow points show locations of Barn Owl detections.

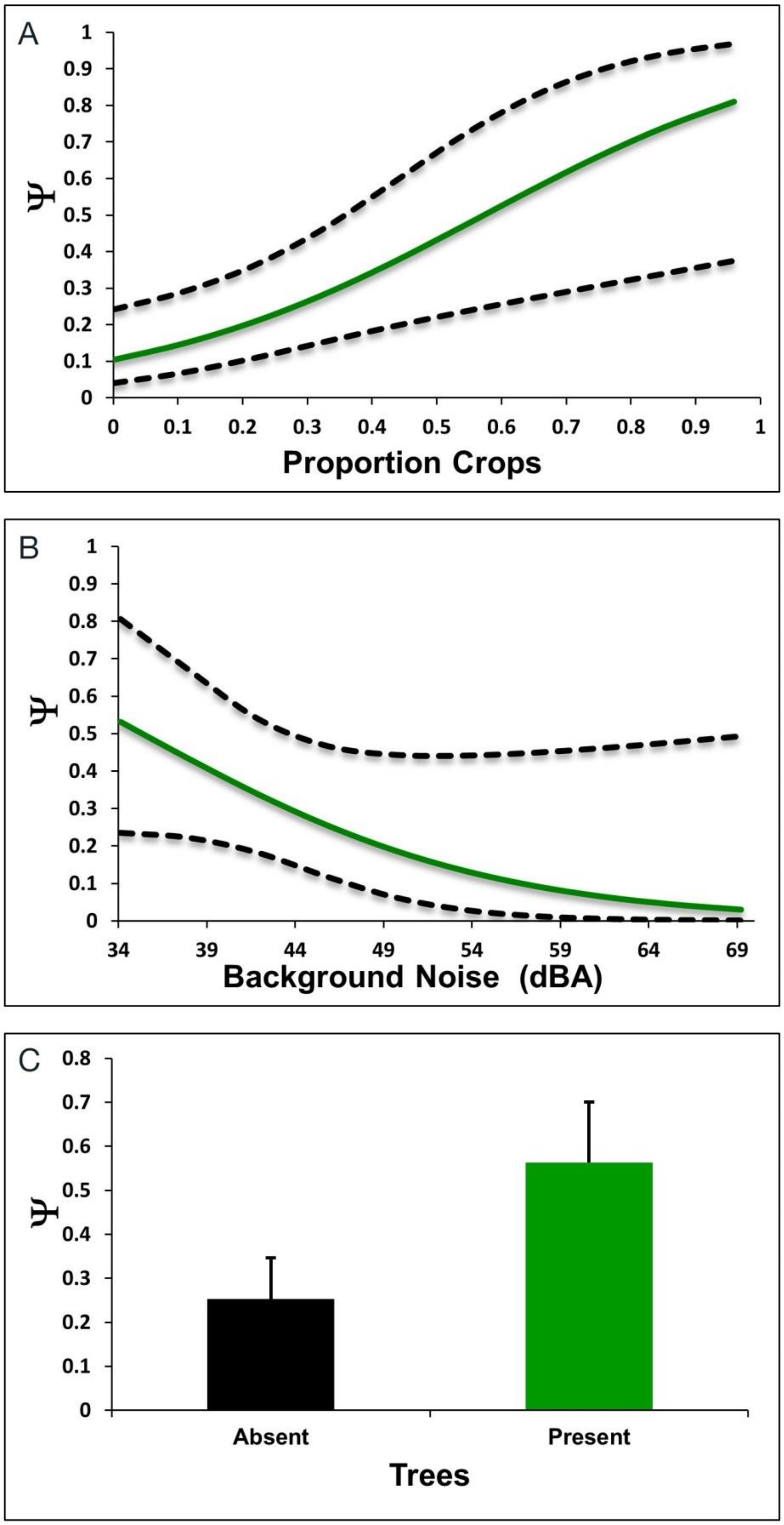

Figure 1.4. **Model predicted relationships (± 95% CI) between Barn Owl occupancy (*Ψ*) and (A) proportion crops, (B) background noise, and (C) presence and absence of trees during the early breeding season.**

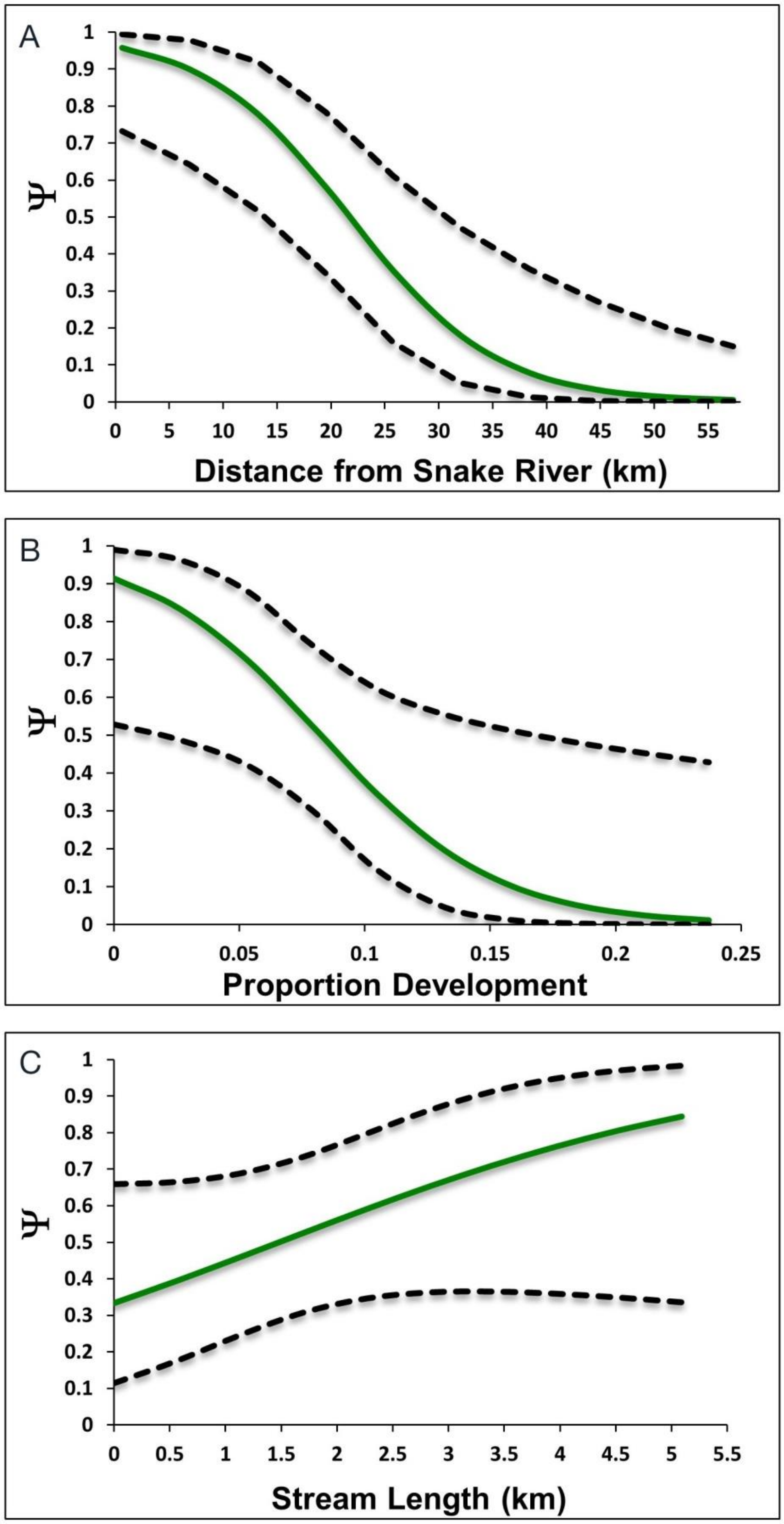

Figure 1.5. **Model predicted relationships (± 95% CI) between Barn Owl occupancy (*Ψ*) during the post-breeding season and (A) distance to the Snake River, (B) proportion development, and (C) stream length.**

Table 1.1. Land cover, anthropogenic, road, and detection variables evaluated in relation to Barn Owl detection and occupancy in southern Idaho.

Covariate	Variable Name in Model	Description	Units
Land cover			
Proportion water	water	Percentage of water within buffer calculated from National Land Cover Database (NLCD2011)	%
Proportion cultivated crops	crops	Percentage of cultivated crops within buffer calculated from National Land Cover Database (NLCD2011)	%
Proportion grassland	grass	Percentage of grassland within buffer calculated from National Land Cover Database (NLCD2011)	%
Proportion hay/pasture	pasture	Percentage of hay/pasture within buffer calculated from National Land Cover Database (NLCD2011)	%
Proportion sage steppe	sage	Percentage of sage steppe within buffer calculated from National Land Cover Database (NLCD2011)	%
Terrain roughness	slope	Standard Deviation of the slope calculated from a Digital Elevation Model (DEM) in GIS	%
Trees	tree	Trees present or absent at a point-count location based on visual assessment	0/1
Distance from Snake river	distSnake	Distance of a point-count location to Snake River, measured in GIS	km
Stream Length	streamlength	Cumulative length of all streams within a buffer	km
Anthropogenic			
Background noise (dBA)	dBA	Level of background noise at point-count location	dB(A)
Distance to nearest dairy	distdairy	Distance of point count location to nearest commercial diary, measured in GIS	km
Other noise	onoise	Type of noise during survey (air traffic, diary infrastructure, agricultural noise, traffic noise)	Noise category

Proportion development	development	Percentage of development (combined low, medium, and high) within buffer calculated from National Land Cover Database (NLCD2011)	%
Fences	fence	Fences present or absent at a point-count location based on visual assessment	0/1
Powerlines	powerline	Above ground Powerlines present or absent at a survey point based on visual assessment	0/1
Road			
Distance from Interstate 84	distI-84	Distance between point-count location and Interstate 84, measured in GIS	km
Distance from Major Roads	distmajorrd	Distance of a point-count location from State Highway, measured in GIS	km
Road length	roadlength	Cumulative length of roads within buffer	km
Detection			
Date	date	Julian date of survey	Julian Date
Cloud cover	cloud	Calculated from visual assessment at each survey point at night	%
Sunset	sunset	Time of sunset using Weather Underground mobile phone app	Time
Percent moon illumination	moonillum	Calculated from "Phases of the Moon" (Universe Today) cellular phone application	%
Broadcast call	call	Whether or not a playback of Barn Owl vocalizations preceded the following listening period	1= call 0= no call
Fog	fog	Calculated from visual assessment at each survey point at night	None/low/ medium/ high
Wind speed (avg)	wind	Measured twice per survey using a Kestrel 4000 handheld weather meter, and calculated by taking the average of all six readings	km/h

Temperature	temp	Measured once per survey using a Kestrel 4000 handheld weather meter, and calculated by taking the average of all three readings	°C
Background noise (dB(A))	dBA	Level of background noise at point-count location	dB(A)
Great Horned Owl	GHOW	Presence or absence of Great Horned Owls at a survey point; detected aurally or visually.	1= P 0=A

Table 1.2. ***A priori*** **models examined in a multi-season occupancy modeling framework and AIC model selection to evaluate covariates associated with colonization by Barn Owls between the early- and post-breeding seasons.**

Model Name	**Model**	**K**[a]	**AIC**[b]	**ΔAIC**[c]	W_i[d]
Terrain	γ (slope), *p*, *Ψ*	14	239.98	0.00	0.37
Fall	γ (distSnake + development + streamlength), *p*, *Ψ*	16	241.41	1.43	0.18
Road	γ (distI-84 + distmajorrd + roadlength), *p*, *Ψ*	16	242.32	2.34	0.12
Dairy	γ (distdairy + dBA), *p*, *Ψ*	15	243.29	3.31	0.07
Noise	γ (dBA), *p*, *Ψ*	14	244.16	4.18	0.05
Null	γ, *p*, *Ψ*	13	244.17	4.19	0.05
Grass	γ (pasture + grass), *p*, *Ψ*	15	244.96	4.98	0.03
Sage	γ (sage), *p*, *Ψ*	14	245.17	5.19	0.03
I-84	γ (distI-84), *p*, *Ψ*	14	245.51	5.53	0.02
Land cover	γ (crops + pasture + grass + sage), *p*, *Ψ*	17	245.74	5.77	0.02
GHOW	γ (GHOW + stream), *p*, *Ψ*	16	245.90	5.93	0.02
Water	γ (distSnake + steamlength), *p*, *Ψ*	15	246.11	6.13	0.02
Development	γ (development + roadlength), *p*, *Ψ*	15	246.40	6.42	0.02
Crops	γ (crops), *p*, *Ψ*	14	247.36	7.38	0.01
Tree	γ (tree), *p*, *Ψ*	14	249.15	9.17	0.00
Perch Site	γ (tree + fence + powerline) *p*, *Ψ*	17	251.02	11.04	0.00

γ**:** Colonization
p**:** Detection (Season, Call, Date, dBA, Percent moon illumination, Cloud)
Ψ**:** Occupancy (Crops, Trees, dBA)
[a]Number of estimated parameters
[b]AIC values of each model
[c]Difference in AIC values from lowest
[d]AIC model weight

Table 1.3. Covariates associated with Barn Owl detection in early-breeding season derived using forward variable selection in an occupancy model framework.

Covariate	Estimate	SE	z	P value
Intercept	-5.67	1.05	-6.06	<0.001
Broadcast call	1.45	0.45	3.18	0.001
Julian date	0.03	0.01	3.42	<0.001
Percent moon illumination	0.01	0.01	2.64	0.008
Percent cloud cover	0.02	0.01	2.13	0.03

Table 1.4. Covariates associated with Barn Owl detection in post-breeding season derived using forward variable selection in occupancy model framework.

Covariate	Estimate	SE	z	P value
Intercept	-27.67	9.72	-2.85	0.004
Broadcast call	2.22	0.55	4.01	<0.001
Julian date	0.10	0.03	3.13	0.002
dBA	-0.09	0.04	-2.16	0.03

Table 1.5. Top occupancy models for the early (Jan-Mar) and post breeding (Sept-Nov) seasons at 1- and 5-km scales (based on a 1 and 5 km radius buffer around each nighttime point count survey).

Early Breeding Season	**Parameter Estimates**	**SE**	**z**	**P value**	**AIC**
Top 1-km Model Parameters					292.86
Intercept	1.79	2.47	0.73	0.47	
Crops	3.76	1.32	2.86	0.004	
Trees	1.34	0.65	2.05	0.04	
Average dBA	-0.10	0.06	-1.62	0.10	
Top 5-km Model Parameters					300.55
Intercept	2.15	2.21	0.97	0.33	
Trees	1.17	0.66	1.79	0.07	
Distance to Snake River	-0.05	0.02	-2.20	0.03	
Average dBA	-0.09	0.05	-1.65	0.10	
Stream length	0.21	0.02	1.36	0.17	
Post Breeding Season	**Parameter Estimates**	**SE**	**z**	**P value**	**AIC**
Top 1-km Model Parameters					169.20
Intercept	4.33	1.77	2.44	0.01	
Distance to Snake River	-0.15	0.04	-3.12	0.002	
Development	-28.62	13.07	-2.19	0.03	
Stream Length	0.47	0.32	1.47	0.14	
Top 5-km Model Parameters					173.11
Intercept	6.97	3.62	1.93	0.05	
Distance from Snake River	-0.12	0.04	-3.19	0.001	
Water	-21.72	14.76	-1.47	0.14	
Average dBA	-0.10	0.08	-1.32	0.189	

Table 1.6. Parameter estimates for top multi-season occupancy models (< 2ΔAIC).

Parameter	Estimate	SE	z	P value	AIC
Terrain Roughness Model					239.98
Intercept	7.71	6.08	1.27	0.21	
Slope	-1.95	1.42	-1.38	0.17	
Fall Model					241.41
Intercept	3.89	2.09	1.86	0.06	
Distance to Snake river	-0.13	0.05	-2.51	0.01	
Development	-28.39	15.33	-1.85	0.06	
Stream length	0.39	0.38	1.01	0.31	

CHAPTER TWO: RELATIONSHIP BEWTEEN BARN OWL OCCUPANCY AND ROADWAY MORTALITY ALONG AN INTERSTATE HIGHWAY IN IDAHO

Abstract

Barn Owls (*Tyto alba*) are killed in greater numbers along roads than any other North American bird of prey, and Interstate-84/86 (I-84/86) in southern Idaho has among the world's highest reported rates of Barn Owl-vehicle collisions. Number of owls killed along this road varies spatially such that there are some segments with low mortality and others with an especially high number of carcasses (hotspots). Because little is known about patterns of Barn Owl occupancy, it is unclear if owls are killed in proportion to their local abundance, or if they are equally abundant near segments with lower mortality and somehow escape collisions there. Thus, my objective was to examine patterns of Barn Owl occupancy using nighttime point counts to compare occupancy with Barn Owl mortality locations observed from 2004 – 2015. I conducted 666 surveys for Barn Owls during the early breeding period of 2014 at 222 locations along a ~250-km stretch of I-84/86. To examine how occupancy changed between seasons, I resurveyed a random sample of 67 of those locations three times each during the post-breeding season. I examined the potential effects of anthropogenic, land cover, and other spatial variables on occupancy of Barn Owls and developed occupancy models for each season. Using these models, I generated predicted occupancy at point-count locations which I then paired with the nearest interstate segment (1- and 5-km lengths) to examine the potential effects of occupancy and season on the likelihood of dead Barn Owls. The likelihood that 1-km

segments near point count locations included a dead Barn Owl increased with occupancy and was greater during the early-breeding season. For 5-km segments, there was an interaction between occupancy and season, with occupancy having a greater positive effect on mortality during the early-breeding season than in the post-breeding season. However, a large proportion (96%) and a moderate proportion (56%) of the variation in road mortality were not explained by owl occupancy at the 1 km scale and 5 km scale respectively. Thus other factors such as geometric features of the roadway, traffic patterns, fluctuations in rodent abundance, and owl behavior near I-84/86, which my study did not address, also potentially influence mortality rates and locations.

Introduction

Roads are important for social and economic aspects of life in the United States as they facilitate movement of people and goods (van der Ree et al. 2015). However, the number of roads as well as the area they cover continues to increase such that approximately 6.2 million km of roads now cover about 1% of the United States, which is an area approximately the size of South Carolina (Forman 2000; Brady 2012). Moreover, 83% of the United States is $\leq$ 1 km to a road (Riitters and Wickham 2003). Traffic volume across the road network increases annually (Brady 2012), and total road area via addition of new lanes to existing roads and new construction is projected to increase 122,000 km^2 by 2030 (Theobald 2010).

Despite some of the benefits of roads for society and commerce, they have a suite of negative effects on wildlife and the environment. Among the negative effects of roads are habitat loss and fragmentation, erosion, surface runoff, anthropogenic light and noise disturbance, direct mortality, and deposition of pollutants into surrounding habitats

(Forman and Alexander 1998; Santos et al. 2011; Brady 2012; Berthinussen and Altringham 2012; Andrews et al. 2015; van der Ree et al. 2015). Linear anthropogenic constructs such as roads can also impede or prevent wildlife movement across the landscape, which is known as a barrier effect where animals are unable to access habitats required for survival and reproduction (Forman and Alexander 1998; Dyer et al. 2002; Santos et al. 2011; Andrews et al. 2015). Of the effects of roads on wildlife, however, the most obvious may be direct mortality through vehicle collisions (Jacobson 2005; Santos et al. 2011).

Approximately 1 million vertebrates are killed on roads each day in the United States (Forman and Alexander 1998; Brady 2012). Roads near wetlands often kill reptiles and amphibians as they migrate *en masse* to or from their breeding ponds (Glista et al. 2008). Collisions with vehicles is also a substantial mortality factor for endangered Florida panthers (*Puma concolor coryi*), and the vast majority of panthers are killed during the winter tourist season when there is a marked increase in the number of motorists on Florida's roads (Taylor et al. 2002; Schwab and Zandbergen 2011). Bats are another mammalian species frequently killed on roadways (Berthinussen and Altringham 2012) likely because they forage at night and cross roads at heights that put them directly in the path of oncoming vehicles (Russell et al. 2008). In addition to reducing population size, road mortality can also result in less obvious effects such as sex- and age-ratio biases and decreasing overall mean individual fitness of a population (Andrews et al. 2015).

For birds, important negative effects of roads appear to be habitat degradation/fragmentation, disturbance and, above all, direct mortality (Jacobson 2005;

Kociolek et al. 2011). For instance, Reijnen et al. (1997) state that 33 of 45 woodland bird species had lower density near roads perhaps because road noise degraded the quality of habitat. Road noise also causes declines in birds at migratory stopover sites, and some species avoid sites with traffic noise completely (McClure et al. 2013). In many studies of direct mortality of animals along roadways, birds are among the most frequent victims (Forman 2003). Indeed, estimates of avian mortality along roads are as high as 146 million per year in the United States alone (Loss et al. 2014).

Birds are susceptible to collisions with vehicles for a variety of reasons. Some species seek out roadways for foraging, whether for carrion or for small mammals as prey in roadside vegetation (Hodson 1962). Paved roads may also attract birds because the low albedo of road surfaces emit heat, water puddles in or beside the road after precipitation, or birds seek the salt and/or grit used for de-icing (Environment Canada 2013). Ground-dwelling birds, scavengers, and low flying birds can be struck and killed as they attempt to cross the road at heights directly in the paths of oncoming vehicles (Hodson 1962; Jacobson 2005). Indecision when crossing the road can result in birds fluttering or turning back which increases time spent within the road corridor and subsequently increases their chance of colliding with a vehicle (Hodson 1962). Presence of perching, roosting and nesting structures in the form of trees, hedgerows, fence posts, and utility infrastructure along roads attracts birds and increases collision likelihood (Orłowski 2008; Environment Canada 2013). High speed limits and higher traffic densities often result in higher avian mortality (Case 1978; Clevenger et al. 2003). Finally, light and noise of passing vehicles may disorient birds near roads leading them to fly directly into the path of oncoming traffic as they attempt to escape (Hodson 1962).

Of particular concern is that negative effects of roads can depress population growth rates of birds such that habitat near roads functions as a sink. This occurs if features of the roadway result in mortality that local reproduction rates cannot overcome, and immigration remains the sole means of maintaining the population (Pulliam et al. 1991). For instance, roads represent sink habitat for Florida Scrub-Jays (*Aphelocoma coerulescens*) because production of yearlings was not sufficient to overcome adult mortality caused by vehicle collisions (Mumme et al. 2000). Roadways can function as ecological traps for birds where “habitat low in quality for reproduction and survival [that] cannot sustain a population yet…is preferred over other available, high-quality habitats” (Donovan and Thompson 2001). Roadways can cause additive mortality where reductions in annual survival of a species is directly tied to increases in roadway mortality rates rather than natural causes of mortality (Sandercock et al. 2011); thus roadway mortality exacerbates a population’s background mortality rate above the threshold sustainable by reproduction. Bujoczek et al. (2011) evaluated the body condition of Yellowhammers (*Emberiza citrinella*), Barn Swallows (*Hirundo rustica*), and Chaffinches (*Fringilla coelebs*) found dead along roads and compared them to those killed by Sparrowhawks (*Accipiter nisus*). Road-killed birds of these species had significantly better nutritional condition than their conspecifics that Sparrowhawks killed, which suggests that roads are not removing the weak or less fit individuals who would otherwise die from natural mortality (Bujoczek et al. 2011). Finally, the sheer volume of roadkill mortality experienced by some species has the potential to cause local extirpation, as observed in Barn Owls (*Tyto alba*) in Spain and Great Britain (Gragera et al. 1992, Newton et al. 1997, Ramsden 2003). Indeed, across all studies of direct mortality along roads, Barn Owls frequently rank as one of the most commonly killed avian species (Loss et al. 2014).

Barn Owls are one of the most widely distributed species of owl (Taylor 2004; Marti et al. 2005). Despite this wide geographic range, Barn Owl populations are in decline in many areas (Colvin 1985; Toms et al. 2001). These declines are attributed to three main factors. First, the loss of grasslands in some areas has reduced small mammal populations and subsequent hunting opportunities for Barn Owls (Colvin 1985; Taylor 2004). Second, conversion of open barns and other old structures into more modern, closed steel buildings, and the cutting of old trees for agricultural field expansion has effectively removed roost and nest sites (Taylor 2004; Ramsden 1998). Finally, roads and traffic volume have increased with a corresponding increase in Barn Owl roadway mortality and decreases in owl persistence (Ramsden 2003; Hindmarch et al. 2012).

Ramsden (2003) noted that Barn Owls in Great Britain have been in decline over the last 100 years and experienced a serious 50% reduction from 1991 – 1996. In central Spain, the Barn Owl population declined 70% in a 10-year period (Fajardo and Pividal 1994). Barn Owl populations in British Columbia, Canada received a Threatened status in 2010, and those in Ontario are considered Endangered, and these are the only two remaining provinces where Barn Owls continue to breed (COSEWIC 2010). In the United States, Barn Owls have declined in numerous Midwestern states (Colvin 1985). Connecticut, Illinois, Indiana, Iowa, Michigan, Missouri, and Ohio have listed Barn Owls as threatened or endangered, and nine other states list Barn Owls as species of special concern.

Barn Owls are killed along roads in many portions of their range and may be especially susceptible to roadway mortality for several reasons. They commonly inhabit open grassland, rangeland, or agricultural areas (Marti et al. 2005) and therefore may be vulnerable to roadways that bisect rural and agricultural areas (Moore and Mangel 1996). Even though Barn Owls possess an acute sense of hearing, their foraging and flight habit make them vulnerable to vehicle collision (Taylor 2004; Moore and Mangel 1996; Grilo et al. 2012). Barn Owls frequently hunt on the wing and while hunting exhibit slow, tortuous flight about 1.5 – 4.5 m above the ground (Bunn et al. 1982). Hunting at this height puts Barn Owls directly in the path of vehicles, especially tall trucks, and because the owls are focused on hunting they may be less aware of oncoming traffic (Ramsden 2003; Jacobson 2005; Russell et al. 2008). On the other hand, Barn Owls may simply be killed as they attempt to cross roads they encounter while moving through the landscape (Shawyer 1998; Ramsden 2003).

Barn Owls may also be attracted to roadsides and highway medians for hunting prey. These areas, which often are covered with grasses and other suitable vegetation, may be important habitat for rodents (Meunier et al. 2000); therefore they represent suitable foraging areas for Barn Owls (Nero and Copland 1981; Shawyer 1998; Ramsden 2003; Condon et al. 2005). However, roadway verges and medians are also risky environments for owl hunting because of the chance of colliding with passing vehicles. In this situation, the vegetated highway verges and median may be acting as an ecological trap for Barn Owls because they perceive it as a quality foraging area but are exposed to potential anthropogenic stressors and direct mortality. For example, American Kestrels (*Falco sparverius*) nesting near major roadways exhibited increased stress hormones and were more likely to abandon their nests (Strasser and Heath 2013). Thus, one cannot simply assume that because a species (e.g., Barn Owls) inhabits a highly disturbed environment it must be tolerant of human disturbance and maintaining healthy population dynamics. Indeed, an estimated > 1,500 Barn Owls per year are killed along a 248-km section of Interstate-84/86 (I-84/86) in southern Idaho, and this is among the world's highest reported rates (Boves and Belthoff 2012). Barn Owls are four times more numerous than the next most commonly killed species, skunks (*Mephitis* spp., Boves and Belthoff 2012). I-84/86 traverses an area that includes extensive agricultural lands as well as grasslands/shrub steppe where there is presumably high habitat suitability for Barn Owls (Boves and Belthoff 2012), but it is possible that this interstate functions as an ecological trap.

One aspect of the Barn Owl road mortality in southern Idaho is that rates vary spatially. For instance, there are interstate sections where Barn Owls are killed in extraordinary numbers and others where only a few owls per year die (Boves and Belthoff 2012; Belthoff et al. 2015). Thus, it is possible that differences in occupancy of Barn Owls at sites near the roadway underlie differences in mortality. My objective was to examine this potential aspect of Barn Owl roadway mortality along I-84/86. I hoped to determine if owls were simply killed in proportion to their occupancy, or if occupancy of owls was equivalently high in regions where they suffered lower mortality indicating the interstate may function as a barrier to owl movement (Figure 2.1). On the other hand, occupancy near the interstate could be low but adjacent interstate segments still have high mortality rates which might indicate owls are being attracted to certain areas of I-84/86 such that the interstate is functioning as an ecological trap (Figure 2.1). To understand the relationship between mortality and occupancy, I conducted nighttime point counts of Barn Owls and used an occupancy modeling framework to estimate the predicted occupancy of Barn Owls along I-84/86. I then examined Barn Owl mortality in relation to predicted occupancy at two spatial scales that are biologically relevant to Barn Owls and during two seasons of the year (early- and post-breeding).

Study Area and Methods

Study Area

I examined occupancy and roadway mortality of Barn Owls in southern Idaho within the Snake River Plain ecoregion (McMahon et al. 2001). My study area was situated between Boise (Ada County, 43°37'N, 116°12'W) and just east of the confluence of I-84 and I-86 (Cassia County, 42°35'N, 113°21'W) near Burley (Figure 2.2).

Interstate-84/86 included two lanes per eastbound and westbound route for the majority of its length and typically a vegetated median (13 – 100m wide) separated eastbound and westbound lanes. Vegetated roadside verges ranged from 7 – 82 m in width. Speed limit along I-84/86 was 121 km/h for cars and 105 km/h for commercial trucks until July 2014, at which time the speed limit increased to 129 km/h for cars and 113 km/h for commercial trucks.

The region traversed by the interstate is mainly rural with predominant land cover types of shrub steppe/disturbed grasslands and irrigated agriculture, in addition to a few small municipalities. Shrub-steppe lands were often a mix of native plants such as big sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), green rabbitbrush (*Chrysothamnus viscidiflorus*), native bunch grasses, and exotic invasive species such as cheat grass (*Bromus tectorum*), tumble mustard (*Sisymbrium altissimum*), and Russian thistle (*Salsola kali*). The main agricultural crops during my study were sugar beets (*Beta vulgaris* cultivars), potatoes (*Solanum* spp.), corn (*Zea mays*), wheat (*Triticum* spp.), barley (*Hordeum* spp.), alfalfa (*Medicago sativa*), and soy beans (*Glycine max*). Agricultural lands also contained irrigation ditches, isolated groves of trees and human structures (barns, grain silos, etc.). Approximately 322 dairy farms were also scattered throughout the study area, where dairies were defined as "any land, place or premises where milking cows, sheep, or goats are kept, and from which all or a portion of the milk produced is offered for human consumption" (Idaho Office of the Administrative Rules Coordinator 2014). Dairy farms are relevant as they provide habitat for rodents, and generally the cows rely on local agricultural fields for food.

The Snake River Plain ecoregion has a semiarid climate (Maupin 1995). In the winter (December – February), monthly mean temperature ranges from -11.9 – 10 °C (Western Regional Climate Center 2015). Monthly mean temperatures in summer average around 21 °C, but daily maximum temperature can be as high as 40 °C (Western Regional Climate Center 2015). During the autumn (October – November), mean monthly temperature ranges from 4.1 – 21 °C (Western Regional Climate Center 2015). Precipitation of 25 – 27 cm falls on the Snake River Basin annually, with most occurring in winter and spring as snow (8.8 cm) and rain (8.9 cm), respectively (Maret 1997, Western Regional Climate Center 2015). Elevation across the entire study area ranges from 820 m above sea level near Boise to 1330 m just east of Burley.

Collection of Mortality Data

Using vehicle-based standardized roadkill surveys as in Boves and Belthoff (2012), roadkill data for Barn Owls were collected twice per month from October 2013 through September 2014 along a 365-km stretch of I-84/86 from Boise to Pocatello (Belthoff et al. 2015; Arnold 2016), during which time researchers surveyed both the east- and west-bound traffic lanes for Barn Owl carcasses. Roadkill data were also collected from several ad hoc surveys in March and April 2014, February 2015, and May 2015. Methods were similar for standardized and ad hoc surveys, but standardized surveys occurred every two weeks while the ad hoc surveys were periodic. Carcass data from 2013 – 2015 were pooled with previously collected data (Boves and Belthoff 2012; and unpubl.) such that the Barn Owl roadkill data I analyzed resulted from 73 road surveys of I-84/86 between 2004 – 2015 and provided locations of 1,335 dead Barn Owls (Table 2.1). I ultimately included only ~85% of those roadkill observations that corresponded to the early- and post-breeding season time periods for which I developed occupancy models for Barn Owls (see below).

Point Count Locations

Using Arc GIS (ESRI 2013, ArcMap 10.1), I generated 222 random point locations within a 10,200 km^2 swath of southern Idaho (Figure 1.3) focused around I-84/86. These points were then relocated to their nearest public road so that I conducted all surveys from public roads; however none were surveyed directly from I-84 itself. Distance between points was restricted to > 1 km, which reduced the chance of double counting an individual owl in one night. Thus, I considered point-count locations to be independent of one another.

Point Count Protocol

To determine patterns of Barn Owl occupancy, I conducted nighttime point count surveys. An assumption of occupancy modeling is that sites are closed to changes in occupancy for the entire survey period. Conducting repeat surveys in quick succession is one way to meet this assumption (MacKenzie and Royle 2005). Thus, I spent 16 min at each point count location conducting three successive surveys. At each location, I used a sequence of silent listening for aural detection of Barn Owls, spotlighting for visual detection of owls, and call broadcast to elicit vocalizations from Barn Owls. Survey 1 began with 5 min of silent listening and spotlighting. This was followed by Survey 2 and Survey 3 in succession which each included 30 sec of broadcast calling followed by another 5 min of silent listening and spotlighting (Figure 2.4).

For broadcast of Barn Owl vocalizations during point counts, I used a FoxPro (FX3) game caller with pre-recorded Barn Owl vocalizations (Stokes and Stokes 2010) broadcasted at 16 screeches/min at 105 dB measured 1 m from the speaker (Mosher and Fuller 1996; Kissling et al. 2010). During each 30-sec broadcast, I directed the speaker in the four cardinal directions for approximately 7.5 sec each.

Unlike other owl species that frequently respond vocally to broadcast of calls from conspecifics, Barn Owls may not consistently respond to playback (Shawyer 2011). Thus, I combined broadcasts of Barn Owl vocalizations with spotlighting (Condon et al. 2005) to increase the chances of detecting Barn Owls that flew by silently without vocalizing. During point counts two observers used high power spotlights (Streamlight Waypoint, 300 lumens) to scan for Barn Owls. I recorded Barn Owls observed within

~250 m of the point-count location (visual detection) and when heard (aural detection) irrespective of distance.

Barn Owls are primarily nocturnal and can be active during all hours of the night (Marti et al. 2005). Thus, I conducted point counts between 0.5 h after sunset and 0.5 h before sunrise. I avoided surveying in heavy rain, dense fog, or when winds exceeded a score of 6 on the Beaufort scale (~ 40-50 km/h), because these conditions could reduce both owl activity and my ability to detect owls (Takats et al. 2001; Condon et al. 2005). When possible, I also avoided surveying within busy residential or developed areas because of the noise associated with these areas and to avoid disturbing people in nearby residences.

Number and Timing of Point Counts

I conducted point counts at 222 locations from January – March 2014, which corresponded with the early-breeding season period for Barn Owls. During these months, Barn Owls typically engage in establishing pair bonds, defending nesting territories, and egg-laying and incubation; for instance, mean date of clutch initiation in nearby Utah is 13 March ± 5.9 (SD) days (Marti 1994). I randomly selected and revisited 67 of the 222 point-count locations to survey for Barn Owls during the post-breeding season (October – November 2014) to examine changes in occupancy and patterns of colonization. During this time most juvenile owls have likely fledged and are initiating their natal dispersal (Marti et al. 2005).

Detection and Occupancy Covariates

For each point-count location, I recorded Julian date, time of sunset, and start and stop time of the 16 min spent at each location. Fog was ranked visually into none, low (no effect on visibility), medium (visibility several hundred meters), and high (visibility ≤50 m). I measured wind speed (km/h) and temperature (°C) using a handheld weather meter (Kestrel 4000; Nielsen-Kellerman Co., Birmingham, MI). I measured wind speed once per survey (3 times per point-count location) and averaged these for the 16 min period. Temperature was measured in the middle of the second survey. I used the mobile phone app "Phases of the Moon" (Allaverdiev and Cain 2014) to estimate the percent of moon illumination for a survey night. I divided the sky into four quadrants, visually estimated the percent cloud cover in each quadrant, where 25% was maximum cloud cover per quadrant, and then summed the quadrants to derive percent cloud cover. I measured background noise intensity in dB(A) twice per survey (6 times per point-count location) in the range 31.5 – 8000 Hz using a digital sound level meter (EXTECH, # G3991644) accurate to ±1.5 dB and then averaged noise at each location. Noise type was categorized as road traffic, stream, wind, airplane, train, or other when possible. I recorded time of detection, type of detection (aural, visual, or both), number and species (Barn Owl, Great Horned Owl (*Bubo virginianus*), Northern Saw-whet Owl (*Aegolius acadicus*), Western Screech-Owl (*Megascops kennicottii*) of owl detected, and number and type of vocal responses (Condon et al. 2005). Presence of above-ground powerlines, fence posts, and trees were also recorded as these represent potential perching, roosting and/or nesting sites for Barn Owls.

Using spatial analyses in Arc GIS (ESRI 2013, ArcMap 10.1), I quantified proportion land cover type, cumulative stream length, cumulative road length and terrain roughness within 1-km radius buffers centered on each point-count location. Barn Owl foraging movements are often within 1 km of nesting or roosting sites (Ramsden 2003;

Marti et al. 2005). I calculated distance from the point-count location to the nearest dairy, the Snake River, Interstate-84/86, and other major roads. I determined proportion of land cover types for cultivated crops, development, grassland/herbaceous, hay/pasture, sage steppe, and water using the 2011 National Land Cover Database (Homer et al. 2015).

Data Analysis – Occupancy Modeling

Prior to formulating either detection or occupancy models, I examined all variables for multicollinearity, redundancy, and lack of variation using JMP Pro 12 (SAS Institute, Inc., Cary, NC). I removed from analysis variables that caused convergence issues once modeling commenced. I used the Unmarked package (Fiske and Chandler 2011) in R (version 64.3.01, R Core Team 2015) for occupancy modeling using forward-stepwise variable selection (Schuster and Arcese 2013) while retaining covariates that lowered Akaike's Information Criterion (AIC, Akaike 1974). I created separate single season occupancy models (MacKenzie et al. 2006) for the early- and post-breeding seasons and considered models with the lowest AIC value as the best models.

Model Performance

I evaluated the performance of the early- and post-breeding season occupancy models by calculating the area under the receiver operator characteristic curve (AUC) using the ROCR package in R. Models with AUC values between 0.5 and 0.7 have a poor ability to distinguish between an occupied and unoccupied site, models with values > 0.7 are thought to be useful, those > 0.8 are considered good, and models with AUC > 0.9 are deemed excellent in their ability to discriminate between an occupied and unoccupied site (Pearce and Ferrier 2000). As I used the same data to fit occupancy models and calculate AUC, AUC values are best viewed as measures of model fit rather than true measures of predictive ability. The metric $R^2(U)$ was used to assess the amount of variation in each model.

Seasonal Comparison of Mortality to Predicted Occupancy

For analysis of the relationship between occupancy of Barn Owls and roadway mortality, I restricted analysis to only those point-count locations I surveyed that were ≤ 5 km from I-84/86. This amounted to 89 locations surveyed in the early-breeding season, of which I re-surveyed 30 in the post-breeding season. The 89 point-count locations were 2.4 ± 1.4 (SD) km (range: 0.1 – 5.0 km) from I-84/86.

Using the early- and post-breeding season occupancy models, I generated predicted occupancy values at each point-count location. I then divided Interstate 84/86 into 1- and 5-km segments, paired point-count locations with their nearest 1- and 5-km segment (Figure 2.5), and determined whether each segment had at least one dead Barn Owl (mortality = 1) or no dead Barn Owls (mortality = 0) based on the cumulative road survey data.

Using a logistic regression in JMP Pro 12, I then examined the potential effects of season (early- and post-breeding), predicted occupancy (ranging from 0 – 1), and their interaction on owl mortality in the 1- and 5-km interstate segments separately. Interactions terms were retained or removed for each analysis depending on which lowered AICc. Means and their SE are presented throughout unless noted otherwise.

Results

Occupancy Estimates

Occupancy during the early-breeding season increased with proportion cultivated crops and tree presence, and decreased with background noise (Table 2.2). During the post-breeding season, occupancy increased with cumulative stream length and decreased with distance from the Snake River, and proportion development (Table 2.2).

Predicted occupancy was 0.35 ± 0.04 (range: 0.01 – 1.0, n = 89) during the early-breeding season, while occupancy estimates were higher for the post-breeding season (0.80 ± 0.05, range: 0.13 – 1.0, n = 30).

Analysis of Mortality in 1-km Interstate Segments

During the early-breeding season 39.3 % of 1-km segments had at least one dead Barn Owl. During the post-breeding season 20 % of 1-km segments had at least one dead owl in them.

When I examined the potential effects of occupancy and season on Barn Owl mortality in the 1-km segments, the model with the lowest AIC had no interaction term. There was a positive relationship between occupancy and Barn Owl mortality such that odds of a dead Barn Owl in 1-km segments more than doubled as predicted occupancy changed from 0 to 1.0. There was also an effect of season in that the odds of a dead Barn Owl in a 1-km segment during the post-breeding season were just 0.27 times the odds of those in the early-breeding season (Table 2.4, Figure 2.6).

Analysis of Mortality in 5-km Interstate Segments

During the early-breeding season most 5-km segments (95.5 %) had at least one dead owl (Table 2.3). There were only two 5-km segments without dead owls and corresponding survey points had low predicted occupancy estimates (0.01 – 0.16, Figure 2.7). Additionally, there was a subset of 28 point-count locations with low occupancy estimates ranging from 0 – 0.2, that had high (~1.0) probability of mortality in corresponding interstate segments. During the post-breeding season 43.3 % of 5-km segments contained at least one dead Barn Owl (Table 2.3).

When I examined the potential effects of occupancy and season on Barn Owl mortality in the 5-km segments, the model with the lowest AIC included the interaction term. The interaction indicated that occupancy had a much stronger effect on the likelihood that segments included a dead Barn Owl during the early-breeding season (Table 2.4, Figure 2.6). For instance, as occupancy increased from 0 to 1 during the post-breeding season, likelihood of a dead Barn Owl in a 5-km segment increased from ~31 % to ~48 % (Figure 2.6). In contrast, for the early-breeding season, when occupancy increased to ≥ 0.25, probability of a dead Barn Owl was 100% (Figure 2.6).

Model Performance at Different Scales (1- and 5-km)

When I assessed model performance the 1-km model demonstrated poor fit for the data (AUC = 0.62) and a large proportion of variation in probability of mortality was unexplained [$R^2(U) = 0.04$]. However, model fit was excellent for the 5-km model (AUC = 0.92) and a more substantial proportion of variation was explained by the model [$R^2(U) = 0.44$].

Discussion

The overarching goal of my study was to examine the relationship between occupancy of Barn Owls and the mortality they suffer along Interstate-84/86 in southern Idaho. After developing occupancy estimates from nighttime surveys of Barn Owls, I found a positive relationship between model-predicted occupancy for Barn Owls near Interstate I-84/86 and road mortality – as occupancy increased, the odds of at least one dead Barn Owl in nearby interstate segments increased and did so at both 1- and 5-km scales. There were also seasonal effects such that the odds that at least one dead Barn Owl occurred in a highway segment were greater during the early-breeding season. This was in contrast to higher occupancy estimates for Barn Owls during the post-breeding season. Finally, the 5-km model fit the data better than the 1-km model based on AUC score.

Occupancy

I found differences in occupancy estimates between the early- and post-breeding seasons which likely corresponded to different stages of Barn Owl life history. Occupancy estimates were ~ 2.3 times greater, on average, during the post-breeding season than the early-breeding season. Barn Owls are one of the most productive birds of prey with relatively large clutches and the ability to raise multiple broods per year (Bunn et al. 1982; Taylor 2004; Marti et al. 2005). These high numbers of juveniles fledging into the population during the post-breeding season may drive the greater occupancy estimates I observed. However, roughly 65 – 75% of juveniles do not survive their first year (Marti et al. 2005) and succumb to road mortality, drowning, starvation, predation, , and freezing weather (Ramsden 2003). Indeed, Ramsden (2003) reported that road mortality was the most common cause of death for Barn Owls in their first year of life. Thus, the influx of juveniles that resulted in higher occupancy estimates I observed in the post-breeding season may have been quickly followed by high juvenile mortality rates that caused lower occupancy estimates I observed in the early-breeding season.

Occupancy and Mortality

During the post-breeding season I found high occupancy estimates corresponding to lower mortality rates than the early-breeding season. It is possible this pattern relates to continued availability of hunting areas away from roads during this time. I defined the post-breeding season as September – November, and during September agricultural areas are still covered in crops such that the harvest is not complete (pers observ.). I speculate that small mammals are thus sufficiently available in areas away from the roadway during this time period. In their study of Barn Owl road mortality, Boves and Belthoff (2012) found low mortality in September and then mortality increased in October – November, leading up to peaks in mortality observed during December and January. During December and January, most fields are left as bare soil after plowing (pers observ.) and small mammal populations may be particularly dense in the vegetated strips that remain along roads (Meunier et al. 2000; Bolger et al. 2001) thus attracting owls to hunt and be killed in these areas during winter (see also Gomes et al. 2009; Grilo et al. 2012).

I found higher mortality in the early-breeding season, even though occupancy estimates during this time were lower. This result may be a function of nest site selection, prey distributions, and traffic patterns. For instance, nest site selection may cause increased road mortality risk because Barn Owls establish territories in agricultural lands adjacent to roads. Owl occupancy during the early-breeding season was higher in areas with increased proportions of cultivated crops (Chapter 1). Nest sites for Barn Owls are often limiting (Colvin 1985; Taylor 2004), and the trees, barns, and haystacks associated with farms and cultivated crops provide suitable nesting locations (Marti et al. 2005). Agricultural lands border approximately one-half of the length of Interstate-84/86 in my study area. Thus, as owls may have established territories in what they perceived as suitable habitat, they consequently could have been drawn closer to the interstate and experienced increased roadway mortality risk (Boves and Belthoff 2012). Indeed, both Arnold (2016) and Boves and Belthoff (2012) found higher road mortality in agricultural areas along I-84/86. Grilo et al. (2012) also found that Barn Owls are more likely to cross roads when croplands extend to the focal highway.

In addition to nesting habitat distribution, shifts in prey numbers and distribution may have influenced Barn Owl mortality in the early-breeding season. Prey availability can limit owls during the early-breeding season when they prepare for energetically expensive reproduction (Taylor 2004). Removal of standing vegetation during the non-growing season reduces vole populations (Jacob 2003a), and voles are one of the main prey of Barn Owls (Marti 2010). As a result, Barn Owls may expand their typical hunting ranges to compensate, which simultaneously increases their chances of encountering a major road and therefore their risk of road mortality (Taylor 2004; Ramsden 2003).

With fields left with bare soil after plowing, small mammals likely congregate in the narrow strips of unplowed roadside vegetation that remain (Meunier et al. 2000; Bolger et al. 2001). Small mammals commonly live and breed in the medians and verges along roadways, with some species occurring in higher densities there than in other habitat fragments (Bolger et al. 2001). Thus, vegetated medians and verges of I-84/86 could represent desirable foraging areas for Barn Owls during the early-breeding season (Nero and Copland 1981; de Bruijn 1994; Shawyer 1998; Ramsden 2003; Condon et al. 2005; Arnold 2016). Indeed, Arnold (2016) showed that a small mammal abundance index was high in most portions of I-84/86. Barn Owls appear to be attracted to small mammal concentrations along highway medians and verges and this may be among the main reasons why Barn Owls are the most commonly killed raptor species along roadways (Bourquin 1983; de Bruijn 1994; Moore and Mangel 1996; Massemin and Zorn 1998; Shawyer 1998; Ramsden 2003; Baudvin 2004; Gomes et al. 2009; Grilo et al. 2012; Grilo et al. 2014). Barn Owls may move across longer distances to hunt these prey-rich areas (Grilo et al. 2014) such that even when owl occupancy near I-84/86 is low, high mortality rates are maintained. If this is the case, then I-84/86 may function as an ecological trap (Donovan and Thompson 2001; Ramsden 2003; Grilo et al. 2012) which could potentially lead to depletion of Barn Owl populations in areas < 5-km of the interstate. Grilo et al. (2014) found a medium – high mortality risk for Barn Owls nesting in proximity to roads even when they occurred at *low levels* across the landscape. They suggested Barn Owls may tolerate road- and traffic-related disturbance because roadway medians and verges provide hunting opportunities not otherwise available in surrounding landscapes during the early-breeding season (Grilo et al. 2014).

Finally, these effects of prey and nest site selection on early-breeding season mortality may be exacerbated by peaks in rush-hour traffic that coincide with onset of owl activity during the early-breeding period. During this time, darkness falls early, so that peak traffic (1630 – 1730 h) occurs just as Barn Owls commence hunting (Massemin et al. 1998; Marti et al. 2005) increasing their chances being struck and killed by traffic. In contrast, the onset of darkness (1800 – 1930 h) occurs after peaks in rush hour traffic during the post-breeding period.

Scale Effects in Early-Breeding Season

When I examined whether scale mattered for assessing the effects of occupancy and season on mortality, I found that a 5-km scale fit the effects of occupancy and season on mortality best. The 5-km model indicated mortality was high even at low occupancy estimates during the early-breeding season. Barn Owl mortality occurred in all 5-km segments but two. These two segments were in the same region and never registered any dead Barn Owls across *three* years of systematic road-kill surveys in addition to four ad hoc surveys. This 10-km stretch began approximately 3.5 km southeast of Boise, Idaho, and adjacent lands were sage steppe and disturbed grassland. Interestingly, occupancy estimates at point-count locations near this portion of highway were low, which I believe is a function of poor habitat quality for Barn Owls, primarily because it lacked trees, human structures, and permanent streams (Figure 2.7). As a result, there was no mortality along the corresponding highway segments. In contrast, although I believe less likely in this case, a zone with no mortality such as this could indicate population depletion in surrounding habitat where previous, unrecorded, high mortality among those interstate segments depressed the local Barn Owl population (Ramsden 2003).

Other Factors Contributing to Mortality

A substantial proportion of variation in roadway mortality was not well explained by occupancy and season. Other factors such as roadway features and traffic patterns may also influence mortality rates and locations of Barn Owls along I-84/86 in ways beyond those suggested above.

Features of the interstate itself, such as elevation of the road surface (i.e. below or above the surrounding landscape) and characteristics of the verge may have influenced mortality. Mortality rates of Barn Owls are particularly high on roadways that are level with or elevated compared to the surrounding landscape (Baudvin 1997; Massemin and Zorn 1998; Ramsden 2003; Grilo et al. 2012), potentially because of the propensity of Barn Owls to fly < 4 m while hunting on the wing (Shawyer 1998; Massemin and Zorn

1998; Ramsden 2003; Gomes et al. 2009; Grilo et al. 2014). Barn Owls are more likely to cross the roadway at above-grade sections, and also in sections with wide road verges containing higher proportion of herbaceous cover (Grilo et al. 2012).

Increased traffic intensity and speed, vehicle size, and number of traffic lanes may also affect mortality rates. Barn Owls are more likely to be killed when traffic intensity is higher (Massemin and Zorn 1998; Ramsden 2003; Baudvin 2004), and one study in Portugal indicated owls selected areas to cross when there were low traffic volumes (Grilo et al. 2012) and in locations with low volume of lighter (smaller) vehicles. Additionally, Hindmarch et al. (2012) found Barn Owls were less likely to persist when they were exposed to increases in traffic and road lengths near nest sites. Ramsden (2003) found larger vehicles more likely to kill Barn Owls, and Arnold (2016) found commercial vehicle traffic to be a better predictor of owl mortality than smaller passenger vehicle traffic.

Conclusions

My research showed that when predicted occupancy of Barn Owls was high there was a corresponding increase in the likelihood of Barn Owl mortality along I-84/86. I examined sites < 5 km from I-84/86, and my results are congruent with prior research suggesting that Barn Owls within 5-km of a major roadway are in danger of mortality (Ramsden 2003). Ramsden (2003) suggested that virtually all Barn Owls nesting within 1 km of a major road are highly likely to be killed. Moreover he indicated that during non-breeding period any owls < 3 km have high chances of being killed, and only those that occupy habitat > 5 km from a major roadway are relatively safe (Ramsden 2003). Thus, Barn Owls should be encouraged to nest a minimum of 5-km away from I-84/86 to reduce risk of vehicle collisions (Ramsden 2003) especially for owls to survive the early-breeding season when mortality rates are the highest. In addition to encouraging owls to nest out of the "death zone", mitigation should be directed both in areas of highest mortality and areas with highest occupancy estimates to reduce mortality along I-84/86. Mitigation efforts should focus especially on reducing mortality during the early-breeding season (Jan – Mar) when occupancy has the largest effect.

<u>Future Directions</u>

My evaluation of occupancy and road mortality along I-84/86 indicated that increased mortality occurred in areas with greater occupancy. However, some point-count locations had low occupancy estimates but were paired with interstate segments containing high mortality. This could indicate specific sections of I-84/86 that function as ecological traps for which further investigation is needed to understand the factors that drive high mortality in these regions.

The occupancy models fit the nighttime point-count location data well however, because of the lack of test data, I was not able to model-validate. Once the ability of the models to *predict* occupancy is determined, then they may become useful for spatially projecting Barn Owl occupancy in areas of planned road development. Thus, any new road alignments could be situated in areas with the lowest Barn Owl occupancy estimates. Additionally, occupancy could be projected along existing roads and then areas with the highest occupancy estimates targeted for mitigation to reduce Barn Owl-vehicles collisions.

Although it is now clear that occupancy has a positive effect on mortality likelihood, this does not answer questions regarding long-term, population level impacts of prolonged high road mortality rates. Using demographic data from other studies of Barn Owls, Boves and Belthoff (2012) extrapolated the effects of current mortality rates on the Barn Owl population in southern Idaho and concluded that this population is at risk of decline. However, in southern Idaho, the actual population size of Barn Owls is not known and nor are the realized impacts mortality may be having on the population. Future work should measure demographics, behavior, movements and dispersal of Barn Owls to develop better understanding of the ability of the population to persist under mortality pressure from roads that continues unabated.

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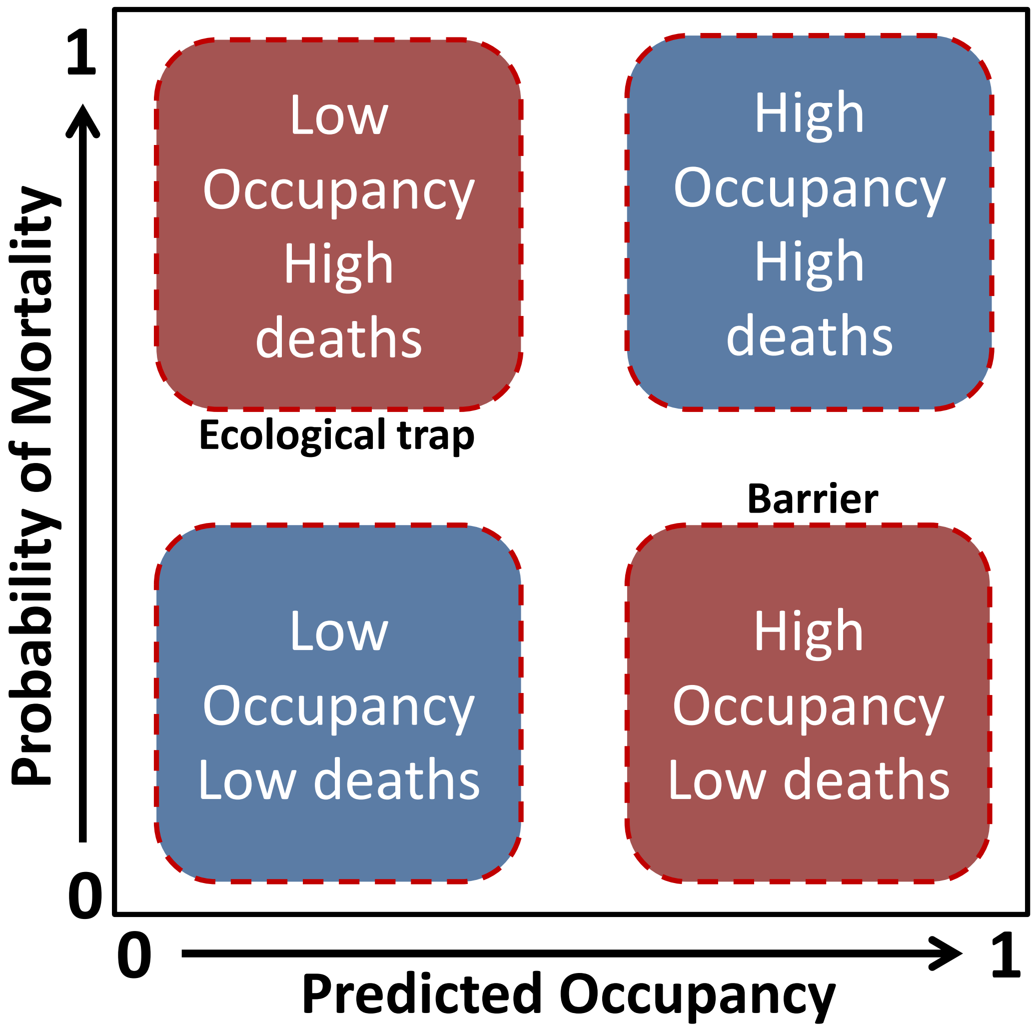

Figure 2.1. Potential relationships between Barn Owl occupancy and mortality along Interstate-84/86 in southern Idaho. Mortality may be in proportion to occupancy (blue cells). Or, occupancy could be low, but interstate segments have high mortality (upper left) such that the interstate functions as an ecological trap, where owls may move long distances to the interstate and end up killed. Finally, the interstate may function as a barrier to owl movement, such that there is high occupancy near the interstate but low mortality in nearby interstate segments.

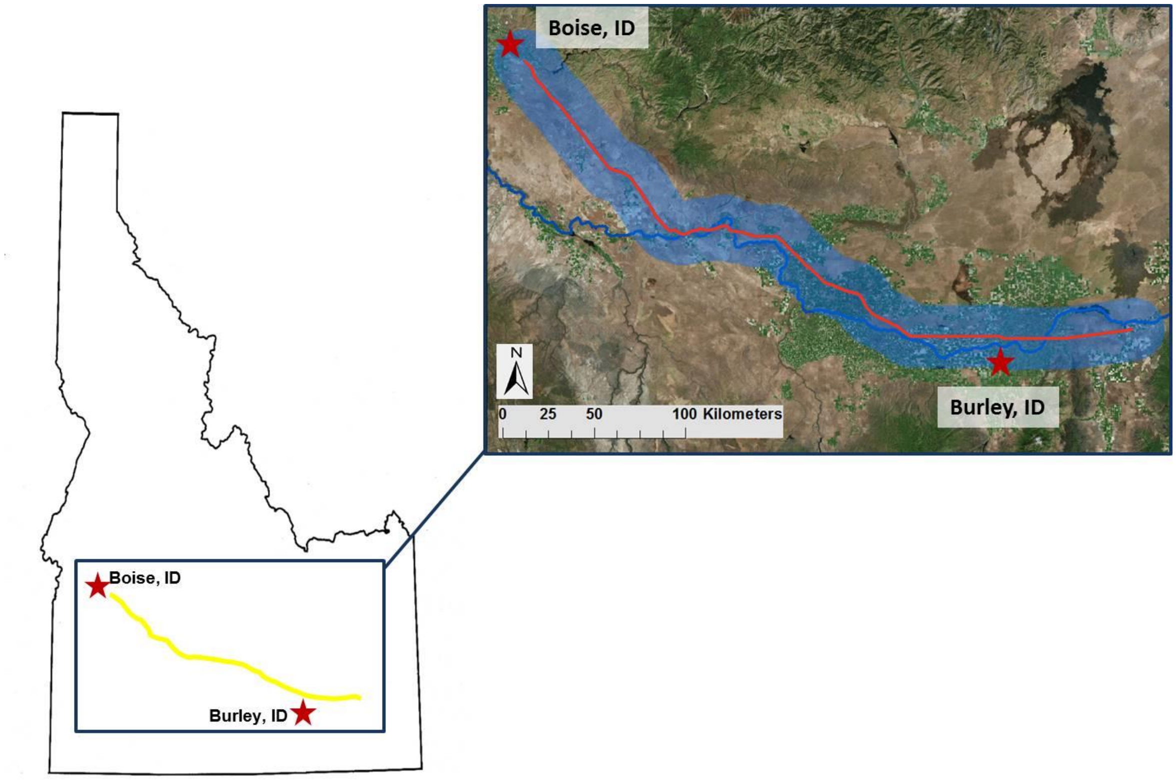

Figure 2.2. Maps illustrating the mortality survey route along I-84/86 in southern Idaho (yellow line), and my 10,200 km^2 study area (blue) where I conducted nighttime point counts for Barn Owls during the early- and post-breeding seasons (2014).

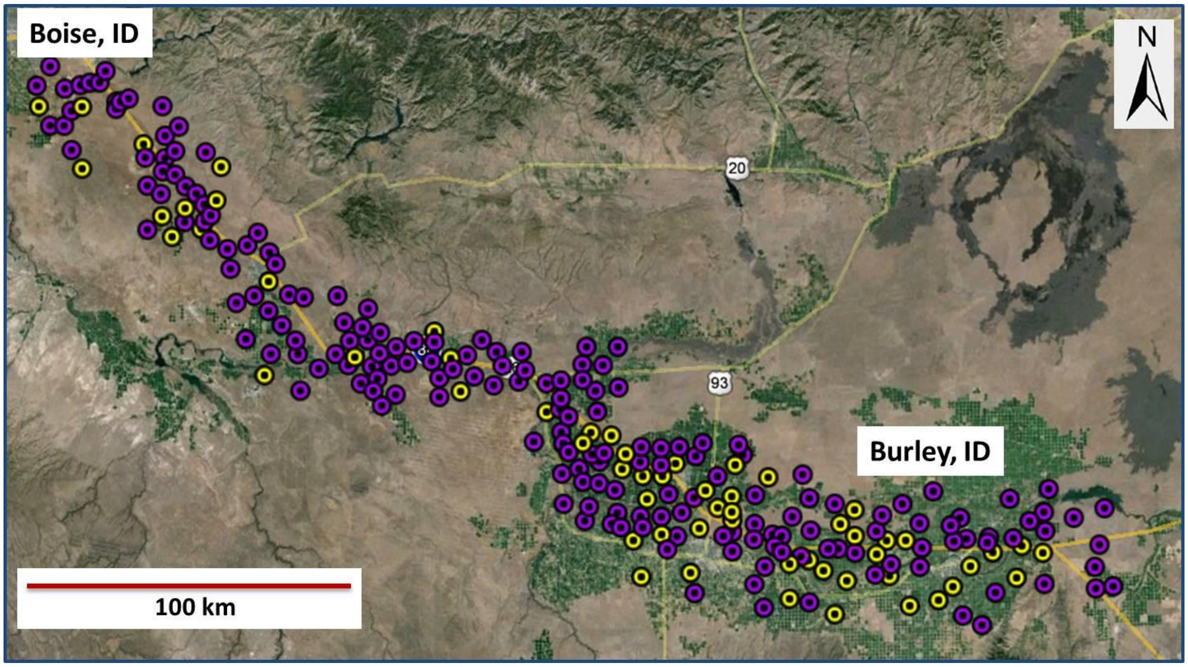

Figure 2.3. **Point-count locations (n = 222) surveyed for Barn Owls in early- and post-breeding seasons in s. Idaho during 2014. Yellow points show locations of Barn Owl detections.**

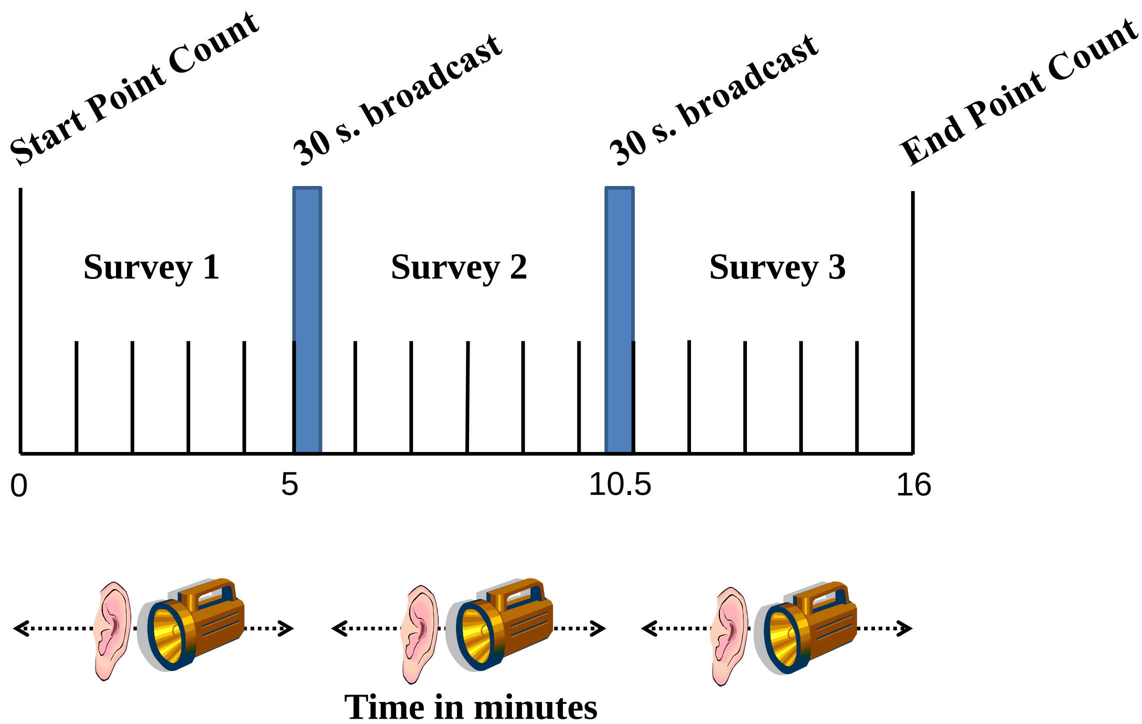

Figure 2.4. **Protocol for point counts for Barn Owls in s. Idaho. Point counts consisted of 3 repeat surveys conducted over 16 min that included a combination of spotlighting, broadcast calls, and silent listening as illustrated.**

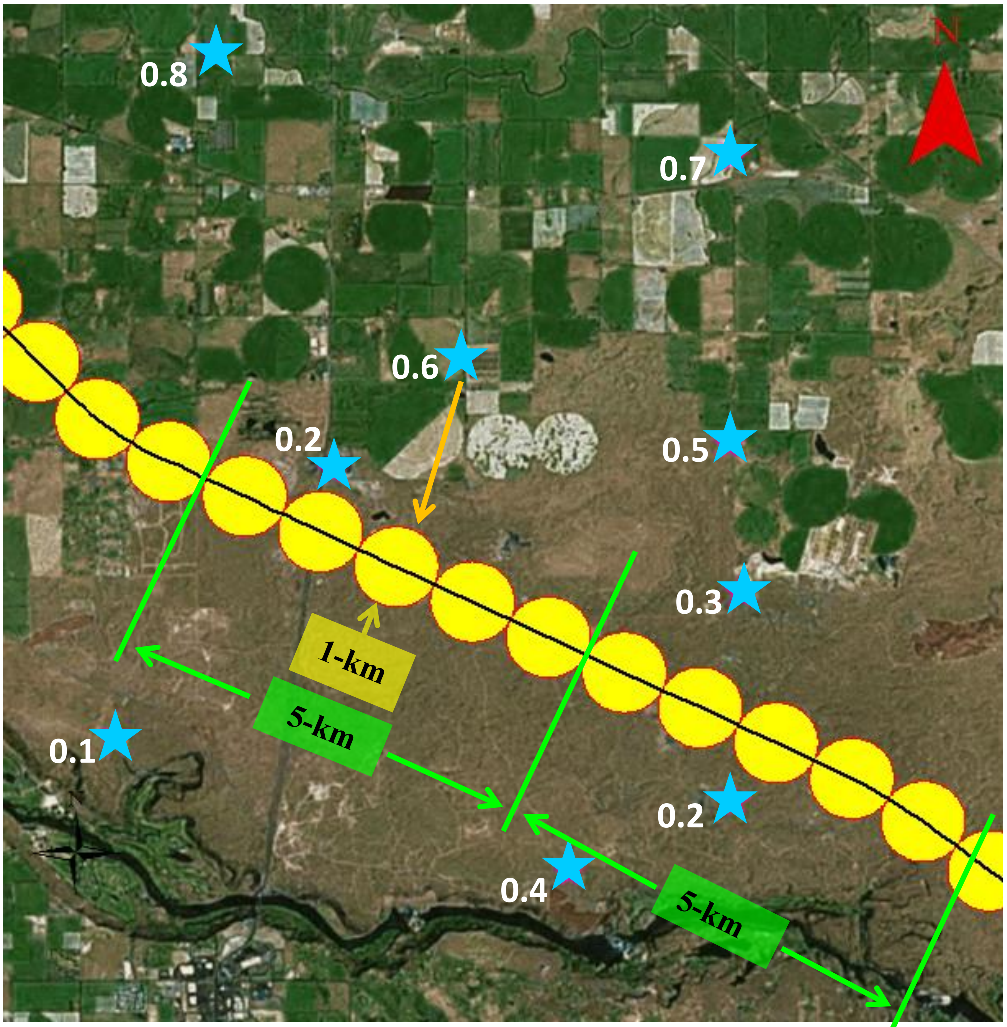

Figure 2.5. Diagram showing the pairing of point-count locations (blue stars) with their respective 1- (yellow arrows) and 5-km (green arrows) interstate segments. Predicted occupancy probabilities for each point-count location are in white. Yellow circles represent 1-km interstate segments, and green lines show 5-km segments.

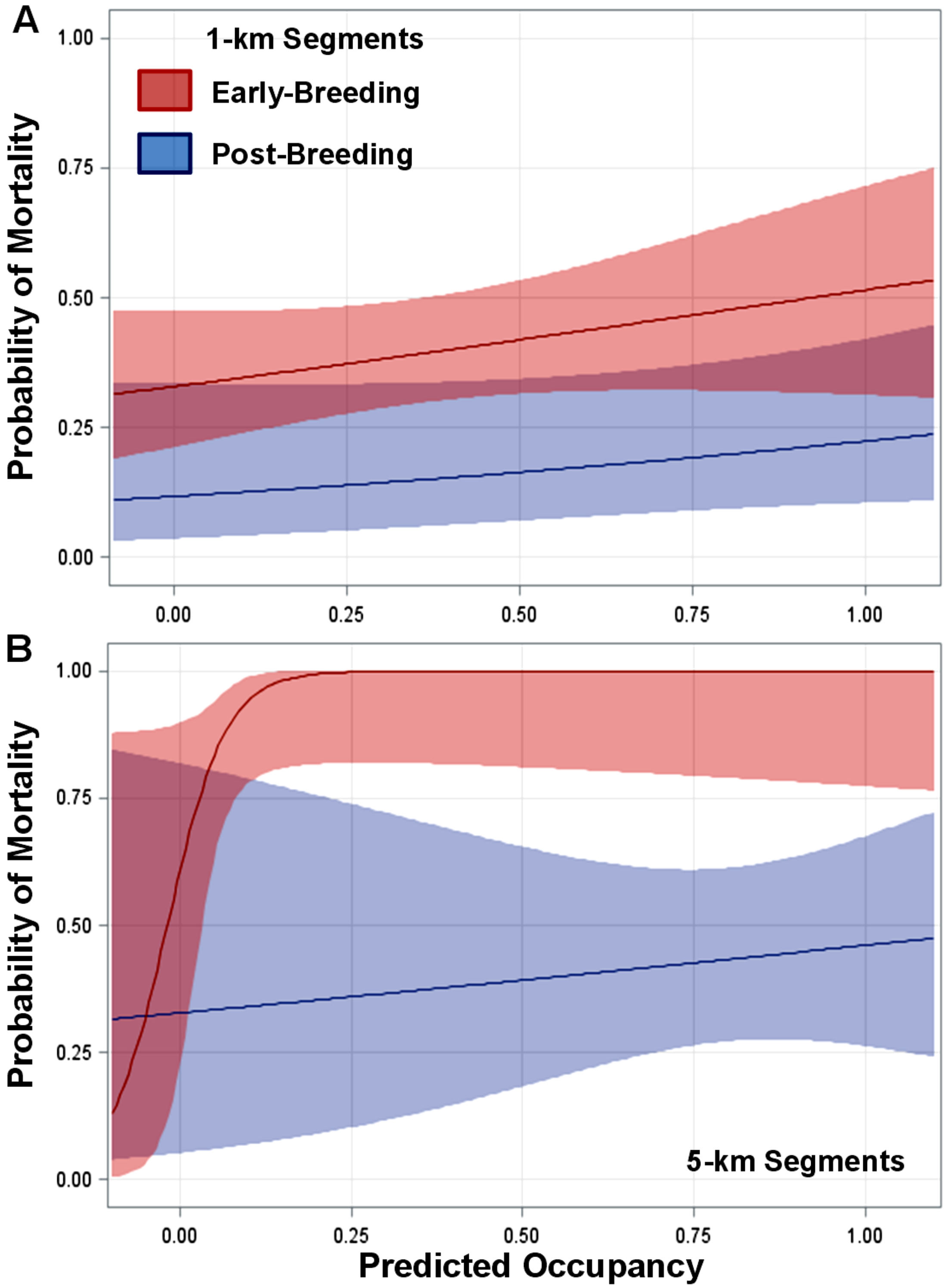

Figure 2.6. **Probability of mortality as a function of predicted occupancy and season (early- and post-breeding) for Barn Owls in A) 1-km segments and B) 5-km segments of Interstate 84/86 in s. Idaho.**

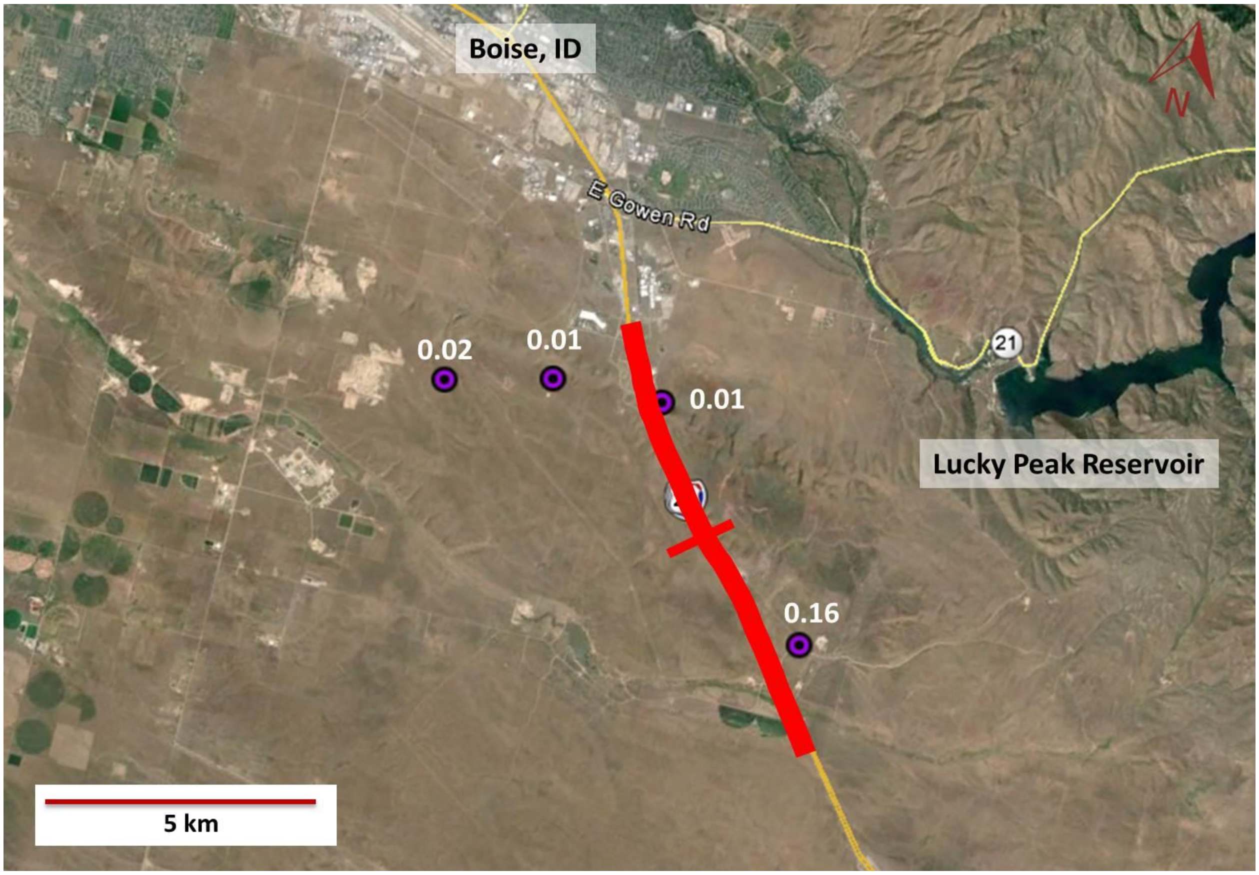

Figure 2.7. Two 5-km segments of Interstate 84 (red) in s. Idaho with no dead Barn Owls detected in road surveys between 2004 – 2015. Purple circles indicate four point-count locations surveyed for Barn Owls during 2014 and the predicted occupancy probability for each.

Table 2.1 Number of dead Barn Owls detected along Interstate 84/86 in s. Idaho, USA during standardized and ad hoc road surveys conducted between 2006 and 2015.

Survey Route	Month/Year	Number of Surveys	Number of Barn Owls
Standardized			
Boise to Pocatello	Oct. 2013 – Sept. 2014	24	106
Boise to Burley	Jul. 2004 – Jun. 2006	48	812
Ad Hoc			
Boise to Wendell	Mar. 2013	1	123
Boise to Pocatello	Mar. 2013	1	230
Boise to Pocatello	Feb. 2015	1	29
Boise to Pocatello	May 2015	1	62

Table 2.2. Results of occupancy models, adjusted for detection (variables noted), for Barn Owls near Interstate 84/86 in s. Idaho, USA for the early- (Jan – Mar) and post-breeding (Sept – Nov) seasons. Models were selected using AIC model selection, and model parameters shown are based on a 1-km radius buffer around each point-count location (See Chapter 1).

Early-Breeding Season	Parameter Estimate	SE	z	P value	Model AIC
Model Parameters					292.86
Intercept	1.79	2.47	0.73	0.47	
Crops	3.76	1.32	2.86	0.004	
Trees	1.34	0.65	2.05	0.04	
Average dB(A)	-0.10	0.06	-1.62	0.10	
p**:** Detection (Call, Julian date, moon illumination, cloud cover)					
Post-Breeding Season	**Parameter Estimate**	**SE**	**z**	**P value**	**Model AIC**
Model Parameters					169.20
Intercept	4.33	1.77	2.44	0.01	
Distance to Snake River	-0.15	0.04	-3.12	0.002	
Development	-28.62	13.07	-2.19	0.03	
Stream Length	0.47	0.32	1.47	0.14	
p**:** Detection (Call, Julian date, dB(A))					

Table 2.3. Number of 1- and 5-km segments along Interstate-84 in s. Idaho with and without dead Barn Owls during the early- and post-breeding seasons. Mortality data were pooled across all surveys between 2004 – 2014 and then subset by Jan – Mar for the early-breeding season and Sept – Nov for the post-breeding season (see Table 1.1).

Early Breeding Season	**# Segments with Dead Owls**	**# Segments with No Dead Owls**
1-km segments	35	54
5-km segments	85	4
Post Breeding Season	**# Segments with Dead Owls**	**# Segments with No Dead Owls**
1-km segments	6	24
5-km segments	13	17

Table 2.4. Results of logistic regression analyses examining potential effects of predicted occupancy and season on likelihood that 1- and 5-km segments along Interstate-84 in southern Idaho contained at least one dead barn owl.

1-km Segments	**β**	***SE* (β)**	**χ^2**	***df***	***P* value**	**Odds Ratio (e^β)**
Intercept	-0.71	0.31	5.30	1	0.021	0.49
Predicted occupancy	0.77	0.59	1.68	1	0.195	2.16
Season (Post Breeding)	-1.03	0.58	5.08	1	0.024	0.27
5-km Segments	**β**	***SE* (β)**	**χ^2**	***df***	***P value***	**Odds Ratio (e^β)**
Intercept	0.43	0.88	0.24	1	0.624	1.54
Predicted occupancy	23.53	12.27	3.68	1	0.055	1.6×10^{10}
Season (Post Breeding)	-1.15	1.43	0.64	1	0.423	0.32
Predicted occupancy x Season	-22.97	12.34	3.47	1	0.062	
1-km model: AUC = 0.62, R^2(U) = 0.04						
5-km model: AUC = 0.91, R^2(U) = 0.44						

CHAPTER THREE: EXAMINING BARN OWL BEHAVIOR, HABITAT SELECTION, AND MOVEMENTS IN RELATION TO INTERSTATE-84 IN IDAHO

Abstract

Barn Owl (*Tyto alba*) populations are threatened by anthropogenic development including roads. Along Interstate-84 in southern Idaho, Barn Owls suffer among the world's highest reported rates of roadway mortality. However, little is known about the behavior of Barn Owls in relation to this roadway. Thus, I initiated studies to examine movements and habitat selection of Barn Owls. I examined the efficacy of using GPS data loggers for tracking Barn Owls and assessed six methods for recapturing them to retrieve the data loggers. I attached data loggers to four male Barn Owls tending nests and obtained location data that spanned approximately two weeks of activity during the nesting season from which I mapped home ranges, evaluated habitat selection, and examined movements. I recaptured all instrumented males and found that manual- or laser-break triggered trap doors mounted on the nest box were effective for recapturing Barn Owls. Within home ranges, the probability a Barn Owl used a site was higher near trees and minor roads and lower as distance from the nearest stream and the nearest major road increased. Barn Owl use of areas also increased as terrain roughness increased. Relative use of development, hay/pasture, and sage steppe land cover were less than for cultivated crops, while owls used grassland/herbaceous and wetland land cover more than cultivated crops. Two male Barn Owls that nested within 3 km of the interstate never

moved closer than 1 km even though their maximum movements ranged up to 3 km. Thus, it is possible major roadways function as barriers to adult owl movements during the breeding season because they avoid roads. However, owls may remain susceptible to road mortality in their more rare attempts to cross.

Introduction

Land use change, often driven by urbanization, negatively affects wildlife through habitat loss, fragmentation, and other forces. Urbanization is one of the most permanent forms of habitat loss (McKinney 2002) and can result in local extinctions for wildlife species (Marzluff 2001; McKinney 2006). In the United States, over 5% of all land area has been converted to urban development (USCB 2001), which is more than the area of all national and state parks and areas under protection by the Nature Conservancy (McKinney 2002). When wildlife populations are threatened by urbanization and anthropogenic disturbance, understanding how animals use different aspects of their habitat during different stages of their life history is important for effective conservation and management (Johnson 1980).

Barn Owls (*Tyto alba*) are one of the most widely distributed species of owl (Taylor 2004; Marti et al. 2005). Despite this wide geographic range, Barn Owl populations are in decline (Colvin 1985; Toms et al. 2001). These declines are attributed to three main factors associated with anthropogenic change: (1) conversion of grasslands, which are habitat for small mammals, the primary source of food for Barn Owls, into development (Colvin 1985; Taylor 2004), (2) removal of nest and roost sites via the conversion of old barns into modern buildings and loss of trees (Taylor 2004; Ramsden 1998), and (3) road mortality (Ramsden 2003).

Previous research has elucidated Barn Owl diet composition (Jaksić and Yáñez 1979; Marti 1988), physiology and susceptibility to winter weather (McCafferty et al. 1998; Altwegg et al. 2006), and roadway mortality (Ramsden 2003; Boves and Belthoff 2012; Grilo et al. 2012; Borda-de Água et al. 2014). There has been less focus on movements, behavior, and habitat selection (Colvin and Hegdal 1986; Massa et al. 2015). Among the reasons is that Barn Owls can be difficult to capture and monitor: (1) they are nocturnal, which makes direct observation challenging, (2) there is a lack of clear methods for effectively capturing Barn Owls because they can be wary both at and away from their nests (Colvin and Hegdal 1986), and (3) some transmitter technologies for tracking avian species such as GPS, solar-power, and GSM (Global System for Mobile Communications) do not work well for Barn Owls. For instance, GPS-tracking units often do not meet weight restrictions (<3% of body mass) the USGS Bird Banding Laboratory established. Moreover, solar powered tags, which reduce weight by not requiring batteries, are less useful for owls because of their nocturnal habit and because they often roost in dense cover during the day, both of which reduce opportunity for solar charging. GSM transmitters are currently too heavy to meet USGS auxiliary marking guidelines, and technology requires the use of cell phone towers to transmit data (Bridge et al. 2011). While conventional VHF radio transmitters meet weight requirements, obtaining location fixes is time- and effort-intensive, and locations may not have the accuracy or spatial resolution required. One alternative to the above are GPS data loggers, which meet weight guidelines and have the ability to collect better fine-scale (temporal and spatial) location data than satellite transmitters or radio telemetry (Hulbert and French 2001); however, one main disadvantage of data logger technology is that the units must be retrieved to access the data.

While Barns Owls are relatively common in southern Idaho, few previous studies have focused on understanding population size, demographics, behavior or movements in this region (Boves and Belthoff 2012). Using transmitter technology to track Barn Owls could help us better understand their biology. For instance, dairy farms, which increased in abundance in portions of s. Idaho over recent decades, harbor robust small mammal populations (Rowe et al. 1983), but whether Barn Owls selectively hunt near dairies is not known. Interstate-84 (hereafter, I-84) in southern Idaho is a major four-lane highway with among the highest reported rates of Barn Owl mortality (Boves and Belthoff 2012; Belthoff et al. 2015). However, whether owls are killed along this or other major roads while foraging or die as they attempt to cross roads remains unclear. Barn Owls may be attracted to roadways because they present quality foraging habitat in the vegetated roadside verges/medians, but at the same time passing vehicles kill hunting owls. This could cause habitat along roads to function as ecological traps (Donovan and Thompson 2001; Ramsden 2003; Grilo et al. 2012). On the other hand, roads may repel Barn Owls, but they are still killed during the few times they attempt to cross roads. In this way, roads could function as barriers to movement. Ramsden (2003) suggests that major roadways act as partial barriers to movement because most owls that encounter a major road are killed. As such, roadways may divide potential Barn Owl habitat, reduce connectivity, and restrict movement of dispersing juvenile owls.

The objectives of my research were to (1) examine the efficacy of using GPS data loggers for tracking Barn Owls, (2) evaluate recapture methods to retrieve data loggers from adult Barn Owls, (3) assess Barn Owl habitat selection in relation to roads and land cover, and (4) understand how Barn Owls in southern Idaho moved in relation to I-84.

Study Area and Methods

Study Area

I studied Barn Owls in southern Idaho, United States (USA) within the Snake River Plain ecoregion (McMahon et al. 2001). I conducted research near the towns of Jerome (Jerome County, 42°43′ N 114°31′ W) and Wendell (Gooding County, 42°46′ N 114°42 W), and near CJ Strike Reservoir east of Grand View (Owyhee County 42°59′N 116°5′ W) Idaho.

Predominant land cover types were disturbed grasslands intermixed with shrub steppe, and irrigated agricultural land, in addition to a few primarily rural municipalities (Boves and Belthoff 2012). Shrub-steppe lands consisted of a mix of native plants such as sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), green rabbitbrush (*Chrysothamnus viscidiflorus*), native bunch grasses, as well as exotic invasive species such as cheat grass (*Bromus tectorum*), tumble mustard (*Sisymbrium altissimum*), and Russian thistle (*Salsola kali*). The main agricultural crops were sugar beets (*Beta vulgaris*), potatoes (*Solanum* spp.), corn (*Zea mays*), wheat (*Triticum* spp.), barley (*Hordeum* spp.), alfalfa (*Medicago sativa*), and soy beans (*Glycine max*). Agricultural lands also contained numerous irrigation ditches, isolated groves of trees, and human structures (barns, grain silos, etc.). Approximately 322 dairy farms were also scattered throughout the study area, where dairies were “any land, place or premises where milking cows, sheep, or goats are kept, and from which all or a portion of the milk produced thereon is delivered, sold or offered for sale for human consumption" (Idaho Office of the Administrative Rules Coordinator 2014).

Portions of my research also occurred in the Morley Nelson Snake River Birds of Prey National Conservation Area, which is home to high densities of breeding raptors. The Snake River Canyon, which is one of the widest and deepest canyons in the USA, was one of the main geologic features. This canyon is characterized by vertical walls of volcanic rock which, in addition to Barn Owls, provide nest and roost sites for many raptor species, such as Prairie Falcons (*Falco mexicanus*), Golden Eagles (*Aquila chrysaetos*), and Great Horned Owls.

The Snake River Plain ecoregion has a semiarid climate (Maupin 1995). In the winter (December – February), monthly mean temperature ranges from -11.9 – 10 °C (Western Regional Climate Center 2015). Monthly mean temperatures in summer average around 21 °C, but daily maximum temperature can be as high as 40 °C. During the fall (October – November), mean monthly temperatures range from 4.1 – 21 °C. Annual average precipitation is 25 – 27 cm, with most occurring in winter and spring (Maret 1997; Western Regional Climate Center 2015). Elevation across the entire study area ranges from 767 m above sea level near Grand View to 1129 m at Jerome, Idaho.

Barn Owl Capture

I captured four adult male Barn Owls in February 2015 during the day at four separate nest boxes by plugging the hole of the nest box (Figure 3.1) as the owls roosted inside. I retrieved only the male owl (discernable by plumage) to avoid handling adult females who were preparing for egg laying. Males were transported within a cloth bag to a vehicle, where I ultimately attached the data logger harness.

Data Logger Settings and Attachment

I used GiPSy 4® data loggers (TechnoSmart, Rome, Italy), which were 23 mm long x 15 mm wide x 6 mm high in size and weighed < 2 g including the battery (Figure 3.2). These data loggers can collect and store up to 4,000,000 locations, along with information about ground speed, date, time, number of satellites available, and a rating of location quality. I programmed the data loggers to come on every other night and set the location fix rate to every 30 s from 1800 to 2100 h which corresponded to onset of Barn Owl activity each night (Marti et al. 2005). I reduced location fix rate to once per minute between 2100 – 2400 h, after which time the data loggers shut off for the night. This schedule allowed collection of fine scale information on owl movements and maintained battery life to track owls longer than continuous data collection throughout the night would have permitted. Under this schedule, data loggers lasted approximately two weeks before their battery died, and each collected location data for about nine nights.

I attached data loggers to adult male Barn Owls backpack style (Figure 3.3; Smith and Gilbert 1981) and included a VHF transmitter (Merlin Systems, model: CMV-393, 3 g, 15.24 cm antenna) which allowed me to use a hand-held receiver and yagi antenna to establish if a male was in a nest box before attempting recapture to remove the backpack. The entire backpack consisted of the data logger, its battery, and a VHF transmitter inserted into a heat-shrink tube case (medium wall thickness, 2.54 cm diameter). I threaded ~22 cm of Teflon ribbon (~0.5 cm wide) through one end of the heat-shrink tube and sealed the tube around the Teflon using heat and pressure prior to field attachment; this side of the case was ultimately placed closest to an owl's head. I then inserted the data logger and VHF transmitter into the heat-shrink tube case and sewed through the

Teflon ribbon and the heat-shrink tube walls using dental floss and a suture needle to close the case. Complete packages weighed < 14 g and were removed from owls upon recapture.

Barn Owl Recapture

I used VHF signals to detect the location of instrumented owls before attempting recapture. I used bal chatri traps (Clover-Noose BC, Northwoods Falconry, BC Noose Trap-Standard, Wildlife Control Supplies), manual plugging of nest boxes during the day, manual plugging during the night, and mist nets (2.1 x 9.1 m, 10.2 cm mesh) in attempts to recapture instrumented Barn Owls. On occasion at sunset I deployed bal chatri traps baited with a lure mouse (*Mus musculus*) with one trap near an owl's nest box and one ~50 m away under a tree where the owl could perch. On other occasions, after determining the location of the instrumented male using VHF signals or watching the male visit a nest with prey, I manually plugged the nest box (during daytime and nighttime) with a telescoping pole to attempt recapture. On one occasion I attempted recapture using mist nests erected ~1 h before dusk at locations near the nest box and at suitable height for owl flight, ~ 3 m.

I also attempted recapture of instrumented Barn Owls using what I referred to as manual- and laser-break triggered trap doors (Figure 3.4 and 3.5). I attached trap doors to the nest box using a loosely inserted pivot screw, which allowed the trap doors to swing freely shut without binding. I installed both types of trap doors and all associated parts on the nest box ~45 min before sunset and the presumptive onset of activity for Barn Owls one night prior to a recapture attempt to allow owls to habituate to new features on the nest box.

For the manual method, I used a wooden trap door (17.8 cm long x 43.8 cm wide) balanced on top of a notched peg (8 cm long x 2 cm wide). I placed the notched peg on top of a screw fixed to below the nest box entrance. I attached monofilament line to the peg and hid nearby with a clear view of the nest box entrance with the other end of the line. When an owl entered the box, I pulled the line and peg, which caused the trap door to close over the nest box entrance. A screw placed on the other side of the entrance hole across from the peg prevented the trap door from over-rotating (Figure 3.4).

I also designed and employed a laser-break triggered trapdoor, which allowed me to be farther from the nest box during recapture attempts to avoid detection by the owls. The laser-triggered trap door (30.5 cm wide x 33.7 cm long) included a piece of plywood with a 0.14 kg weight which ensured the door closed quickly and completely (Figure 3.5 and 3.6). I propped the door open using a wooden peg. Monofilament line ran from the peg to a latch mechanism (Figure 3.7). The latch mechanism was equipped with a motor that spun when the laser beam was interrupted causing a steel shank to rotate and pull the wooden peg out from under the trap door, which then covered the nest box entrance. The laser diode and a photoresistor were mounted on a U-shaped piece of wood, with the laser directly below, and the photoresistor directly above, the center of the nest box entrance (Figure 3.8). Appendix 1 has additional details regarding parts and programming of the laser and trigger mechanism. After installation at a nest box, I calibrated the sensitivity of the photoresistor and tested the laser and trigger mechanism before observing from vehicle parked ≥ 500 m from the nest box during recapture attempts.

Spatial Analyses

After recapture of owls and download of location data from data loggers, I filtered each owl's location data by removing points with HDOP (Horizontal Dilution of Precision) > 4, because these fixes had poor satellite reception. I also filtered location data at 5-min intervals to reduce spatial and temporal autocorrelation in preparation for a resource selection function analysis (Swihart and Slade 1997). The data loggers captured instant ground speed for each location, and I assumed that when instant ground speed = 0 owls were either perched, at the nest box, or on the ground perhaps during a bout of prey capture.

I used ArcGIS (ESRI 2013, ArcMap 10.1) to quantify space use and estimate home range size. I created home-range estimates with the Geospatial Modeling Environment (GME; Beyer, 2014) extension using the 10 – 90 % (intervals of 10), 95 % and 99 % isopleths of the utilization distribution from kernel density estimates. I considered the ≤ 50 % isopleths to indicate core areas of use for each Barn Owl.

To measure land cover and distance-related variables, I used ArcGIS to create four 3.5 km radius buffers around the nest box of each instrumented Barn Owl. I buffered at this distance because it included the maximum movements of most of the Barn Owls I tracked. Within each buffer I then generated 500 random points constrained to be at least 10 m from other random points (hereafter referred to as available), which served as an index of available habitat for comparison to locations of Barn Owls in a resource selection analysis. Although 2000 total random points were plotted, the number available for analysis was less because some points fell in land cover categories that were not useful for analysis such as open water.

I calculated the distance from each used and available point to the nearest dairy, major road, minor road, stream, and tree, as well as to the Snake River. The focal major road was I-84, and minor roads included all other road types (secondary highway, paved, and gravel). I determined whether each used and random point occurred in cultivated crops, development, grassland/herbaceous, hay/pasture, sage steppe, and wetlands using the National Land Cover Database 2011 (Homer et al. 2015).

Statistical Analyses

I initially screened land cover and distance-related variables for multicollinearity and removed distance from nearest dairy and distance to the Snake River from subsequent analysis because they were too highly correlated with other variables. To establish resource selection functions (Manly et al. 2007), I evaluated Barn Owl habitat use with a generalized linear mixed model (binomial distribution, log link, and individual owl as a random effect) using the package lme4 (Bates et al. 2015) in the statistical platform R 3.0.1 (R Core Team 2015). I evaluated the potential effects of terrain roughness, distance from the nearest stream, distance from the nearest tree, distance from nearest minor road, distance from nearest major road, and land cover type (cultivated crops as reference category). I modelled the likelihood that a location was used in comparison to available and considered this to reflect selection by Barn Owls when regression parameters differed significantly from 0. Means are given with standard error throughout unless otherwise indicated.

Results

Barn Owl Capture

I captured and instrumented four adult male Barn Owls in February 2015 during the daytime by manually plugging the nest box with a nest box plug. Captures were early enough in the nesting season that males were still roosting in the nest box with females, capture of the male during this time period did not cause nest desertion, and nests were successful in producing fledglings in each case.

Barn Owl Recapture

By the time I recaptured the four instrumented Barn Owls to retrieve data loggers, they were no longer roosting in the nest box consistently. As I detail below, I ultimately attempted to recapture the instrumented Barn Owls on 15 nights, and made eight additional attempts during daytime hours.

I attempted to recapture owls by plugging the box during the day, but either the male was not in the box at the time of my visit or he flushed upon my approach. I made no successful captures using this method during the day (Table 3.1). I recaptured one of four male owls by manually plugging the entrance at night (Table 3.1). The only situation where I succeeded was in an open environment with little shrubby vegetation during which time I was able to make quiet approaches that did not flush the owls.

Barn Owls showed some interest in bal chatri traps, but I never recaptured an instrumented owl using them (Table 3.1). One Barn Owl landed on a trap once but flew off without being entangled. Males tended to perch in a tree and watch the trap rather than attempt to capture the lure mouse. During this time, the males also never visited the box with prey for the brood.

I attempted recapture of instrumented Barn Owls with mist nests on only one trap night. The net was up for only 30 min because of inclement weather that approached, and I did not recapture the targeted Barn Owl, even though he and his presumptive mate flew near the nest (Table 3.1).

I recaptured two instrumented Barn Owls using the manual-triggered trap door method (Table 3.1). Both successful recaptures occurred on the second night of attempts. I triggered the manual trap door after the first owl entered the box and, in both cases, it was the male that I captured. Thus, it appears that the male was making the first prey delivery of that night at these two locations.

I recaptured one instrumented Barn Owl using the laser-break triggered trap door at a site where the pair of owls was particularly wary and inhabited a brushy area that made it difficult to approach the box without notice. I attempted to recapture the instrumented owl at this location on four separate days and over six nights using the other methods. Similar to the manual-triggered trap door, it took two nights of trapping for the laser-break trap door to succeed. On the first night, the trap door was triggered, but no owls were captured. On the second night, approximately 1 h after sunset, I captured both the instrumented male and his mate during the same trapping attempt (Table 3.1). Because the laser-break triggered trap door captured both the male and female, they must have entered in quick succession, so it is not clear which entered the nest box first.

GPS Data Loggers

Two of the data loggers on adult male Barn Owls collected location data for nine individual nights each, but both only functioned for 30 min on the last night. One unit collected location data for 10 nights, and the other collected location data for only three nights. Together, the four data loggers captured 155.5 h of activity (Table 3.2).

Individual Owl Locations and Movements

Two males were captured and instrumented within 3 km of I-84 (near Jerome and Wendell, Idaho), and two were > 30 km from the interstate (near CJ Strike Reservoir, Grand View, Idaho). One nest box was on the outside of a steel corrugated barn (Jerome male), one was inside a three-sided steel corrugated barn with the fourth side permanently open (Wendell male), and the other two boxes were mounted on elm (*Ulmus* sp.) and Russian olive (*Elaeagnus angustifolia*) trees (Snake River Birds of Prey and Borden Lake males, respectively).

Wendell Male

After filtering, there were 356 locations for the Wendell male (Table 3.2). This owl was not moving (instant ground speed = 0) during 18.9 ± 2.2 instances per night and at 53.1 % of all locations. The Wendell male's home range was ~ 2.5 km northeast of I-84, and its 95 % isopleth home range was the second largest of the four owls I monitored (Table 3.3, Figure 3.9). The highest concentration of locations was centered on the nest box and an apparent daytime roost site (Figure 3.9) which was located ~0.5 km southwest of the nest box in a spruce tree (*Picea* sp.). This owl had the second smallest average distance moved between point locations (Table 3.3).

Jerome Male

After filtering, there were 454 locations for the Jerome male (Table 3.2). This owl was not moving during (instant ground speed = 0) 25.1 ± 2.9 instances per night and at 49.7 % of all locations. Its nest box was ~ 2 km north of I-84, and the 95 % isopleth home range was the smallest of the four owls I tracked (Table 3.3, Figure 3.10). The highest concentration of locations was centered on the nest box and an apparent daytime roost site (Figure 3.10) ~0.5 km south/southwest of the nest box in a spruce tree. This owl had the greatest average distance moved between point locations (Table 3.3).

Borden Lake Male

The Borden Lake male was located > 30 km south of I-84 in the Borden Lake Wildlife Management area. Its data logger malfunctioned after working properly the first two nights. On the third night, it came on for three hours (0330 – 0630 h) and took one location every second until the battery failed. Thus, this male had only 114 location fixes for analysis after filtering points (Table 3.2). This owl was not moving (instant ground speed = 0) 28.3 ± 4.8 times per night and at 74.6 % of all locations. The 95 % isopleth home range was the largest of all owls (Table 3.3, Figure 3.11). Unlike the other three owls, the highest concentration of locations was not centered on any particular area, perhaps because the data logger malfunctioned. This owl had the smallest average distance between point locations (Table 3.3).

Snake River Birds of Prey Male

The Snake River Birds of Prey male nested just southeast of CJ Strike Reservoir, > 30 km from I-84. After filtering, there were 509 locations (Table 3.2), and this owl was not moving (instant ground speed = 0) 26.1 ± 3.4 times per night and at 46.1 % of all locations. The 95 % isopleth home range was the second smallest of all four owls (Table 3.3, Figure 3.12) and overlapped the Borden Lake male's home range. The highest concentration of locations was centered on the nest box and an apparent daytime roost site (Figure 3.12) located ~0.6 km north of the nest box in a spruce tree. This owl had the second largest average distance moved between point locations (Table 3.3).

Resource Selection Function

Barn Owls used locations in cultivated crops (33.6 %), development (9.7 %), grassland/herbaceous (22.6 %), hay/pasture (8.8 %), sage steppe (5.5 %), and wetlands (19.7 %, Table 3.5). Points available for use by Barn Owls were in cultivated crops (27.2 %), development (14.1 %), grassland/herbaceous (19.2 %), hay/pasture (20.4 %), sage steppe (18.6 %), and wetlands (0.4 %, Table 3.4). The average terrain roughness and average distance of used (n = 1427) and available (n = 1799) points to the nearest tree, stream, minor road, and major road were similar to each other (Table 3.5).

Relative probability that a location was used declined with increasing distance from the nearest tree and increasing distance from the nearest minor road (Table 3.6, Figure 3.13). Use was greater with distance from the nearest stream and major roads, and with increasing terrain roughness (Table 3.6, Figure 3.13). Relative use of development, hay/pasture, and sage steppe each were less than cultivated crops (Table 3.6, Figure 3.13). That is, odds of use in development were just 0.37 (95 % CI = 0.32, 0.48) those in cultivated crops, while odds of use in hay/pasture and sage steppe were 0.47 (95 % CI = 0.07, 0.60) and 0.52 (95 % CI = 0.37, 0.75) the odds of use in cultivated crops, respectively. In contrast, grassland/herbaceous and wetland land cover were used relatively more than cultivated crops (Table 3.6, Figure 3.13), such that odds of use in wetlands and grassland/herbaceous were 12.5 (95 % CI = 5.93, 26.05) and 1.5 (95 % CI = 1.15, 1.97) times higher than the odds in cultivated crops, respectively.

Movements Near Interstate-84

Two owls (Wendell and Jerome, ID) nested within 3 km of I-84 (Figure 3.14). While both had maximum movements of > 3 km from their respective nest, neither moved to or across the interstate (Figure 3.14). Instead, each remained > 1 km from it (Figure 3.14).

Discussion

My goals were to examine efficacy of using GPS data loggers for tracking Barn Owls, evaluate recapture methods for adult Barn Owls that had been instrumented with data loggers, and gain information on Barn Owl movements and habitat selection, especially in relation to an interstate highway with high rates of owl road mortality. I equipped four male Barn Owls with GPS data loggers and found that manual or laser-break triggered trap doors were especially effective for recapture. Barn Owl home range size and length of movements varied by individual and potentially because of surrounding habitat. When Barn Owls selected habitat, probability of use at a site was lower with increasing distance from the nearest tree and nearest minor road. Probability of use was higher with increasing distance from the nearest stream and major roads, as well as increasing terrain roughness. Relative use of development, hay/pasture, and sage steppe were all less than cultivated crops while grassland/herbaceous and wetland land cover were used more than cultivated crops. Finally, Barn Owls nesting within 3 km of Interstate-84 never approached closer than 1 km of the interstate, even though they made movements > 3 km in length.

Use of GPS Data Loggers to Track Barn Owls

Even when paired with a VHF unit, the backpacks containing data loggers that I deployed on Barn Owls met the < 3 % body weight limit for auxiliary markers mandated by the USGS Bird Banding Laboratory. I also was able to collect more than 22,000 unfiltered locations for the four Barn Owls that received the backpacks at time intervals that ranged from one every 30 sec to once per minute. For my purposes, data filtered to 5 min intervals were suitable to assess habitat selection by adult Barn Owls.

Only one other study has assessed the use of data loggers on Barn Owls. In that study, a single owl was tracked, and the data logger took locations every 20 – 30 sec for 13 hours per night, lasted eight nights, and collected a total of 12,501 locations (Massa et al. 2015). Both my study and Massa et al. (2015) provide evidence that data loggers are effective for tracking Barn Owls and for obtaining large amounts of fine scale location data.

Use of data loggers necessitates recapture of instrumented animals for data retrieval. For Barn Owls, recapture can be difficult because they become more wary and evasive after initial capture. Fortunately, I was able to recapture all of the Barn Owls I tagged, but this was made easier because their activities were tied to nest boxes during the time of my study. Indeed, several tracking studies of Barn Owls relied on nest boxes to access adults (Colvin and Hegdal 1986; Massa et al. 2015). I suspect that recapture success decreases outside of the breeding season, and I purposely did not track juvenile owls because they exhibit extensive natal dispersal movements that can be up to 1500 km. Thus, there likely would have been a very low probability of relocating and recapturing dispersing juveniles to allow me to retrieve the data.

<u>Recapture Methods</u>

I evaluated six different recapture methods in my study: manual plugging of the box during the day and/or night, bal chatri traps, mist nest and manual- and laser-break triggered trap doors. Their efficacy varied depending on characteristics of the environment around the nest box and individual owl responses to disturbance associated with trapping attempts.

Plugging the nest box manually by day or by night worked well if the box was mounted where the approach was relatively quiet and flushing owls from the nest box could be avoided. Recapturing male Barn Owls using a bal chatri trap was not an effective method. In my study, I always aborted bal chatri trapping attempts before capture because owls delayed hunting and delivering prey to their mate and brood. Colvin and Hegdal (1986) found Barn Owls tended to ignore the bal chatri trap altogether and had no successful recaptures with this method. I attempted to use mist nets to recapture Barn Owls but could not fully evaluate their efficacy because of inclement weather during the one attempt I made. However, Colvin and Hegdal (1986) suggest that mist nets may be most effective if they are used inside a barn or other structure, where the net can be strategically placed and exits can be blocked such that owls are limited in their ability to evade the net.

Colvin and Hegdal (1986) recaptured 44 % of all adult Barn Owls using manual-triggered trap doors. Similarly in my study, the most successful and efficient recapture method was a manual- or laser-break triggered trap door mounted on the nest box. Invariably, it took one night for owls to acclimate to the addition of novel features to their nest box, such that trap doors were always successful on the second night, within the first hour after sunset. Both my study and Colvin and Hegdal (1986) indicate Barn Owls need 1 – 3 nights to become accustomed to any changes to their nest box before attempting a recapture.

Regardless of recapture method, it is likely that trapping success will be improved by having all equipment in place by sunset at the latest (Colvin and Hegdal 1986). I found onset of Barn Owl activity usually began before dusk, and owls were observant and wary. Most owls were able to detect me even in a well concealed place, which supports Colvin and Hegdal's (1986) suggestion that wearing camouflage or dark clothing and minimizing movement once Barn Owls are active will increase chances of successful capture/recapture.

Barn Owl Home Ranges and Movements

Consistent with other studies (Taylor 2004; Thomsen et al. 2014), most of the owls I tracked had areas of concentrated use centered on the nest box and at one or more daytime roost sites. In my study three of four Barn Owls used spruce trees as their daytime roost site, potentially because the dense branches and foliage provide appropriate cover, shade, and protection (Rudolph 1978). However, there was disparity between the home range size of Barn Owls that I tracked and those in different regions. For example, home range sizes of Barn Owls in southern Idaho were larger than those on the Channel Islands, California (Thomsen et al. 2014). Indeed, the 90 % isopleth home ranges of Barn Owls in southern Idaho (0.50, 0.70, 1.0, and 1.71 km^2) were 1.85 times larger than the Channel Island owls (0.06, 0.46, and 1.12 km^2). Landscape composition and associated prey availability may have driven the variation in home range size I observed. Barn Owls in southern Idaho might roam farther for access to suitable resources because the agricultural lands they inhabit have disturbance regimes that may depress prey populations (Taylor 2004; Jacob 2003a). Accordingly, Thomsen et al. (2014) speculate that constricted home ranges of Channel Island owls were related to high prey densities, and Arlettaz et al. (2010) found that Barn Owls in areas with less desirable foraging habitat tended to have larger home ranges.

Thomsen et al. (2014) found Barn Owls on the Channel Islands with overlapping home ranges and speculated this was related to abundant and concentrated prey causing reduced territoriality and overlapping home ranges. Barn Owls are already one of the least territorial raptor species (Marti et al. 2005), and a surplus of resources may further reduce territoriality because owls receive more benefit from hunting and delivering prey to their brood rather than defending their territory (Carpenter 1987). Within my study area, two Barn Owls that nested 2 km apart had overlapping home ranges. Similar to Thomsen et al. (2014), this may indicate a surplus of prey or high habitat quality for Barn Owls in that area.

Resource Selection Function

The negative association between use and increasing distance from the nearest tree that I detected perhaps was driven by peak activity concentrated around nest and roost sites and protection from predators. Average nightly movements of Barn Owls around a central feature, such as the nest site, are roughly 1 km in length (Marti et al. 2005). Thus it is logical that use would be highest within a 1-km radius of the nest site, with use decreasing the further an owl travels beyond this zone. Barn Owls prefer roost sites with minimal exposure, such as far back in crevices or in dense conifers or shrubs (Rudolph 1978) thus trees likely represent cover and places to rest between hunting bouts. Additionally, Barn Owls might be more vulnerable to predation by Great Horned Owls (*Bubo virginianus*) at greater distances from tree cover because they are more exposed. Great Horned Owls are locally abundant in my study area (pers. observ.), are dominant to Barn Owls, compete with Barn Owls for resources, and prey on Barn Owls (Rudolph 1978). Despite that Great Horned Owls also associate with trees, Barn Owls likely are able to conceal themselves in trees and evade the larger Great Horned Owl.

Land use change and prey distributions might result in increased Barn Owl use of areas along minor roads. My data suggested that at 500 m from a minor road, probability of Barn Owl use was just 0.1, and at 1 km probability of use was zero. In southern Idaho, many agricultural fields are plowed and left fallow during winter, and plowing of fields is known to reduce vole populations (Jacob 2003a) which are the primary prey source for Barn Owls (Marti 2010). After plowing, thin strips of vegetation often remain only in the margins along secondary roads and provide refuge for small mammals (Meunier et al. 2000). These areas might represent quality foraging areas for Barn Owls (Nero and Copland 1981; Shawyer 1998; Ramsden 2003; Condon et al. 2005) because they are among the few remaining suitable places for a Barn Owl to hunt in an agricultural matrix comprised mainly of plowed soil during winter months

Barn Owl use of areas was higher as distance from the nearest stream increased. Reasons for this pattern within my study area are unclear but may be explained by Barn Owls nesting and roosting in trees *associated* with streams, but then traveling out away from sites near streams into agricultural areas to hunt. All four Barn Owls I tracked exhibited this general pattern of movement, and it was most obvious when nests were in trees in riparian zones (e.g., Snake River Birds of Prey and Borden Lake males).

However, in Portugal Barn Owl presence was negatively associated with distance to streams (Grilo et al. 2012). I also found (Chapter 1) that Barn Owl occupancy was higher when there are greater amounts of streams (km) within an area. However this pattern may be driven by trees in my study area primarily occurring within riparian corridors in an arid environment. Thus, based on Chapter 1 and Grilo et al. (2012), it seems that streams may be important for occupancy of Barn Owls because they provide adequate water for trees that Barn Owls require for nest and roost sites. However, based on the results presented herein, they are not directly important when assessing Barn Owl habitat selection while hunting because of the negative relationship exhibited between distance to streams and probability of use.

Several owl species avoid major roads. For example, Burrowing Owls (*Athene cunicularia*) avoid roads with high traffic speeds that result in increased noise (Scobie et al. 2014). Similarly, Silva et al. (2012) found that Tawny (*Strix aluco*) and Little Owls (*Athene noctua*) are less abundant near roads with high traffic rates and hypothesized that noise and light disturbance reduce the ability of owls to locate prey. I found probability of use was greater the farther a Barn Owl was from major roads, potentially for the same reasons as the aforementioned species. Congruent with this, one other study showed Barn Owls avoid moving toward major roads when in proximity to them and only attempt crossing when traffic and associated noise is low (Grilo et al. 2012).

In southern Idaho, Barn Owls hunt over flat, agricultural landscapes, but rock cliffs often used for roost and nest sites occur in areas with greater topographic relief, mainly along volcanic canyons (Snake River, Malad River, Rock Creek). These canyons provide nest and roost sites for many raptor species, including Barn Owls (Boves and

Belthoff 2012). Thus, the increased use of areas with rough terrain that I observed could be related to availability of, and proximity to, roost and nest sites.

In addition to distance from features, resource use of Barn Owls also differed by land cover type. Barn Owl occurrence is often negatively associated with development (Chapter 1), and development negatively affects fledging success of Barn Owls (Hindmarch et al. 2014), which may explain the decreased use of developed areas I observed. It is not clear why hay/pasture was used less than croplands. Croplands potentially offer better areas for hunting because fields managed for hay receive early and frequent cutting, sometimes as much as four times a growing season (pers. observ.). Such frequent mowing may reduce prey densities; however there are conflicting results on whether mowing negatively impacts small mammals (Jacob 2008). Alternatively, frequent mowing of hay/pasture areas consistently reduces vegetation height and might make prey more accessible for Barn Owls (Arlettaz et al. 2010).

Barn Owls use their long legs to land on and pin prey to the ground while hunting (Marti 1974) thus accessibility of prey may drive the negative relationship I observed between sage steppe and probability of use. Sage steppe may not be a high quality hunting area because the tall, woody growth makes this method of prey-capture difficult. Arlettaz et al. (2010) found that although wildflower areas had the highest small mammal densities, Barn Owls avoided hunting those areas likely because of decreased prey detectability and accessibility associated with tall, dense vegetation. Successful Barn Owl nests in England have lower proportions of shrub cover within a 1-km radius, further supporting the notion that shrub habitats are not high quality habitat for Barn Owls (Bond et al. 2005).

American Kestrels (*Falco sparverius*) selectively and more successfully hunt over grasslands compared to croplands (Toland 1987), and Barn Owls in Switzerland hunt more intensively over grasslands than other land cover types, even though grasslands had the lowest prey densities (Arlettaz et al. 2010). Thus, it is possible that the higher than expected Barn Owl use of grasslands in my study could have been related to prey accessibility. Croplands vary in height based on time of planting and crop type, such that access to small mammals is restricted in crops planted earlier in the growing season or tall crops like corn (Toland 1987). Grasslands, in contrast, are usually grazed or sparse enough that small mammals can still be located and captured by avian predators (Toland 1987).

The southern Idaho landscape where Barn Owls occur is a semi-arid shrub steppe mostly devoid of trees. Thus, wetlands and riparian corridors support the highest density of trees given the available moisture; as such, they provide abundant nest and roost sites for Barn Owls. In my study, wetlands had the highest proportion of use for any land cover type, potentially driven by two of the four Barn Owls which nested at wetland edges. In contrast to my findings, successful Barn Owl nest sites in England tended to have little to no proportion of wetlands (Bond et al. 2005), potentially because regular, repeated flooding of wetlands depresses small mammal populations (Jacob 2003b). However, in southern Idaho, it is possible that wetlands were only used for nesting and roosting rather than hunting. Consistent with this, I observed instrumented Barn Owls traveling away from nest sites in wetlands to hunt elsewhere.

Movements in Relation to a Major Roadway

I was particularly interested in the two owls closest to I-84 (Wendell and Jerome, ID) for assessing movements of Barn Owls in relation to a major road. Although both of these owls had movements > 3 km from their respective nest box, neither approached the interstate closer than 1 km. This suggests that adult male Barn Owls nesting near I-84 during the breeding season may avoid it such that it is acting as a linear barrier to movements. Grilo et al. (2012) similarly found Barn Owls in southern Portugal avoided moving towards the road when in proximity to it and situated their home ranges adjacent to a major roadway, but home ranges usually did not contain large portions of the roadway. Finally, major roadways in Britain appear to act as partial barriers to dispersal in that ~72% of Barn Owls known to encounter major roads are killed (Ramsden 2003).

Conclusions

Conducting a resource selection analysis that examines Barn Owl spatial use within a habitat matrix is a key step in understanding what features of the environment affect Barn Owl behavior. My study showed that Barn Owls preferentially used grasslands and wetlands when compared to use in cultivated crops as well as other areas depending on proximity to landscape features such as trees and minor roads. This supports previous speculation that Barn Owls do not use all areas of their home range equally (Marti et al. 2005) and thus is a factor to consider when prioritizing conservation actions.

Although I was only able to attach data loggers to four male Barn Owls, this sample size is similar to that of other Barn Owl tracking studies. For instance, a study in Portugal used VHF telemetry to obtain home range and movement information for five

Barn Owls (Grilo et al. 2012); a study in the United States collected enough data for analysis on three individuals using VHF telemetry (Thomsen et al. 2014); and a recent study in Argentina tracked one Barn Owl with a GPS data logger (Massa et al. 2015). While these studies are small individually, together they assemble valuable information about Barn Owl movements and behavior beyond simply observing owls at a nest box. My study has also provided insight into the behavior of Barn Owls near I-84 where road mortality is an important conservation concern (Boves and Bethoff 2012; Belthoff et al. 2015). I did not find any evidence that Barn Owls regularly crossed the interstate or hunted in roadside vegetation. Rather adult males living near the interstate seemed to avoid and not approach it. The fact that males nesting this close to the interstate were not using it as habitat and apparently avoided it begs the question of what owls are contributing to the large number of road mortalities commonly observed along I-84 (Boves and Belthoff 2012; Belthoff et al. 2015; Arnold 2016)? It is possible that juvenile or adult female Barn Owls make different use of the highway corridor than adult males as both these age and sex classes suffer higher roadway mortality rates (Massemin et al. 1994; Moore and Mangel 1996; Newton et al. 1997; Boves and Belthoff 2012). However, studies of their behavior and movements using GPS technology remain to be conducted.

Future Directions

I was only able to record the movements of adult male Barn Owls during the breeding season. However, females and juveniles suffer higher road mortality in southern Idaho (Boves and Belthoff 2012) and elsewhere (Massemin et al. 1994, Moore and Mangel 1996; Newton et al. 1997; Grilo et al. 2012). Furthermore, peaks in mortality usually occur during late fall to early winter (Boves and Belthoff 2012), while I tracked

Barn Owls during late winter and early spring. Thus, while I am able to draw some conclusions about Barn Owl movements and behavior along the I-84 corridor, exploration of female and juvenile movements, and movements during other seasons, is needed. The data loggers I used required recapturing instrumented owls to retrieve location data. Recapture of juveniles would likely be more challenging because most exhibit natal dispersal movements that put them well beyond the limits of many studies to relocate them for recapture/data retrieval. Nonetheless, my study provides information on tracking and recapture techniques that might facilitate collecting location, movement, and behavior data on other age and sex classes of Barn Owls, in other seasons, to complete our understanding of seasonal, spatial, and life history-related trends in Barn Owl road mortality.

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Figure 3.1. Barn Owl nest boxes were plugged manually to capture owls for data logger attachment.

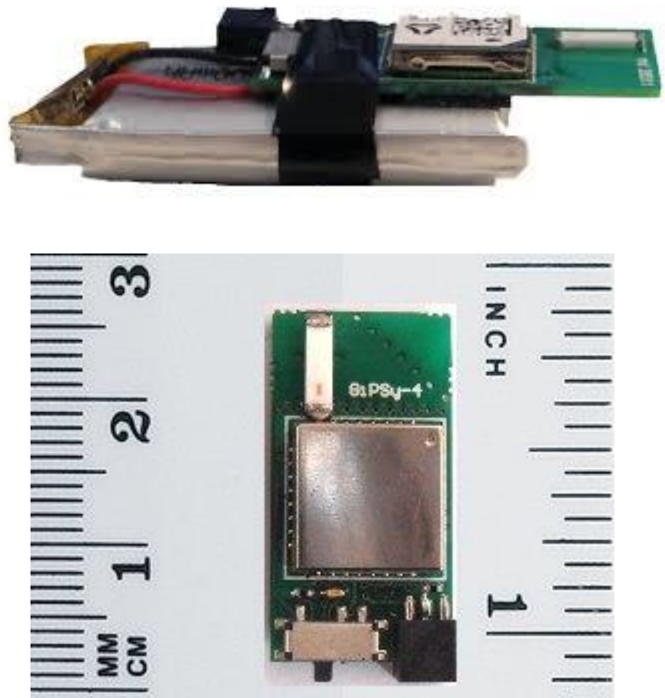

Figure 3.2. GiPSy 4 data-logger with rechargeable battery (manufactured by TECHNOSMART, Rome, Italy).

Figure 3.3. Backpack holding GPS data logger and VHF transmitter attached to an adult male Barn Owl near Jerome, Idaho, USA.

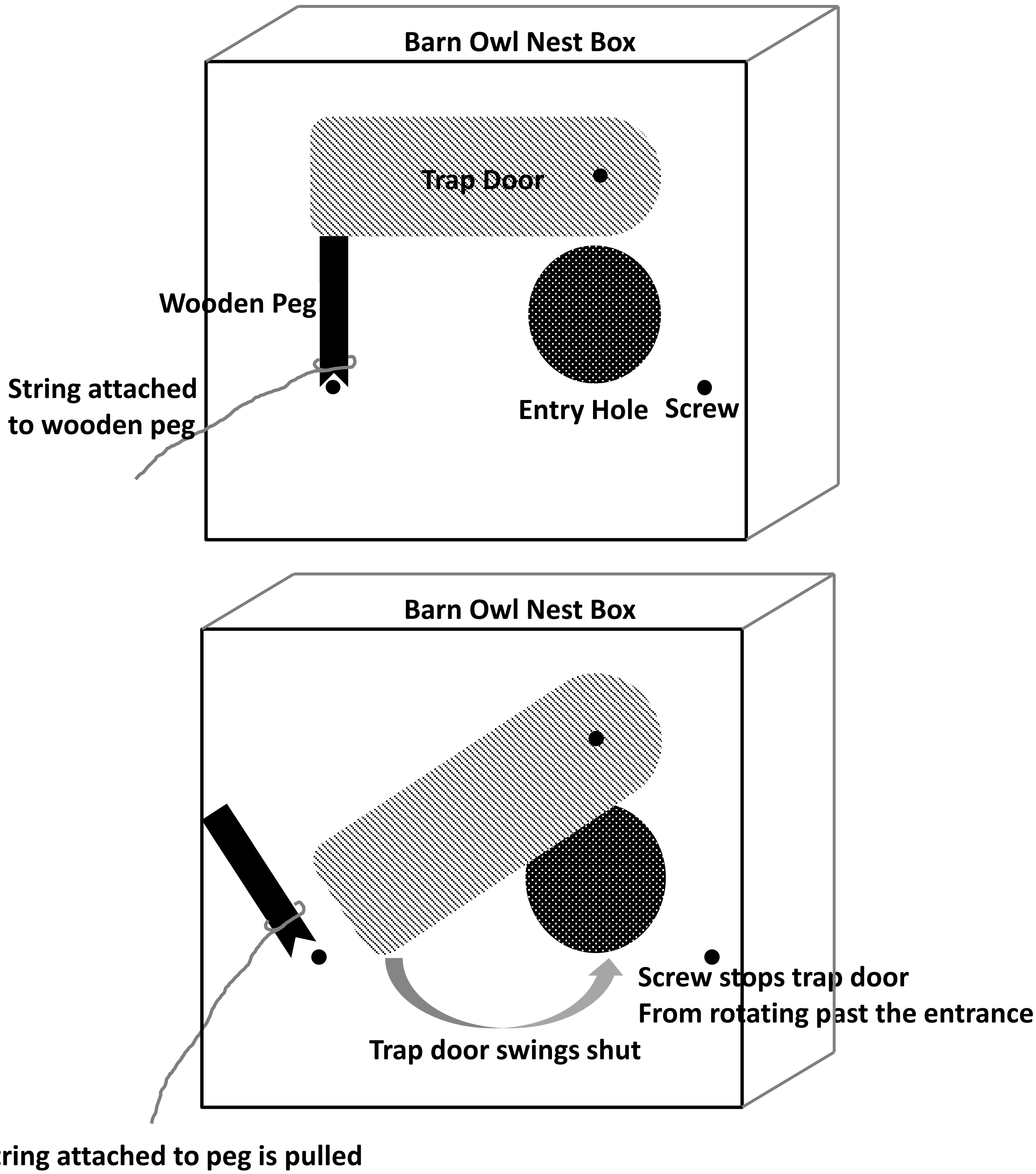

Figure 3.4. Diagram of manual-triggered wooden trap door affixed to Barn Owl nest boxes.

Figure 3.5. **Installation of laser-break triggered trap door on a Barn Owl Nest Box near CJ Strike Reservoir, east of Grand View, Idaho, USA.**

Figure 3.6. **Nest box with laser-triggered trap door installed. To the bottom left is the trigger mechanism and wooden peg used to hold the door open. The small black box on top of the box holds the Arduino Nano microprocessor and associated wiring. On the top left of the trap door is the weight used to adjust the center of gravity of the trap door so that it appropriately swung to cover the entrance.**

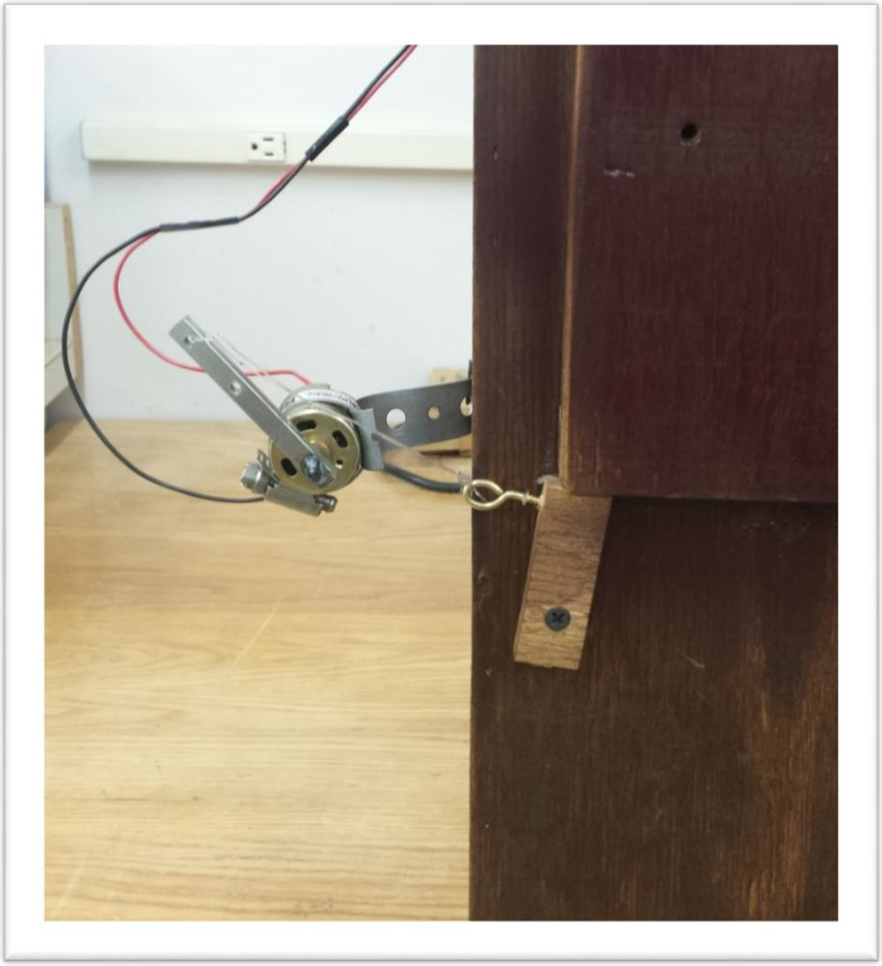

Figure 3.7. Photo of trigger mechanism on laser-trigged trap door. Monofilament line is attached to a wooden peg and connected to steel shank. After the laser-beam is broken, the motor in the trigger mechanism spins and rotates the steel shank, which in turn pulls out the wooden peg allowing the trap door to fall over the entrance hole.

Figure 3.8. **Photo of (A) photo resistor and (B) laser diode mounting on a Barn Owl nest box, both of which are held with foam inside small pieces of PVC pipe.**

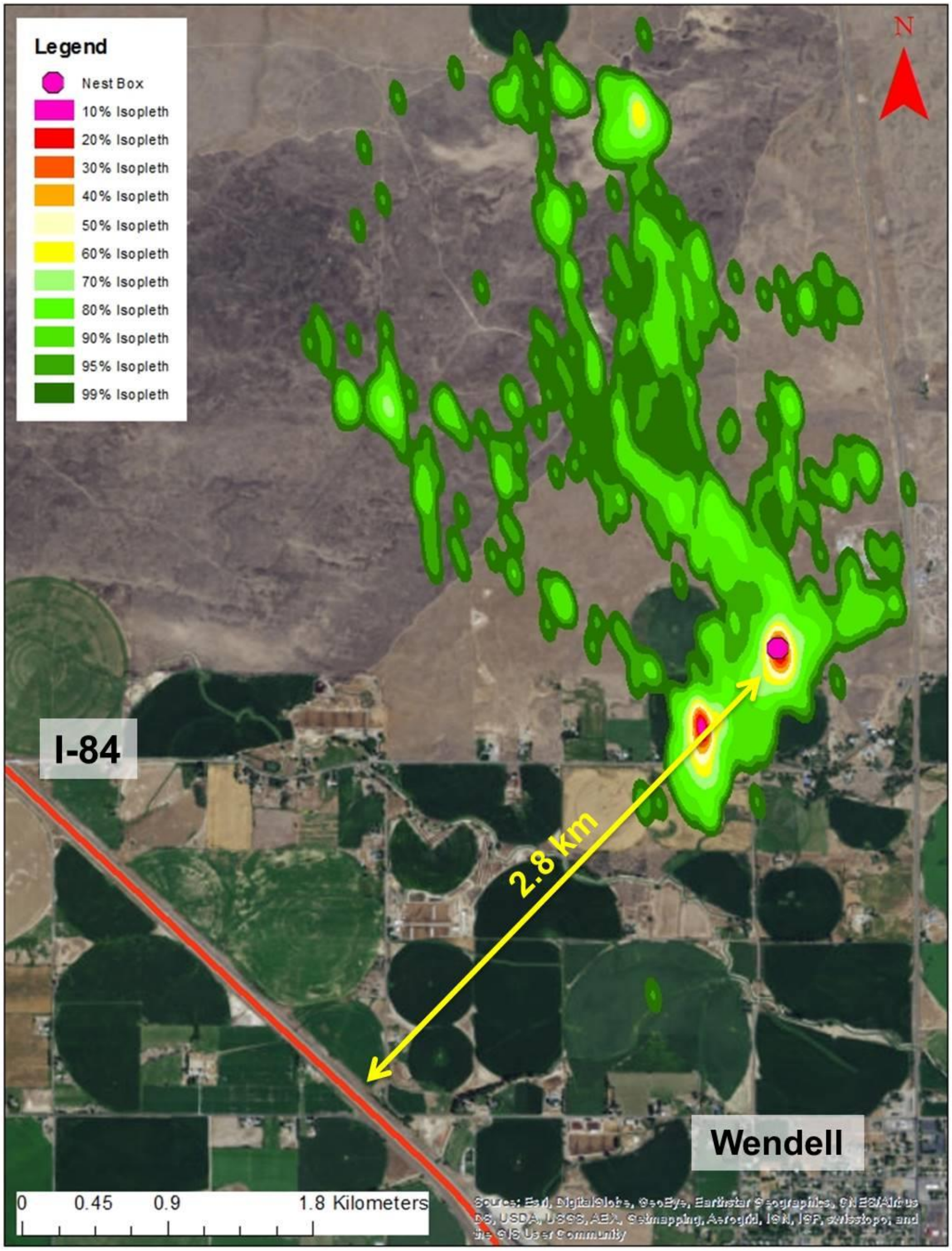

Figure 3.9. **Isopleth home-range map an adult male Barn Owl outside of Wendell in s. Idaho. The arrow shows the shortest straight-line distance from the nest box to Interstate-84.**

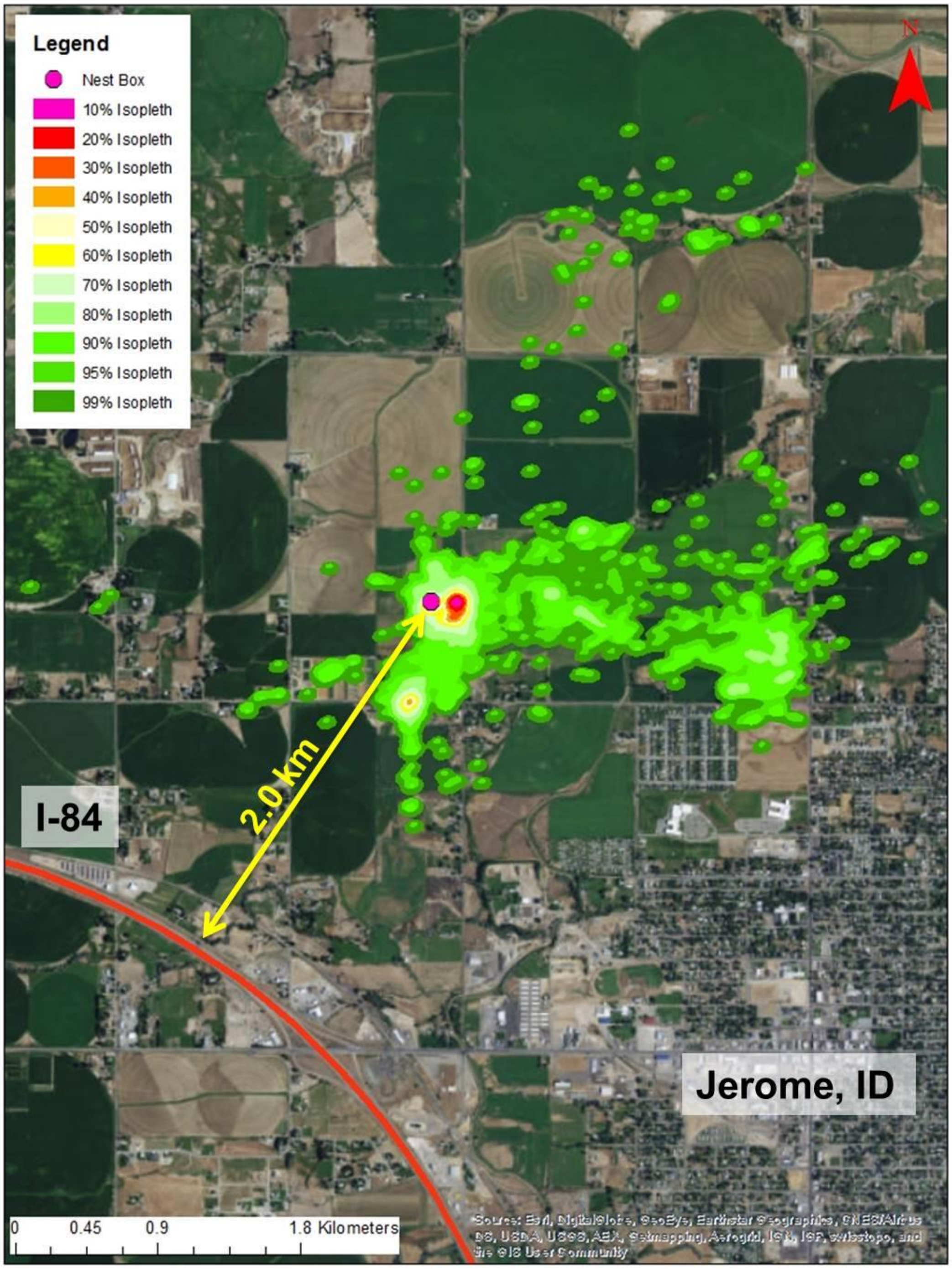

Figure 3.10. Isopleth home-range map an adult male Barn Owl outside of Jerome in s. Idaho. The arrow shows the shortest straight-line distance from the nest box to Interstate-84.

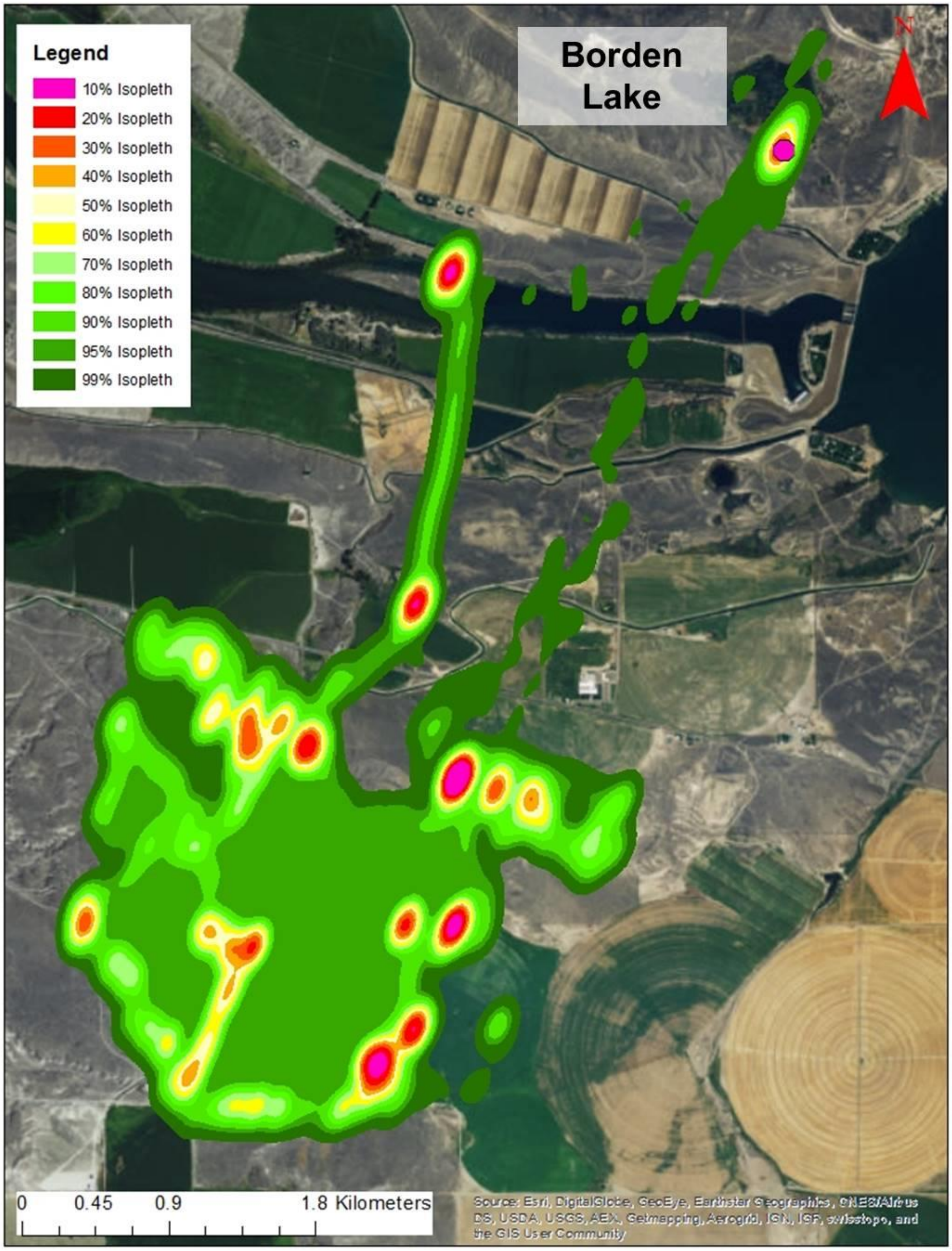

Figure 3.11. Isopleth home-range map of an adult male Barn Owl near Borden Lake in the CJ Strike Wildlife Management Area in s. Idaho.

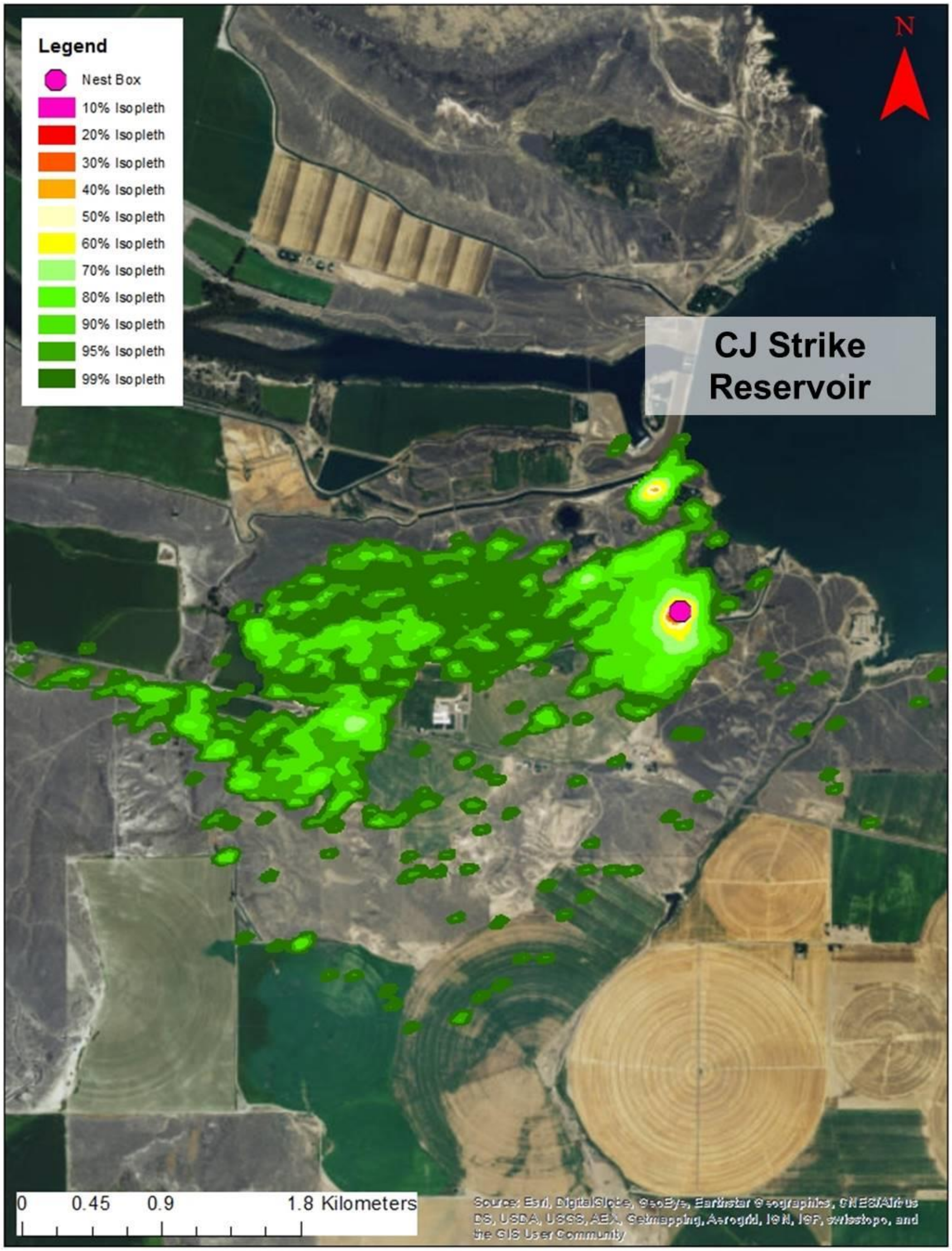

Figure 3.12. Isopleth home-range map of an adult male Barn Owl in the CJ Strike Wildlife Management Area, near CJ Strike Reservoir in s. Idaho.

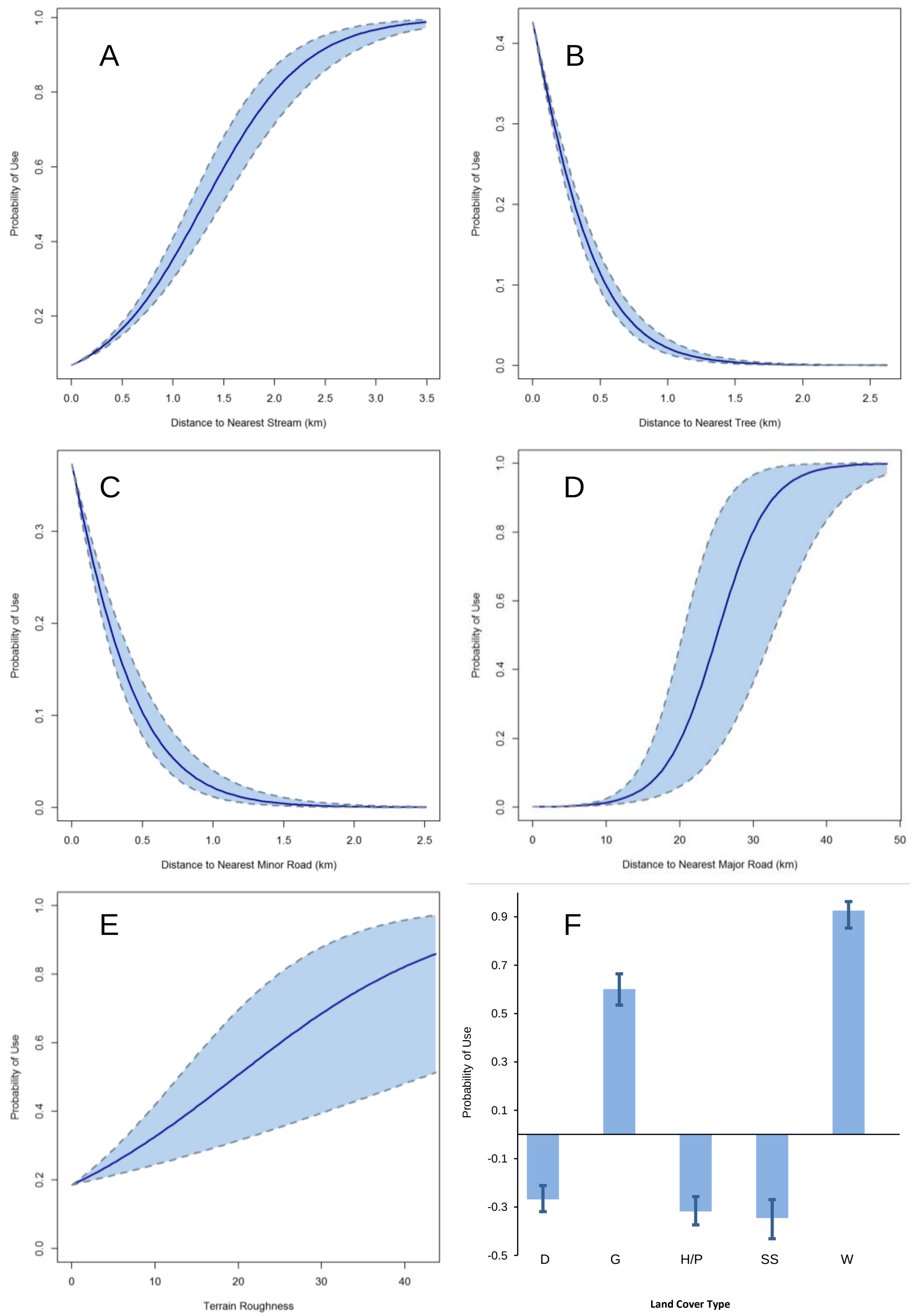

Figure 3.13. Relationship between probability of use (± 95% CI) by Barn Owls and (A) distance to the nearest stream, (B) distance to the nearest tree, (C) distance to nearest minor road, (D) distance to nearest major road, (E) terrain roughness, and (F) land cover type in reference to cultivated crops where D = development, G = grassland, H/P = hay/pasture, SS = sage steppe, and W = wetlands.

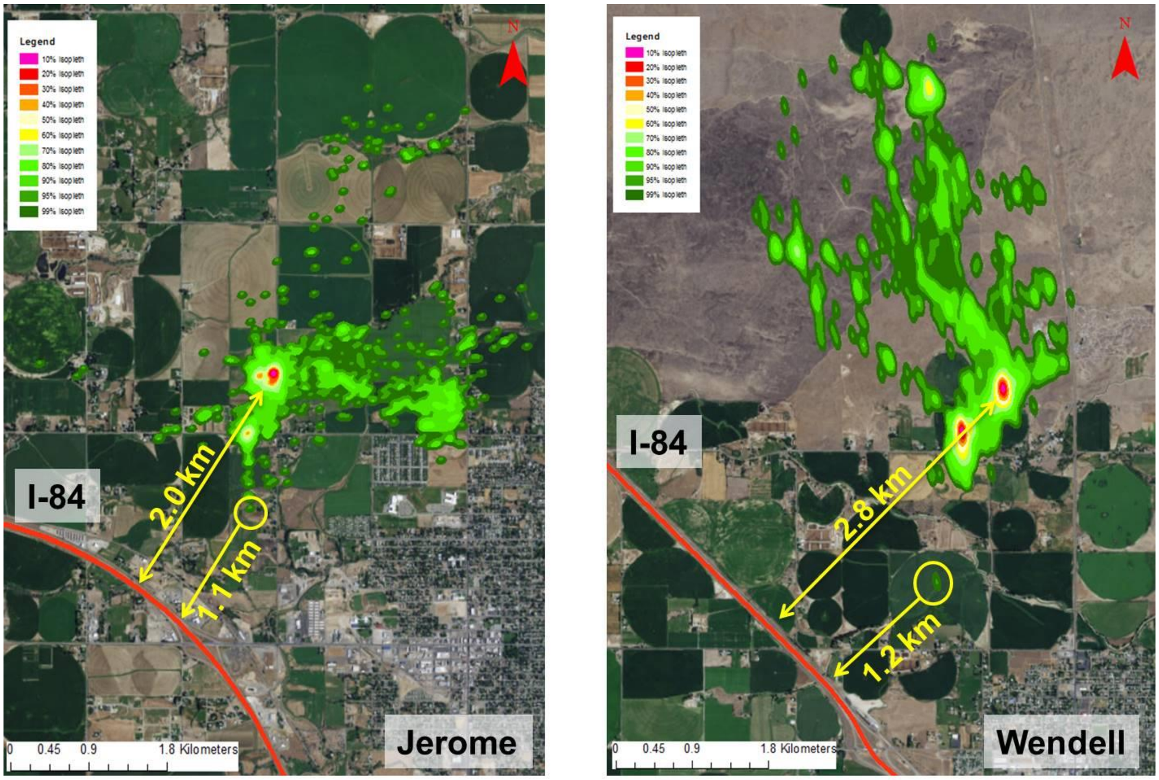

Figure 3.14. Home range maps showing proximity of nest boxes and closest movement to Interstate-84 of male Barn Owls in s. Idaho, USA.

Table 3.1 Summary of number of recapture attempts and successes for male Barn Owls nesting in nest boxes in s. Idaho, USA.

Recapture Method	Number of attempts (by night)	Number of Successes
Manual plugging during the day	8	0
Manual plugging during the night	6	1
Bal chatri trap	5	0
Mist Net	1	0
Manual-triggered trap door	6	2
Laser-break triggered trap door	2	1

Table 3.2 Operating times and location information from GPS data loggers placed on four adult male Barn Owls in s. Idaho, USA.

Barn Owl ID	Transmitter Operating Hours	# Locations	# Locations after HDOP >4 Filter	# Locations after 5 min Filter	Locations/night (mean ± SE)
Wendell	49.5	2,722	2,535	356	35.6 ± 3.23
Jerome	48.5	3,933	3,334	454	50.4 ± 5.87
Borden Lake	9	11,842	11,621	114	48 ± 4.49
Snake River Birds of Prey	48.5	4,353	3,915	509	56.6 ± 5.94

Table 3.3 Descriptive measurements of four instrumented male Barn Owls in s. Idaho, USA.

Barn Owl ID	Nest Box Distance to I-84 (km)	95 % Isopleth Home Range (km^2)	90 % Isopleth Home Range (km^2)	Maximum Movement (km)	Average Distance Moved Between Point Locations (m)
Wendell	2.78	1.79	1.0	3.04	71.9 ± 2.3
Jerome	1.97	0.93	0.50	3.15	83.8 ± 2.8
Borden Lake	31.07	3.48	1.80	5.06	55.7 ± 8.2
Snake River Birds of Prey	32.31	1.25	0.71	3.13	81.7 ± 2.1

Table 3.4 Number of used and available points, by land cover type, for analysis in a resource selection function on four GPS-tagged adult male Barn owls in s. Idaho, USA.

Land Cover Type	# Available Points	# Used Points	Total Points
Cultivated Crops	491	480	971
Wetlands	8	281	289
Sage Steppe	334	78	412
Grassland/Herbaceous	345	323	668
Hay/Pasture	367	126	493
Development	254	139	393
Total	***1799***	***1427***	***3046***

Table 3.5 Distance of used and available points from variables used for analysis in a resource selection function on four GPS-tagged adult male Barn owls in s. Idaho, USA.

Continuous Variables	Range	Mean ± SE
Used Points (n = 1427)		
Terrain roughness (slope, %)	0.0 – 43.7	3.5 ± 0.04
Distance to nearest tree (km)	0.0 – 2.6	0.3 ± 0.01
Distance to nearest minor road (km)	0.0 – 2.5	0.1 ± 0.00
Distance to nearest major road (km)	0.0 – 48.2	20.9 ± 0.38
Distance to nearest stream (km)	0.0 – 3.6	0.7 ± 0.01
Available Points (n = 1799)		
Terrain roughness (slope, %)	0.0 – 43.7	3.6 ± 0.04
Distance to nearest tree (km)	0.0 – 2.6	0.3 ± 0.01
Distance to nearest minor road (km)	0.0 – 2.5	0.2 ± 0.01
Distance to nearest major road (km)	0.0 – 48.2	23.7 ± 0.38
Distance to nearest stream (km)	0.0 – 3.6	0.7 ± 0.01

Table 3.6 Results of resource selection function analysis for four male Barn Owls in s. Idaho during the breeding season. Individual owl was included as a random effect and cultivated crops was used as a reference category for the categorical land cover variables.

Main Effect(s)	Parameter Estimate (β)	Parameter SE	P value	Odds Ratio (e^{β})
Intercept	-7.18	3.09	0.02	0.0001
Continuous Variables				
Slope	0.08	0.02	<0.001	1.08
Distance to Trees	-3.51	0.21	<0.001	0.03
Distance to Stream	2.01	0.12	<0.001	7.46
Distance to Minor Road	-3.28	0.32	<0.001	0.04
Distance to Major Road	0.28	0.03	<0.001	1.32
Land Cover Variables				
Wetlands	2.52	0.38	<0.001	12.42
Sage Steppe	-0.64	0.18	<0.001	0.529
Grassland/Herbaceous	0.41	0.14	0.003	1.508
Hay/Pasture	-0.76	0.13	<0.001	0.468
Development	-1.00	0.14	<0.001	0.368
Random effect = individual owl, Variance = 35.49, SD = 5.98				

APPENDIX

Parts and Programming for Laser-Trigger Trap Door

Introduction

Contained in this appendix are the methods of building and programming the laser and trigger mechanism for the laser-break triggered trap door which was used to successfully recapture male Barn Owls instrumented with GPS data loggers in southern Idaho, USA. See the primary manuscript for a full description of field methods used for trap door installment and use.

Methods for Building the Laser

Parts List

1 – Arduino Nano microprocessor

1 – 8000RPM 9v 68mA high torque magnetic cylindrical mini DC motor

1 – 5V 5 mW red laser diode

1 – 50-100K ohm photoresistor

2 – 2 in x ¾ in PVC pipe segments

2 – foam to fit inside PVC pipe

Black paint - for painting PVC pipe

Various colors – 22awg multi-strand wire

2 – 9v batteries

2 – 9v battery holders

1 – SPST power switch

1 – 5mm 15-18ma 3.2v LED

1 – 120 ohm 1/8w resistor

1 – 5v relay shield for the Arduino Nano microprocessor

1 – small plastic box to enclose all parts and protect them from weather

<u>Electronics</u>

A laser diode was held with foam inside a small piece of black PVC pipe (2 in x 0.75 in). The laser was mounted below the door and directly below the center of the nest box entrance. Another black PVC pipe was mounted above the door and inside this one a photoresistor was held in place with foam. The function of the photoresistor was to resist an electrical current if exposed to light. In this way, the beam of the laser passed vertically across the widest part of entire entrance hole, and when powered, created a point of light that covered the entire face of the photoresistor but no more. This created the highest possible resistance values from the beam itself. The photoresistor was placed on the top to minimize effects of ambient light, which could prematurely trigger the door. I programmed the triggering mechanism with a 2.5 second delay such that after the laser beam was broken there would be 2.5 seconds before the trigger pulled the metal peg causing the door to fall. This was important to reduce the chance of injuring an owl as it attempted to enter the nest box. A microcontroller (Arduino Nano microprocessor; Arduino 2016) was programmed to flash a white light that would signal observers that the laser had been triggered.

The Arduino Nano microcontroller (Arduino 2016) was wired to both the photoresistor and the laser diode. The photoresistor was connected to A1 and ground for an input signal, and the laser diode was connected to D10 and ground where D10 was set as a digital output to power the laser. This allowed the laser to be manually turned on and off with the microcontroller. A relay shield was connected to D12 (set to digital output power), ground, and the switching leg of the relay was connected to D13. Two 9v batteries were used, one to power the Arduino, and one to provide power to a motor that either held open or triggered the metal peg holding the trap door open. The switch portion of the relay switched power to the motor when the relay was closed via the microcontroller. The motor had a small piece of steel stock attached to it to give it enough momentum to release the latch mechanism holding the trap door up.

Code Explanation

The main functions of the code were to constantly read the value of the laser beam-break setup, adjust it based on ambient light conditions, and to trigger the latch mechanism if the laser beam was broken. When the laser was shining on the photoresistor, a lower value for the analog pin of the Arduino Nano microprocessor (Arduino 2016) was recorded. When the laser beam was broken, the resistance decreases and high values were recorded; this is what resulted in the motor spinning and pulling the metal shank and wooden peg out from under the trap door. I tested the laser in the lab to determine the average value created by the photoresistor when the laser beam was shining on it under ambient light conditions. Next I tested the laser to determine what the average value of the photoresistor was under little, to no light conditions. The range between the values under *different* levels of ambient light and low light stayed relatively constant; values just shifted higher under more light and lower under less light. From this, the trigger mechanism was programmed to make a "rolling average", where the sensor would constantly adjust itself by averaging the light it received over 50 sec intervals, reset its average and then re-start the process. This meant that as dusk approached and ambient light decreased while the machine was on, it would adjust itself to avoid prematurely triggering the trap door.

For the trap door to be triggered, the code was based on a range above and below the rolling average. If the Arduino Nano microcontroller received a number 1.25 times higher than the rolling average, it registers that the laser beam has been broken. During the time the beam is being broken, the microcontroller stays in a loop to prevent the trap door from triggering while something is passing through the nest box entrance. Once the laser beam is no longer being broken, a timer starts and after ~ 2.5 sec trap door is triggered and falls. If the beam is broken again while the countdown is happening, the microcontroller enters the loop again to keep the door from shutting, and the trap door timer resets back to 2.5 sec. In this way, I hoped to avoid injury to any owls entering the box. Once the trap door has been triggered, the microcontroller activates the relay, which sends power to the motor. The motor spins, pulling the steel shank with its microfilament line tight enough to pull the wooden peg out from underneath the trap door and the trap door falls. Once the trap door has been triggered, a status light on the outside of the box blink white to show that the trap has been sprung.

<u>Arduino Nano Microprocessor Code</u>

```
int irPin = 10;
int sensorPin = 1;
int relayPin = 12;
int relayPwr = 13;
int statusLED = 11;
unsigned long rollAvg = 0;
unsigned long rollCount = 0;
unsigned long rollValue = 0;
```

```
bool startup = true;
unsigned long lineCheck = 0;
bool trapSprung = false;
bool springTrap = false;
int trapCount = 0;

void setup() {
pinMode(irPin, OUTPUT); //laser pin
pinMode(statusLED, OUTPUT); //status led pin
pinMode(relayPin, OUTPUT); //relay pin
pinMode(relayPwr, OUTPUT); //relay power pin (~5V)
pinMode(A1, INPUT); //photoresistor
digitalWrite(irPin, HIGH); //turn on laser
digitalWrite(statusLED, HIGH); //turn on status LED
digitalWrite(relayPin, LOW); //turn off relay
digitalWrite(relayPwr, HIGH); //turn on relay power
Serial.begin(9600); //start the serial port
}

void loop() {
//if the trap has not already sprung, start the loop. If it has, blink the led (code at the bottom)
if (trapSprung == false) {
```

```
if (springTrap == true) { //if the command to spring the trap is counting down but less than 2.5 seconds
  if (trapCount < 50){ //counter used to determine how long it has been
    trapCount ++; //add 1 to the trapCount
    Serial.print("springTrap, count "); //debugging
    Serial.println(trapCount); //debugging
  }
  //if the command to spring the trap is counting down and it time is > 2.5 seconds, spring the trap
  else if (trapCount >= 50){
    Serial.println("Trap Sprung!");//debugging
    trapCount = 0; //reset the trapCount
    trapSprung = true; //set the variable to true so that the trap does not try to spring again
    digitalWrite(relayPin, HIGH); //turn on the motor relay to spring the trap
    delay(2000); //wait 2 seconds
    digitalWrite(relayPin, LOW); //turn off the motor relay
    digitalWrite(irPin, LOW); //turn off the Laser
  }

}//spring trap end
```

```
if (startup == true && rollCount > 50) { //initialization of the laser/photoresistor - wait 2.5 seconds before reading values
  startup = false; //turn of startup sequence
  digitalWrite(statusLED, LOW); //turn off the status LED
  Serial.println("Startup to false"); //debugging
}

lineCheck = analogRead(A1); //read the value of the photoresistor
if (startup == false && (lineCheck > (1.25 * rollAvg))) { //if the value of the photoresistor is 1.25 times higher than the average, trigge the trap
  while (lineCheck > (1.25 * rollAvg)) { //use a while loop to make sure that the trap does not spring while the line is broken (no owl guillotine needed)
  Serial.println("LINE BROKE");//debugging
  delay(50); //wait .5 seconds before reading again
  lineCheck = analogRead(A1); //read the sensor again, if it is still broken we remain in the while loop, if not then exit
  }
 springTrap = true; //lets spring the trap
 trapCount = 0; //resets the trap count because line was broken
 Serial.println("Spring trap true"); //debugging
}
```

```
//rolling average counter, adjusts the set point to trigger the trap based on the changing ambient light
if (rollCount == 0) { //if roll count is 0, we have not started averaging yet
  rollCount = 1; //set to 1 to start averaging - need this for starting an average
  rollValue = analogRead(A1); //read the photoresistor
  Serial.println("values initialized"); //debugging
}
else if (rollCount < 1000){ //if the rolling average has been through less than 1000 cycles (~50 seconds), continue averaging
   if (rollValue < 500){ //if the value of the resistor is less than 500, something is wrong - reset the average
      rollCount = 1; // reset the roll count because of this abnormal value
      rollValue = analogRead(A1); //read again
      rollAvg = analogRead(A1); //set the average to the reading
     }
     if (analogRead(A1) >= (0.90 * rollAvg)){ //if the current reading is more than 90% of the average, add it to the average
       rollCount = rollCount + 1; //add 1 to the count for averaging
       rollValue = rollValue + analogRead(A1); //add the current value to the unaveraged sum of values
       rollAvg = rollValue / rollCount; //average the unaveraged sum
       //Serial.println(analogRead(A1)); //debugging
       //Serial.println(rollValue); //debugging
```

```
            //Serial.println(rollAvg); //debugging
            //Serial.println(rollCount); //debugging
            }
           else if (analogRead(A1) <= (0.90 * rollAvg)) { //if the value is less than
90$ if average, print an error
            Serial.println("Sensor Error: sensor, value, avg, count");
            Serial.println(analogRead(A1));
            Serial.println(rollValue);
            Serial.println(rollAvg);
            Serial.println(rollCount);
            }
          }
          else if (rollCount >= 1000){ //if the number of values averaged is greater than
1000, start the rolling average over
           rollCount = 1;
           rollValue = analogRead(A1);
           rollAvg = analogRead(A1);
           Serial.print("Roll avg reset to ");
           Serial.println(rollAvg);
           //delay(1000);
          }

        }// end of trap sprung = false
```

```
    else if (trapSprung == true) { //if the trap has been sprung, make the status LED blink
      digitalWrite(statusLED, HIGH);
      delay(1000);
      digitalWrite(statusLED, LOW);
      delay(1000);
      digitalWrite(statusLED, HIGH);
      delay(1000);
      digitalWrite(statusLED, LOW);
      delay(1000);
    }
  delay(50);
  }//end void LOOP
```

Literature Cited

Arduino. 2016. Accessed online <https://www.arduino.cc/en/Main/ArduinoBoardNano>.

Arduino Nano Front   Arduino Nano Rear

Figure A1.1. Arduino Nano microprocessor used to control laser, photo resistor, and triggering mechanism functions for the laser-break triggered trap door (Arduino 2016).