SPACE USE, HABITAT SELECTION, GENETIC VARIATION AND POST-FLEDGING ECOLOGY OF NORTHERN PYGMY-OWLS (*GLAUCIDIUM GNOMA*) IN NORTHERN IDAHO

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Authorization to Submit Dissertation

This dissertation of Harry R. Jageman, submitted for the degree of Doctor of Philosophy with a major in Natural Resources and titled "Space Use, Habitat Selection, Genetic Variation and Post-Fledging Ecology of Northern Pygmy-Owls (*Glaucidium gnoma*) in Northern Idaho," has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

In this dissertation, I investigate various aspects of the ecology of Northern Pygmy-owls (*Glaucidium gnoma*) in Northern Idaho. The dissertation includes three chapters and a previously published article on post-fledging ecology (Frye and Jageman 2012). Chapter one examines space use and habitat selection of Northern Pygmy-Owls. To test for habitat selection, I developed forty-one *a priori* models and used two different analysis methods (logistic regression and the synoptic model) to compare results. Results were similar between methods and indicated that two variables (vegetation structural stage) and (distance to stream) were most important in predicting the probability of use by Northern Pygmy-Owls, which selected forested habitats with larger tree sizes and preferred areas closer to stream courses.

Chapter two discusses losses of Northern Pygmy-Owls to intraguild predation by larger raptors. The study suggests Northern Pygmy-Owls utilizing fragmented landscapes are more vulnerable to predation loss than their counterparts that utilize more forested landscapes.

In chapter three, I examine genetic variation of Northern Pygmy-Owls in Idaho as compared to individual owls from Montana and British Columbia. I found no genetic differences or clustering in samples from Idaho, Montana, or British Columbia. No unique alleles were found in either Montana or British Columbia that distinguish them from Idaho birds, despite these populations being 300-500 kilometers (km) from the Idaho population. Thus, the results did not corroborate the current subspecies status of *G. g. swarthi* of British Columbia and *G. g. pinicola* of Idaho and Montana. Genetic analysis accurately (100%)

assigned gender to birds of known sex and in most other instances was congruent with the "projected" gender that was assigned by owl weight and behavior prior to DNA analysis.

In appendix H, I incorporate an earlier article that was published in the Wilson Bulletin in June 2012 (Frye and Jageman 2012). This article discusses post-fledging behavior of Northern Pygmy-Owls from this study and a similar study in Western Montana. Northern Pygmy-Owl adults were found to continue to feed and associate with their young for 9 to 34 days following the departure of the young from the nest.

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Dedication

This work is dedicated to my wife Mary Ann for her generous support and tolerance of my efforts on this project and to my parents Harry R. Jageman, Sr. (1927-1988) and Nancy Jane Jageman for the values and love of outdoors that they instilled in me at an early age.

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Chapter 1

Habitat Selection and Space Use of Northern Pygmy-Owls in Northern Idaho

1.1 Abstract

I examined space use and habitat selection of Northern Pygmy-Owls (*Glaucidium Gnoma*) in Northern Idaho using a variety of different methods. To evaluate space use I estimated home range size using fixed kernel, adaptive kernel, two mode bivariate normal and minimum convex polygon methods. I compared these “traditional” methods of analyzing space use to a newer method of analyzing space and habitat use called the synoptic model (Horne et al. 2008, Johnson et al. 2008). Space use was estimated for seasonal ranges because the battery life of the radio transmitters placed on these small owls is only 11 to 14 weeks and space use potentially changes in different seasons. A total of 26 radio-tagged owls were captured during the study, but only 16 owls had a sufficient number of locations (at least 29) to be utilized in the study. Using synoptic methods, I determined the average seasonal range size was 306 hectares. This compared to an average of 276 hectares using more traditional methods.

Habitat selection was evaluated with two different methods. The first method applied simple logistic regression as described by Manley et al. (2002) to estimate the resource selection function. In using this method, I compared actual radio locations of individual owls to randomly selected points within a 2500 meter radius circle of each owl’s area of use. For the second method I again used the synoptic model (Horne et al. 2008, Johnson et al. 2008). To test for habitat selection, I developed forty-one *a priori* models and used the two different analysis methods (logistic regression and the synoptic model) to

compare the results. I selected the "best" models using Akaike's Information Criterion (AIC; Akaike 1973). Results were similar with both methods and indicated that two variables (Vegetation Structural Stage) and (Distance to Stream) were most important in predicting the probability of use by Northern Pygmy-Owls, which selected forested habitats with larger tree sizes and preferred areas closer to stream courses than available.

1.2 Introduction

The Northern Pygmy-Owl is a small (60-70 grams) owl species found in Western North America. Their range extends from Southern Alaska to Northern Mexico and is largely centered in forested areas of coastal British Columbia, Washington, Oregon and California. They are also found in forested areas of the Rocky Mountains in in Idaho, Montana, Colorado and Arizona and considered "one of the least studied owls on the continent" (Holt and Petersen 2000, pg. 1).

Only one radio telemetry study of this species on the Olympic Peninsula of Western Washington has been reported (Giese and Forsman 2003). In that study (page 117) it was suggested that "Structurally diverse and older forests were most heavily used" by Northern Pygmy-Owls. However, an older observational study (Hayward and Garton 1988) suggested that the species is a "habitat generalist". Giese and Forsman (2003) found the average breeding season home range for male owls was 296 ± 42 ha by the minimum convex polygon method and 209 ± 28 ha for the fixed kernel method. Northern Pygmy-Owls are thought to be non-migratory, but appear to move to lower elevations or more southerly locations in response to snowfall and cold weather (Hannah 1999, Holt and Petersen 2000).

The intent of this chapter is to increase the basic understanding of the ecology of this species and to help to clarify discrepancies in the literature regarding space and habitat use. Although I have used a variety of methods to achieve this goal, my intent is merely to produce the best possible results regarding Northern Pygmy-Owl habitat and space use. When I have used more than one method to evaluate habitat and space use, my intent is to display to the reader how results might vary with newer techniques as compared to more traditional approaches. It is not my intent to evaluate the pros and cons of different analysis methods in this dissertation.

I have used the latest techniques in evaluating resource selection and space use including the "synoptic model" of space use (Horne et al., Johnson et al. 2008). That approach uses maximum likelihood methods to simultaneously estimate home range as a probability density function and incorporates resource selection functions that can be used to identify preferred habitats. This approach has a distinct advantage over traditional methods that require defining available habitat and do not incorporate habitat into the estimation of home range space use.

I have compared this approach to more traditional methods that evaluate resource selection and home range use separately rather than simultaneously. For example, I have used logistic regression to compare radio telemetry locations to randomly generated habitat points within a 2500 meter circle of each owl's center of use. This approach compares "used" locations with a sample of points that are assumed to represent the "available" habitat. Determination of "available habitat" is always difficult with traditional methods as in this case where we are not sure if the area within the 2500 meter circle is actually what is available to each owl. I have used a variety of traditional home range estimation methods such as fixed kernel analysis and minimum convex polygon methods to estimate seasonal range size from the known radio locations. Unlike the synoptic model, traditional methods of home range estimation do not consider underlying habitat conditions and generally rely on mathematical formulations that assume uniform habitat or sharp boundaries.

1.3 Methods

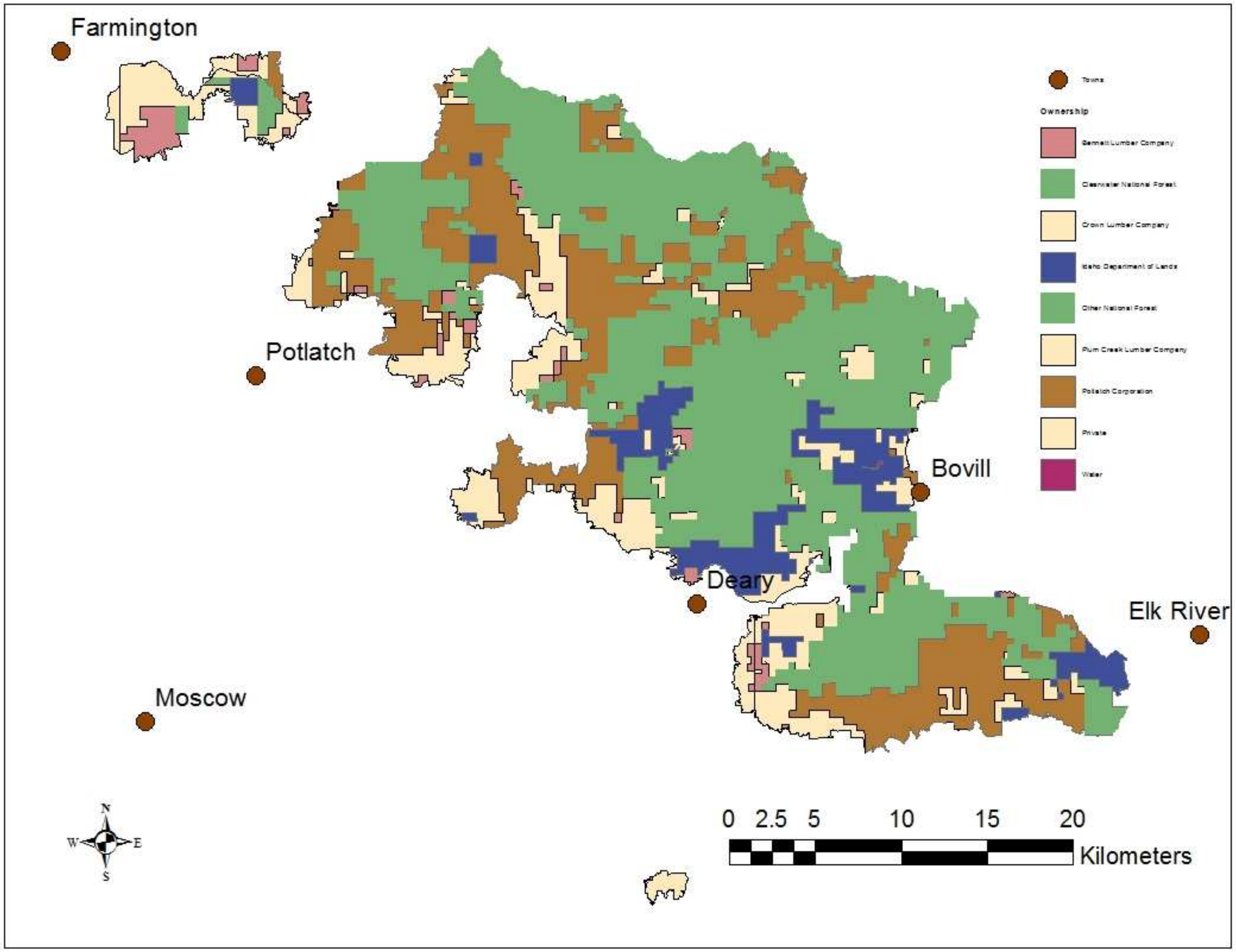
1.3.1 Study Area

The study area is located in North Central Idaho near the town of Moscow, Idaho. Most land within the study area is found within the confines of the Palouse Ranger District, Clearwater National Forest. These lands are intermingled with industrial forest lands and ownership is almost equally divided between national forest (43,650 hectares) and State and private lands (44,112 hectares). Potlatch Corporation is the dominate owner of private lands (21,996 hectares) and the State of Idaho manages approximately 7% of the study area (6,373 hectares). Bennett lumber manages 1853 hectares or approximately 2% of the study area. Total area in the study area is approximately 87,762 hectares and elevation ranges from 468 meters to 898 meters (Figure 1.1 – Study Area and Land Ownership).

Some of the most mesic forests in the Rocky Mountains are found in the study area, largely due to the influence of Pacific maritime flows that bring moisture to the area (Cooper et al.1991). Hejl (1995 pg. 221) described the area as part of the “Cascadian Forest” largely due to the presence of “species typically found in the Cascade Mountains of the Pacific Northwest”. Forest habitat types (Cooper et. al. 1991) are dominated by western red cedar (*Thuja plicata*), with grand fir (*Abies grandis*) habitat types occurring as inclusions on drier south slopes.

Forest stands are generally composed of a mixed conifer association with grand fir being the most dominant species at this time. Historically, many stands in the area contained a high component of western white pine (*Pinus monticola*); Western larch (*Larix occidentalis*), western red cedar and Douglas-fir (*Pseudotsuga menziesii*) are common stand associates. Ponderosa pine (*Pinus ponderosa*) is limited in distribution and is generally found on drier south slope inclusions. There are minor amounts of lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*) within frost pockets (generally associated with low elevation meadows) and at higher elevations. Because of the good growing conditions and high value of the forest stands in the study area, there has been a long history of forest management. In the past, logging treatments generally focused on even-age systems with clearcutting being the dominant silvicultural treatment. However in recent years there has been increasing use of shelterwood, seed tree and group selection regeneration harvest prescriptions (Smith 1962). In many cases, the leave trees associated with these prescriptions are not being removed following seedling establishment, as would have been the standard approach a few years ago. The trees are left as sources of structural diversity in the developing stand. There has been an increasing amount of intermediate treatment, with prescriptions that generally follow traditional commercial thinning or stand improvement practices (Smith 1962). Increased emphasis has been placed on these types of prescriptions and fuel reduction, as a result of concerns about increased fire risk. Less popular has been the use of uneven age management or non-traditional variable retention prescriptions (Kohm and Franklin 1997).

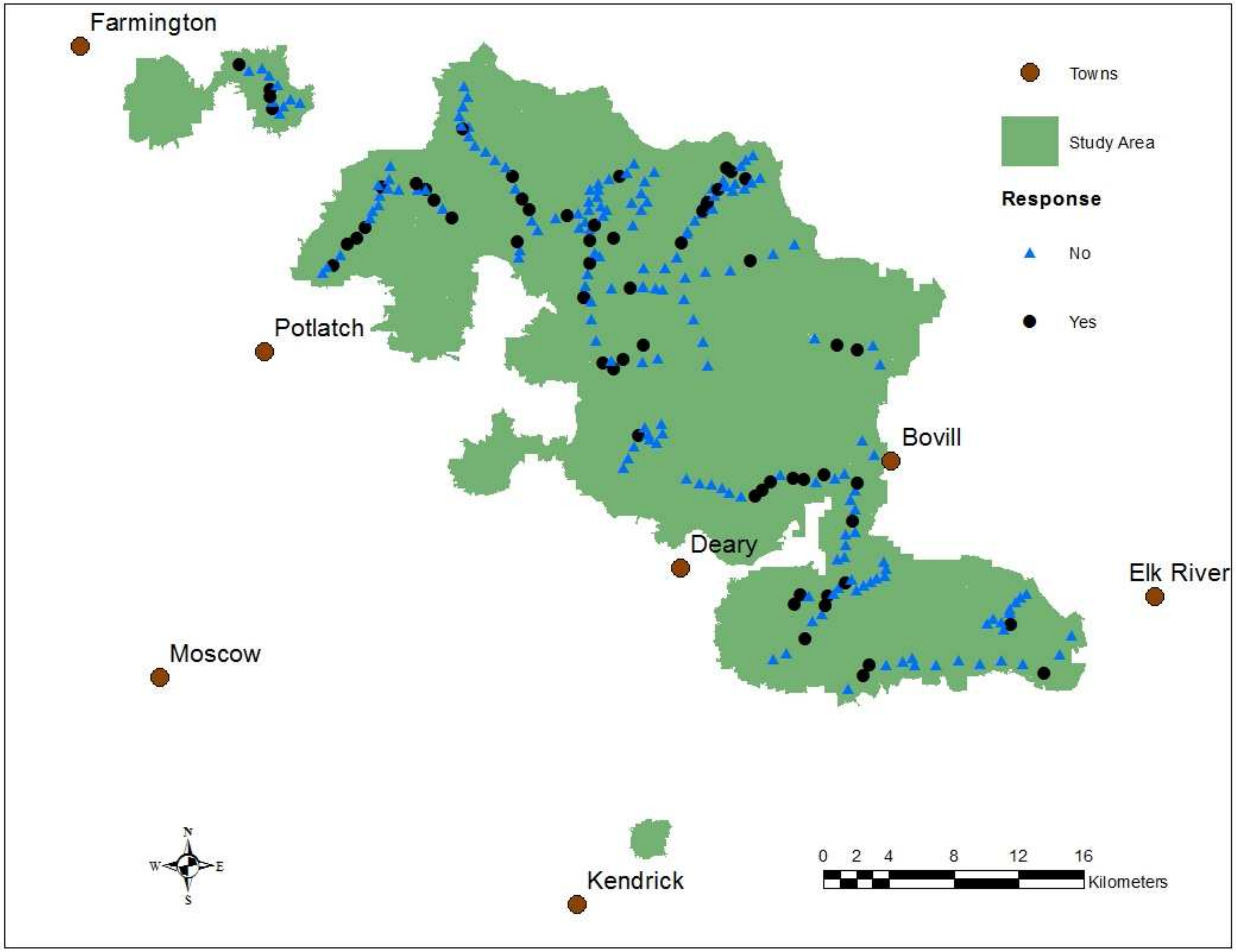
Figure 1.1 – Study Area Showing Land Ownership



1.3.2 Acoustical Surveys

I conducted acoustical surveys throughout the project area from May 2006 to October 2007 to identify potential use by Northern Pygmy-Owls (See Figure 1.2). The purpose of these surveys was to establish abundance and locate owls for future trapping. Surveys were conducted along open and gated roads using recordings of Northern Pygmy-Owl calls. A FoxPro game caller was utilized to broadcast calls which were played at 1609 or 3219 meter intervals along the roads. The initial interval length of 1609 m was selected based on the literature (Piorecky and Prescott 2006) and modified later to 3219 m to test if there might be a possibility that some owls were being double counted. Surveys were conducted during both spring (April to June) and fall (September to October) based on previous reports that Northern Pygmy-Owls actively called during these seasons (Sater 1993). Surveys consisted of a 10 minute calling and listening session at each station and were conducted between the hours of 6:00 AM and 12:00 Noon (Piorecky and Prescott 2006, Sater 2006). I began each survey count by silently listening for two minutes for unsolicited calls and after that I alternated between playing the recorded calls and listening for responses of nearby owls. I used the proportion test function (prop.test) in program R (Wilson 1927, Newcombe 1998a, Newcombe 1998b, R Development Core Team 2012) to test if there was any significant difference between the different spacing intervals (1609 m vs. 3219 m) and season of use (spring vs. fall).

Figure 1.2 – Distribution of Study Area Call Stations



1.3.3 Capture and Radio Telemetry Locations

I used the acoustic surveys to locate owls and targeted those locations with subsequent trapping efforts. I did not capture owls across the entire study area, due largely to logistical constraints. Transport of capture equipment would have been difficult and time consuming in unroaded portions of the study area. Also, access to upper elevation areas was difficult especially in the spring when roads were blocked by snow. As a result I tended to concentrate capture efforts near open and gated roads and at lower elevations (Figure 1.3).

Pygmy-Owls were trapped from September 2006 to July 2008 and fitted with radio-transmitters following methods outlined by Giese and Forsman (2003). Owls were captured in mist nets or balcha-tri traps and live pet store mice were utilized as bait. I lured owls to the general trapping location by utilizing acoustic calls. Transmitters were attached using the crisscross backpack method (Smith and Gilbert 1981) and were secured with 80 pound test Teflon-coated Dacron braided fishing line. I was unable to re-trap any owls during the study. The battery life of the transmitters varied from 11 to 14 weeks depending on the weight and model of the transmitter (1.4-1.8 gm Holohil Systems Ltd., Carp, ON, Canada - Model BD-2).

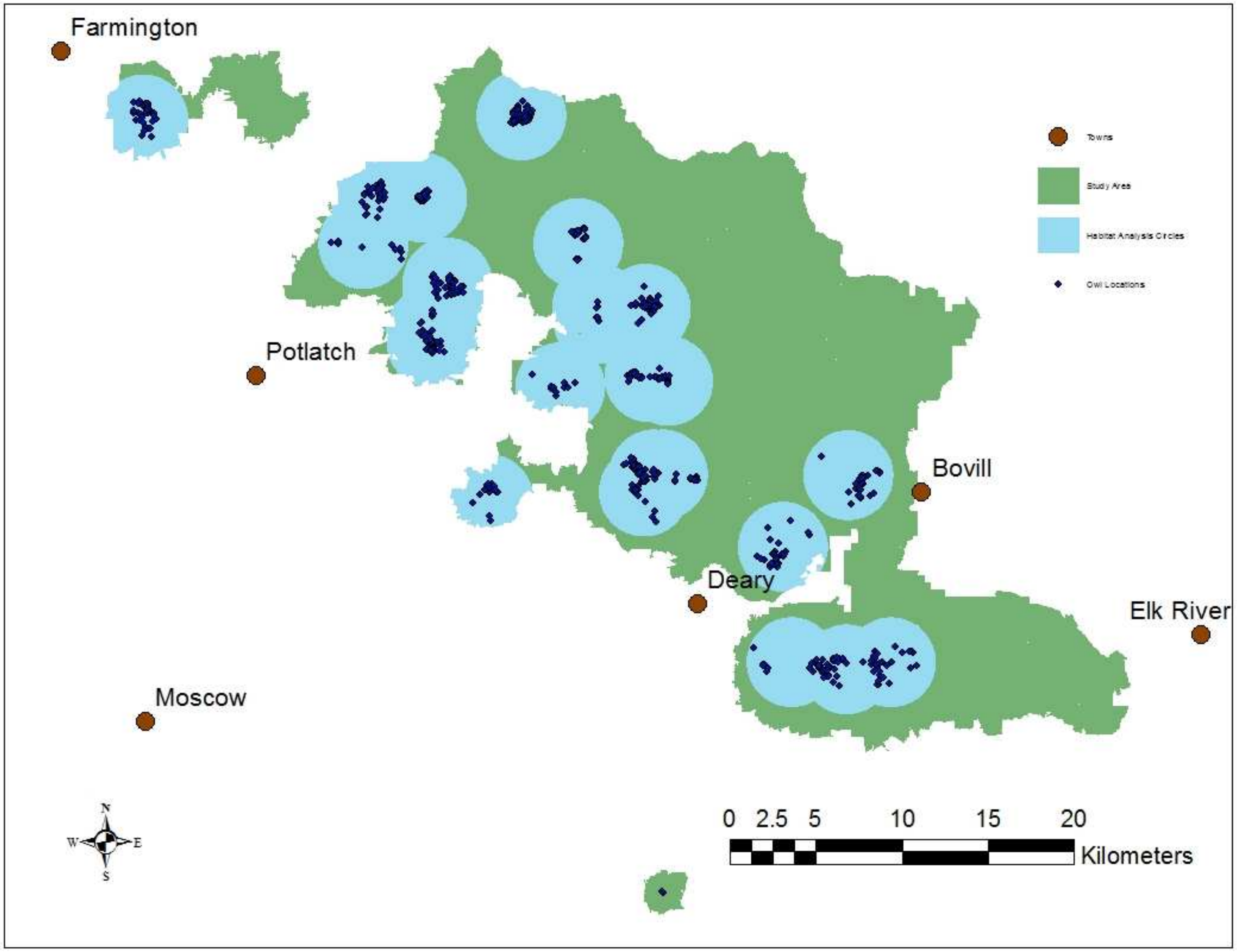
Locations were determined by VHF methods using both triangulation and homing to the owl, until the owl was either seen or a very strong radio signal could be obtained. Strong signals were assured by removing the hand-held antenna on the tracking unit and moving toward the owl until the signal strength meter of the receiver (Communications Specialists Model R-1000, Orange, California) was at or near the maximum level. Observed owls were usually seen within 15 meters of the observer when signal strength was this high.

Visual observations and radio tracking responses suggested little movement of owls in response to the presence of researchers. Because of the dense and tall forests where these owls were found, I had few visual observations of these small cryptically colored birds. It is likely that they felt very secure even when researchers were nearby. Once the researcher either saw the owl or was satisfied he was as close as possible, GPS coordinates and error estimates were recorded using a handheld GPS (Garmin Inc., Kansas City, Kansas)

Triangulations from known points were mapped using the program Locate II (Nams 2000). Locations with a 95% probability error ellipse (Nams 2000) exceeding 19.6 hectares (approximate radius equal to 250 meters) were eliminated from the analysis. A minimum of three bearings were used for all locations and an effort was made to complete all bearings within a half hour of each other.

Locations were generally recorded every two or three days for each of the radio tagged birds. Owls were followed for the life of the radio transmitter or until discovered as a mortality (10 of 26 owls were lost to larger raptors during the study duration). Three birds apparently exited the study area or their transmitters failed and could not be relocated. Occasionally, owls were followed more intensively over the course of one day. When birds were visible, researchers often spent longer periods of time observing bird behavior. This sometimes resulted in new locations as birds moved around over the course of the observation period. Due to the dense forests where these owls were found, movements did not appear to be significantly influenced by observer presence. Locations were generally recorded during daylight hours, but some birds were tracked the entire night.

Figure 1.3 – Radio Locations and Available Habitat



1.3.4 Space Use, Seasonal Ranges and Movements

I used traditional methods of home range analysis to estimate home range size including fixed kernel, adaptive kernel, two-mode-bivariate circle and minimum convex polygon (Rodgers et al. 2005) and compared them to newer approaches such as the bivariate normal and exponential power synoptic models (Horne et al. 2008). The synoptic model is unique in that habitat use and animal space use are analyzed together. Synoptic models with the lowest overall AICs were used to calculate seasonal range size for each owl.

With the exception of the minimum convex polygon method, probability distributions were calculated at the 95%, 90%, 75%, and 50% levels. Probability distributions for the minimum convex polygon method were limited to the 95% level and were calculated using the area added method (95% of the locations that result in smallest home range area are retained) and the fixed mean method (95% of the locations that are closest to the geographic center of the home range are retained).

When the fixed kernel and adaptive kernel were selected as the best seasonal range method an appropriate smoothing factor was calculated using both the likelihood cross-validation (CVh) and least squares cross-validation (LSCVh) methods (Horne 2006b).

To identify the best traditional methods for the home range analysis I utilized information theoretic measures (Horne and Garton 2007). These measures included Akaike's Information Criterion (AIC - Akaike 1973) and the Cross-Validation Criterion (CVC - Stone 1977, Horne 2006a).

Owl movements were monitored as part of the radio telemetry work and analyzed in ArcGIS (ESRI). I recorded seasonal, daily and other non-typical movements as they were observed.

1.3.5 Habitat Characteristics

I conducted the habitat analysis using individual owls as the sampling unit, and summarized general habitat conditions and use for all owls (Appendix B). I summed habitat conditions available to the owls in a series of 2500 meter radius circles that were placed around the centroid of known locations for each individual owl. I selected the circle size of 2500 meters radius based on the largest distances I observed between known radio locations (4635 meters) and the average size of individual seasonal ranges. I wanted the circle to encompass observed movements of individual owls and the seasonal range of individual owls. The goal was not to analyze habitat and space use with this summary data, but rather to give the reader an idea of the available habitat conditions within the study area as compared to area actually being utilized by the radio marked birds. The total area of all of these circles turned out to be 34,815 hectares when overlapping circles and agricultural areas outside of the project area were eliminated (Figure 1.3).

I do not report habitat values for the entire study area since I had not captured owls throughout the study area and did not believe habitats located far from capture sites where truly available to individual owls. Thus I am estimating 3rd level habitat selection (Johnson 1980).

Available habitat was determined from United States Forest Service (USFS) inventory data for the Clearwater National Forest (Clearwater NF 2010) based on field exams conducted according to guidelines of the Region 1 – Timber Stand Management Record System (TSMRS). All available field exams collected up to August 25, 2009 were used in the analysis and these exams had been updated by the forest service to 2009 using the Forest Vegetation Simulator (FVS – Crookston et al. 2003). Data was checked for consistency with ground conditions at the time when owls were being radio tracked and modified accordingly. Most modifications were associated with recent timber harvest.

Field data was augmented by several GIS layers that were downloaded from the Clearwater National Forest website that included information about the study area. For example, I downloaded the timber stand polygons, stream and road layers. Digital elevation models and satellite imagery were downloaded from the INSIDE Idaho website (http://inside.uidaho.edu/). NAIP Satellite imagery was available for 2004, 2006 and 2009 for the project area and was also downloaded from the INSIDE Idaho website (INSIDE IDAHO 2012). Since these images were taken just prior to the start of the study, during the study, and at the very end of the study, I had excellent photographic coverage for the entire project area and the lifespan of the project. I placed this data and the information from the owl locations in both ArcMap 9.3 and ArcMap 10 project files (ESRI Corporation) and used ArcMap to manipulate the data.

I found that there were some minor problems with the timber stand data layer, as downloaded from the USFS, and made corrections to fix obvious errors. For example, stand boundaries were often displaced from obvious cutting boundaries that I could clearly see on the satellite imagery. There were also some stands that had been harvested recently and these changes had not been incorporated into the USFS stand data layer.

Since the USFS timber stand data layer did not extend onto State and private land, I augmented the USFS stand layer by hand digitizing polygons of similar size and structure onto the layer. I based these additional polygons on features that were apparent on the satellite imagery and generally used the 2009 imagery as the basis for the classification. I referred to 2004 and 2006 imagery for clarification of questionable stands and to identify stands that were harvested during the life of the study. The original USFS stand layer had 3370 stands in the project area but I subdivided some of these stands to make 499 additional stand polygons. This was, mostly, due to recent timber harvest that was apparent on the satellite imagery, but which had not been incorporated into the USFS stand layer. I added an additional 4210 stands on State and private land. The resulting project area had a total of 8,440 different stands and covered an area of 87,762 hectares.

On existing USFS stands, there were field surveys for 2479 stands and characteristics of the remaining 1,251 USFS (1250 of 1251) stands had been estimated by the USFS using most similar neighbor projections (Crookston et al. 2002). In a manner that was analogous to the USFS method for unsampled stands on the National Forest, I used the USFS field data and the nearest neighbor approach to impute characteristics to the 4210 unsurveyed stands on State and Private land (Crookston et al. 2002, Crookston and Finley 2008). This procedure is described in detail in Appendix A.

I assigned a structural stage and crown closure category to all polygons based on visual observations of the satellite imagery and available stand data. On “new” stands (State and private land) I had no information regarding stand character other than what I could see on the imagery and recollections from telemetry fieldwork. When I “homed” to owls during telemetry field work, I took habitat photos in four cardinal directions at all owl locations. I made notes on stand character at the location site, but did not take detailed field measurements. I gathered detailed vegetation information at known nest sites (N=3), but I did not gather additional vegetation information in the study area due to limited funding and time constraints.

I used the following 7 classifications for the structural stage estimates (**HJ_Size**): Non-forest areas - **(0)**, Seedling/Shrub – Trees less than 2.5 cm Diameter Breast Height (DBH) - **(1)**, Sapling 2.5-12.6 cm DBH **(2)**, Pole 12.7-22.8 cm DBH **–** **(3)**, Small Trees – 22.9-38.0 cm DBH **(4)** , Medium Trees - 38.1 – 53.2 cm DBH **(5)** and Large Trees-53.3^{+} cm (DBH) - **(6)**. These categories were identical to size class and stratum codes utilized by the USFS in TSMRS.

Finally, I estimated crown closure (**HJ_CRN_CLR**) using stand exam information and/or visual estimates on the satellite imagery. I assigned crown closure of the existing trees into five categories: Non-stocked **–** **(0)**, Very Low 10-24.9% - **(1)**, Low 25-39.9% - **(2)**, Moderate 40-59.9% - **(3)** and High - >60%. **- (4)**. These determinations were based on visual observation of the satellite imagery. The classification of overstory crown closure was based on the largest trees. Thus, if a stand was a shelterwood cut, I estimated the crown closure of the residual shelterwood and not the crown closure of the seeding or sapling understory. If there was no overstory on the stand I estimated the crown closure of the appropriate size class.

Once the stand layer was completed, I identified possible variables to include in the analysis. I based variable selection on my knowledge of Northern Pygmy-Owl behavior, results of past studies (Giese and Forsman 2003, Sater et al. 2006) and variables that I felt might be important to land managers. I decided that I would use four physical variables: **percent slope**, **aspect** (0-360 degrees and flat = -1), **elevation** (meters) and **distance to stream** (meters to the nearest perennial stream). I used the ocular estimates of structural stage (**HJ_Size**) and crown closure (**HJ_CRN_CL**) based on the 2009 satellite imagery and the USFS stand exam data. Ocular structural stage estimates (**HJ_Size**) agreed with the projected size class estimates from “nearest neighbor estimates” and USFS stand exam information approximately 75.3% of the time. Based on the extensive comparisons of the satellite imagery to nearest neighbor projections and the fact that the ocular estimates included some refinements (identification of recently harvested stands and correction of obvious errors in USEID assignment), I decided to use the ocular estimate information to designate general structural stages for the analysis area.

I included several variables that came directly from the stand exam data and the “nearest neighbor” estimates (Table 1.1). In most cases, values came directly from the field measurements and imputed data, but I grouped the variable (tree species in plurality) into three groupings for ease of manipulation in the models. For my purposes, the number of available tree species groups was excessive in the stand exam data. This included a dry forest group (ponderosa pine, Douglas-fir, western larch); a moist forest group (Western red-cedar, grand fir, western hemlock (*Tsuga heterophylia*) and white pine); and an “other” forest group that consisted mostly of lodgepole pine and stands of a few other species like Engelmann spruce (*Picea engelmannii*) and subalpine fir.

This structural stage and crown closure information based on the stand exam information is similar to remotely sensed data that has been used commonly in many other habitat analyses. I considered the possibility of using these types of data for the habitat analysis in substitution for the stand exam data or as an additional data source. Three remotely sensed data layers were available for the entire study area: Idaho Gap Analysis (http://www.wildlife.uidaho.edu/idgap/idgap_landcover.asp), LANDFIRE (http://www.landfire.gov/) and the USFS Region 1 – Vmap project (http://www.fs.usda.gov/detailfull/r1/landmanagement/gis/?cid=stelprdb5331054&width=fu

llMap). The three remotely sensed layers had an advantage over the stand exam data since they covered the entire project area and did not require the level of manipulation associated with nearest neighbor projections. However, the data for all of these layers had been collected at a much larger scale (State and Multi-State levels) and did not include the detailed field sampling of the study area that was included in the stand exam data. This created a dilemma regarding which habitat layer to utilize for the analyses.

Of the three remotely sensed data layers, I felt the Vmap coverage offered the best choice of vegetative variables that would likely be important to Northern Pygmy-Owls. For example, Vmap provides more information on stand size structure than either Idaho Gap Analysis or LANDFIRE. I was able to obtain stand size class, canopy closure, and stand species group from Vmap.

After comparing the stand exam and the remotely sensed (Vmap) vegetation data, it was clear that each offered distinct advantages. However, it was unclear which of these data sets might produce the best results in defining Northern Pygmy-Owl habitat within the study area. I finally decided that I would conduct the analysis with both datasets.

Vmap treats stand size class (Vmap_Size) in five categories: Nonstocked, trees with an average DBH between 0 and 12.4 cm, trees with an average DBH between 12.5 and 25.3 cm, trees with an average DBH of 25.4 to 38.0 cm, and trees with an Average DBH greater than 38.1 cm.

Crown closure (Vmap_Canopy) is classified into five categories by Vmap: Nonstocked, Crown closure 10-24.9%, Crown closure 25-39%, Crown closure 40-59.9%, and Crown closure greater than or equal to 60%.

Like the stand exam data, dominant species groupings identified by Vmap are very extensive. I collapsed these multiple groupings into three categories for easier manipulation in the models.   Species groups such PIPO (*Pinus ponderosa*) PSME (*Pseudotsuga menziesii*), and LAOC (*Larix occidentalis*) and IMIX (Intolerant Mix) were condensed into a group called Vmap_PP_DF_L. I called the second group Vmap_C_GF_H which included THPL (*Thuja pilicata*), ABGR (*Abies grandis*), TSHE (*Tsuga heterophylla*), and TMIX (Tolerant Mix).   The final group includes PICO (*Pinus contorta*) and all other species such as PIEN (*Picea engelmannii*) and ABLA (*Abies lasiocarpa*).

Table 1.1 – Variables Originally Considered in the Analysis And Tested for Correlation

Symbol	Description	Source
HJ_Size	(0-6) Non-stocked, Seedling, Sapling, Pole, Small, Medium, Large	Satellite Imagery - cstands
HJ_CRN_CL	(0-4) Non-stocked, Very Low, Low, Moderate, High	Satellite Imagery - cstands
PP_DF_L	Tree species in plurality (Ponderosa pine, Douglas fir, Larch)	cstands
GF_C_H_WP	Tree species in plurality (Grand fir, Cedar, Hemlock or White Pine)	cstands
LP_OTHER	Tree species in plurality (Lodgepole Pine and all other species)	cstands
TPHA	Trees per hectare	cstands
TDTPHA23	Trees per hectare over 22.9 cm DBH	cstands
TDTPHA38	Trees per hectare over 38.1 cm DBH	cstands
RDTPHA23	Recently dead trees per hectare over 22.9 cm DBH	cstands
RDTPHA38	Recently dead trees per hectare over 38.1 cm DBH	cstands
BAM2HA	Basal Area (Meters squared per hectare)	cstands
TOTVOLM^3	Total volume of wood (M^3 per hectare)	cstands
BADBHCM	Average DBH in Cm based on stand basal area	cstands
QMDCM	Quadratic Mean diameter (DBH) in Cm	cstands
TOPHTM	Height of the largest 40 trees in meters	cstands
CRNCLS	Crown Closure	cstands
TCOV	Total Cover	cstands
COVHT1	Cover zero to 20 feet	cstands
COVHT2	Cover 21 to 60 feet	cstands
COVHT3	Cover 61 to 100 feet	cstands
COVHT4	Cover > 100 feet	cstands
UPAGE	Age of trees in the upper 50th to 90th percentile by basal area	cstands
Vmap_Size	(0-4) - Non-stocked, 0-12.4 cm, 12.5-25.3 cm, 25.4-38.0 cm, >= 38.1 cm	Vmap
Vmap_Canopy	(0-4) - Non-stocked, 10-24.9%, 25-39.9%,40-59.9%, >= 60.0%	Vmap
Vmap_DF_PP_L	PIPO, PIPO-1MIX, PSME, PSME-IMIX, LAOC, LAOC-IMIX, IMIX	Vmap
Vmap_C_GF_H	THPL, THPL-TMIX, ABGR, ABGR-TMIX, TSHE, TSHE-TMIX, TMIX	Vmap
Vmap_LP_OTHER	PICO, PICO-	Vmap
STRM_DIST	Distance in meters to the nearest perennial stream	ArcMap
SLOPE	Percent Slope (-1 equal flat)	Elev. Model
ASPECT	Aspect -1 to 360 degrees (-1 equal flat)	Elev. Model
ELEV	Elevation in meters	Elev. Model

I examined the correlation coefficients of these variables using Pearson, Kendall and Spearman methods in program R. I eliminated all variables whose correlation exceeded 60% or which had limited representation in the study area. For example, the "PP_DF_L" variable was, highly, negatively correlated with "C_GF_H_WP" variable. Likewise, most of the variables from the stand exam data were highly correlated with "HJ_Size" (Table 1.2). I did retain TDTPHA23 and TDTPHA38 which were correlated at 60%, because I felt these variables provided useful management information and both were highly correlated with the snag level variables that I did not utilize. Recently dead snag levels (RDTPHA23 and RDTPHA38) were not correlated very well with "HJ_Size" (36 and 39% respectively). Results were similar with Kendall and Spearman methods. The final variables used in the analysis are displayed in Table 1.3.

Table 1.2 – Pearson Correlation Matrix for Vegetation Variables

	Slp	**Asp**	**Ele**	**STR**	**DF**	**GF**	**LP**	**TA**	**TA23**	**TA38**	**RD23**	**RD38**	**DBH**	**QM**	**BA**	**HJS**	**HJC**	**Vsiz**	**Vcan**	**VDF**	**VGF**	**VLP**
Slp	1.00	0.02	0.47	-0.04	0.06	0.07	-0.11	0.09	0.09	0.14	0.04	0.09	0.15	0.11	0.14	0.23	0.23	-0.12	0.09	-0.03	0.08	-0.04
Asp	0.02	1.00	0.04	0.01	0.03	-0.03	0.01	0.00	0.01	0.00	-0.01	-0.01	-0.03	-0.01	-0.02	-0.01	0.01	0.01	-0.05	0.04	-0.05	0.04
Ele	0.47	0.04	1.00	0.08	0.08	0.04	-0.11	0.06	0.10	0.15	0.05	0.10	0.15	0.13	0.14	0.23	0.24	-0.18	0.12	-0.07	0.12	-0.02
STR	-0.04	0.01	0.08	1.00	0.07	-0.07	0.03	-0.02	-0.05	-0.06	-0.05	-0.05	-0.06	-0.05	-0.09	-0.08	-0.06	0.01	-0.06	0.04	-0.06	0.01
DF	0.06	0.03	0.08	0.07	1.00	**-0.81**	-0.19	-0.06	-0.15	-0.15	-0.12	-0.10	-0.12	-0.05	-0.22	-0.11	-0.09	-0.06	-0.09	0.02	-0.05	0.02
GF	0.07	-0.03	0.04	-0.07	**-0.81**	1.00	-0.25	0.16	0.23	0.25	0.16	0.19	0.31	0.19	0.37	0.31	0.27	0.04	0.17	-0.04	0.11	-0.03
LP	-0.11	0.01	-0.11	0.03	-0.19	-0.25	1.00	-0.02	-0.04	-0.10	0.03	-0.10	-0.05	0.01	-0.04	-0.02	0.01	0.06	-0.03	0.05	-0.06	0.01
TA	0.09	0.00	0.06	-0.02	-0.06	0.16	-0.02	1.00	-0.04	-0.05	-0.15	-0.15	0.01	-0.31	0.20	0.14	0.21	-0.03	0.09	-0.01	0.06	-0.01
TA23	0.09	0.01	0.10	-0.05	-0.15	0.23	-0.04	-0.04	1.00	**0.60**	**0.74**	0.49	0.43	0.51	0.58	0.47	0.37	0.13	0.27	-0.01	0.12	-0.03
TA38	0.14	0.00	0.15	-0.06	-0.15	0.25	-0.10	-0.05	**0.60**	1.00	0.34	**0.64**	0.51	0.49	0.52	0.48	0.33	0.12	0.24	-0.03	0.13	-0.02
RD23	0.04	-0.01	0.05	-0.05	-0.12	0.16	0.03	-0.15	**0.74**	0.34	1.00	0.52	0.30	0.51	0.49	0.36	0.31	0.11	0.23	-0.02	0.10	-0.01
RD38	0.09	-0.01	0.10	-0.05	-0.10	0.19	-0.10	-0.15	0.49	**0.64**	0.52	1.00	0.41	0.53	0.47	0.39	0.28	0.10	0.22	-0.03	0.11	-0.01
DBH	0.15	-0.03	0.15	-0.06	-0.12	0.31	-0.05	0.01	0.43	0.51	0.30	0.41	1.00	**0.69**	**0.66**	**0.69**	0.46	0.15	0.33	0.00	0.16	-0.04
QMD	0.11	-0.01	0.13	-0.05	-0.05	0.19	0.01	-0.31	0.51	0.49	0.51	0.53	**0.69**	1.00	**0.66**	**0.66**	0.51	0.16	0.32	0.02	0.15	-0.03
BA	0.14	-0.02	0.14	-0.09	-0.22	0.37	-0.04	0.20	0.58	0.52	0.49	0.47	**0.66**	**0.66**	1.00	**0.81**	**0.69**	0.16	0.45	-0.02	0.23	-0.06
HJSi	0.23	-0.01	0.23	-0.08	-0.11	0.31	-0.02	0.14	0.47	0.48	0.36	0.39	**0.69**	**0.66**	**0.81**	1.00	**0.77**	0.12	0.44	-0.02	0.23	-0.06
HJC	0.23	0.01	0.24	-0.06	-0.09	0.27	0.01	0.21	0.37	0.33	0.31	0.28	0.46	0.51	**0.69**	**0.77**	1.00	-0.02	0.33	-0.05	0.20	-0.05
Vsiz	-0.12	0.01	-0.18	0.01	-0.06	0.04	0.06	-0.03	0.13	0.12	0.11	0.10	0.15	0.16	0.16	0.12	-0.02	1.00	0.27	0.29	0.04	0.12
Vcan	0.09	-0.05	0.12	-0.06	-0.09	0.17	-0.03	0.09	0.27	0.24	0.23	0.22	0.33	0.32	0.45	0.44	0.33	0.27	1.00	-0.04	0.35	-0.03
VDF	-0.03	0.04	-0.07	0.04	0.02	-0.04	0.05	-0.01	-0.01	-0.03	-0.02	-0.03	0.00	0.02	-0.02	-0.02	-0.05	0.29	-0.04	1.00	**-0.78**	-0.19
VGF	0.08	-0.05	0.12	-0.06	-0.05	0.11	-0.06	0.06	0.12	0.13	0.10	0.11	0.16	0.15	0.23	0.23	0.20	0.04	0.35	**-0.78**	1.00	-0.14
VLP	-0.04	0.04	-0.02	0.01	0.02	-0.03	0.01	-0.01	-0.03	-0.02	-0.01	-0.01	-0.04	-0.03	-0.06	-0.06	-0.05	0.12	-0.03	-0.19	-0.14	1.00

Highly correlated variables are displayed in bold highlights

Table 1.3 - Habitat Variables Used in the Analysis

Variable Abbreviation	Description	Source
HJ_SIZE	Stand Size Class (0-6)	S. Imagery/cstands
GF_C_H_WP	(0-1)	cstands
TPHA	Trees per hectare	cstands
TDTPHA23	Trees per hectare over 22.9 cm DBH	cstands
TDTPHA38	Trees per hectare over 38.1 cm DBH	cstands
Vmap_Size	(0-4) - Non-stocked, 0-12.4 cm, 12.5-25.3 cm, 25.4-38.0 cm, >= 38.1 cm	Vmap
Vmap_Canopy	(0-4) - Non-stocked, 10-24.9%, 25-39.9%,40-59.9%, >= 60.0%	Vmap
Vmap_C_GF_H	(0-1)-THPL, THPL-TMIX, ABGR, ABGR-TMIX, TSHE, TSHE-TMIX, TMIX	Vmap
SLOPE	Generated in ArcGIS from digital elevation model	ArcGIS/Inside Idaho
ASPECT	Generated in ArcGIS from digital elevation model	ArcGIS/Inside Idaho
ELEV	Elevation – Model downloaded from INSIDE Idaho website	Inside Idaho
STRM_DIST	Distance to nearest stream - Generated in ArcGIS using USFS Stream Layer which displayed all perennial streams	USFS - ArcGIS

After eliminating highly correlated variables, I constructed 51 *a priori* models in three general categories. However, ten models included poorly represented parameters such as lodgepole pine and the likelihood analysis did not converge. Lodgepole pine was poorly distributed in the study area and not heavily used by Northern Pygmy-Owls (only 40 of 766 locations). Models that included these parameters were eliminated and only 41 *a priori* models were carried forward into the final analysis. The reader should be aware that the original model numbers have been retained in the text to avoid confusion and that these numbers are only used to identify the actual models which are displayed in Tables 1.4 to 1.6. Models were constructed based on parameters that appeared to be important from the literature, fieldwork and initial model runs. I did not test all possible parameter combinations due to the sheer magnitude of this task.

The first category of models relied strictly on the physical variables of slope, aspect, elevation and distance to stream and included 8 models (Table 1.4). I termed this the "Physical" category and the full model for this category was:

$$Wx = \beta_0 + \beta_1*(SLOPE) + \beta_2*(ASPECT) + \beta_3*(ELEV) + \beta_4*(STRM\_DIST)$$

The second category included sixteen models and was based on a combination of the remotely sensed Vmap vegetation parameters and the physical parameters (Table 1.5). I termed this the "remotely sensed Vmap" category and the full model for this category was:

$$Wx = \beta_0 + \beta_1*(SLOPE) + \beta_2*(ASPECT) + \beta_3*(ELEV) + \beta_4*(STRM\_DIST) + \beta_5*(Vmap\_Size) + \beta_6*(Vmap\_Canopy) + \beta_7*(Vmap\_C\_GF\_H)$$

The third category included seventeen models and used the modified USFS stand exam data and nearest neighbor projections (Table 1.6). I termed this the "Stand Exam" category and the full model for this category was:

$$Wx = \beta_0 + \beta_1*(SLOPE) + \beta_2*(ASPECT) + \beta_3*(ELEV) + \beta_4*(STRM\_DIST) + \beta_5*(GF\_C\_H\_WP) + \beta_6*(TPHA) + \beta_7*(TDTPHA23) + \beta_8*(TDTPHA38) + \beta_9*(HJ\_SIZE)$$

Table 1.4 – Physical Models (N=8)

Model Number*	Slope	Aspect	Elevation	Distance to Stream
14	x			x
15		x		x
16			x	x
17	x	x		x
18	x		x	x
19		x	x	x
20 (Full)	x	x	x	x
21				x

Table 1.5 – Vmap Models (N=16)

Model Number*	Slope	Aspect	Elevation	Distance to Stream	Vmap Size	Vmap Canopy	Vmap C_GF_H
4 (Full)	x	x	x	x	x	x	x
6	x	x		x	x	x	x
8	x			x	x	x	x
10				x	x	x	x
12				x	x	x	
22				x	x		
23				x		x	
24				x			x
30	x	x	x	x	x		
31	x	x	x	x		x	
32	x	x	x	x			x
33	x	x	x	x	x	x	
34	x	x	x	x	x		x
35	x	x	x	x		x	x
50		x	x	x		x	
51		x	x	x	x	x	

Table 1.6 – Stand Exam Models (N=17)

Model Number*	Slope	Aspect	Elevation	Distance to Stream	Stand Exam C_GF_H_WP	TPHA	TPHA 23	TPHA 38	Stand Exam Size
5 (Full)	x	x	x	x	x	x	x	x	x
7	x	x	x	x	x		x	x	x
27				x	x		x		x
28				x	x				x
29				x					x
37	x	x	x	x	x				
38	x	x	x	x		x			
39	x	x	x	x			x		
40	x	x	x	x				x	
41	x	x	x	x					x
43	x	x	x	x		x	x	x	x
44	x	x	x	x			x	x	x
45	x	x	x	x				x	x
46	x	x	x	x			x		x
47	x	x	x	x		x			x
48		x	x	x			x	x	x
49		x	x	x		x	x	x	x

* Models 1, 2, 3, 9, 11, 13, 25, 26, 36 and 42 were eliminated from the analysis

1.3.6. Analysis

I tested a variety of different models in each of the three categories with two different methods. The first method utilized a “synoptic” model approach as outlined by Horne et al. (2008) and Johnson et al. (2008). The second method utilized a traditional simple logistic regression approach to estimate resource selection functions (RSFs, Manley et al. 2002). I wanted to compare the results and ease of use of newer approaches like the synoptic model to more traditional approaches like simple logistic regression as alternative approaches to identifying key environmental characteristics selected or avoided by Northern Pygmy-Owls.

The synoptic model (Horne et al. 2008) evaluates the probability of finding an animal at a specific point on a habitat grid of points that encompasses the total area used by the animal. The probability of use on the gird sums to one and is termed the utilization distribution function (UDF) or probability density function (PDF). Individual owls were used as the sampling unit under this approach.

Central to the method is a null model of space use that displays how the animal might use the area in the absence of habitat variables. For a territorial central place foraging animal like the Northern Pygmy-Owl whose territory is often centered on a nest snag, this might be a circular area around the nest as represented by exponential power model (Horn and Garton 2006a) or a bivariate normal distribution (Jennrich and Turner 1969) that might be skewed to a more elliptical distribution due to physical factors such as valley topography or a linear stream course. Habitat covariates that might influence this null distribution are then added to the model and actual locations of use are utilized to estimate selection coefficients using maximum likelihood analysis (Horne et al. 2008). For example, the

Northern Pygmy-Owl is thought to prefer older forests for foraging (Giese and Forsman 2003).

The formulation of the synoptic model as outlined by Horne et al. (2008) and Johnson et al. (2008) is:

$$f_u(x) = \frac{f_0(x)\exp(\beta' H(x))}{\int_x f_0(x)\exp\big(B' H(x)\big)}$$

where $f_u(x)$ is the probability of use of location x, $f_0(x)$ is an available location's probability of use under the null model (e.g., bivariate normal or exponential power) and (β_i) are estimated maximum likelihood coefficients for each predictive categorical or continuous covariate ($H_i(x)$).

The synoptic model generally works best with continuous variables, but categorical variables can be utilized, if they are coded as a series of “ones” and “zeros”, and each category is identified as an individual variable. Thus, a point in the habitat grid is coded as a “1” if the value is in the category, or as a “0” if it is not in the category. The problem with this is that if there are several categories, then a large number of model variables are required for the analysis. For example, I identified seven structural classes in the categorical variable for stand structure. In order to code this into the synoptic model I would need to code seven variables into the model instead of just the one. Such a model would get heavily penalized in the Akaike’s information criterion (AIC - Akaike 1973) that I used to evaluate models. AIC penalizes maximum likelihood deviance (an estimate of goodness of fit) as the number of model parameters increase (Manley et al. 2002).

To minimize this problem, I changed categorical variables for size class and canopy closure into continuous ordered variables starting from the lowest category to the highest.

For example, I coded the categorical variable **HJ_Size** to **“0”** for Non-forest areas, **“1”** for Seedling/Shrub – Trees less than 2.5 cm Diameter Breast Height (DBH), **“2”** for Sapling 2.5-12.6 cm DBH, **“3”** for Pole 12.7-22.8 cm DBH, **“4”** for Small Trees – 22.9-38.0 cm DBH, **“5”** for Medium Trees - 38.1 – 53.2 cm DBH and **“6”** for Large Trees-53.3$^+$ cm (DBH). **Vmap_Size** (Coded 0-4) and **Vmap_Canopy** (Coded 0-4) were treated similarly. Note this assumes that selection for sizes of trees behaves in an ordered, linear manner of preference and probability of use increasing or decreasing with size class order. This is exactly analogous to many non-parametric statistical tests (i.e. Wilcoxon rank sum test, Friedman, etc.) which convert continuous variables to ranks and then perform standard statistical tests assuming normality of the statistics calculated from the ranks.

Since I only used one species group for the models (**Vmap_C_GF_H** or **GF_C_H_WP)** I only had to code these categorical variables as **“0”** or **“1”.** All other variables (TPHA, TDTPHA23, TDTPHA38 TPHA, SLOPE, ASPECT, ELEV and STRM_DIST) were continuous numerical variables.

For the logistic regression model, I selected a comparison of known locations to random points. I conducted the analysis at the seasonal range scale (Level 3 selection – Johnson 1980) and used individual birds as the sampling unit. For each owl, I placed a 2500 meter radius circle around known owl locations using the centroid of all known locations as the center of the circle. I based the circle size on the largest observed distance between any two known owl locations for an individual owl (4635 meters). These circles contained all known locations of each individual owl and my assumption was that owls could move distances defined by the circle to find resources. Because of the nature of the study area, a few circles extended outside of the study area onto nearby agricultural lands which contained little or no Northern Pygmy-Owl habitat. When this happened I cropped the circles to the study area.

For each individual owl, I selected the same number of random points within the circle as the number of locations I had for that owl. Thus if I collected 35 locations on an owl, I would generate 35 random points within the appropriate circle. Thus availability for each owl was defined as a uniform distribution of available points for logistic regression. I then conducted logistic regression on the various models using a “binomial” approach in program R (Hosmer and Lemeshow 2000, UCLA 2013).

Although, I captured 26 owls (22 males and 4 females) during the course of the study, I only evaluated 16 owls (15 males and 1 female) using both methods since I did not obtain enough locations to determine home range size for the other owls (Table 1.7). I assumed owls had been “adequately sampled” if more than 29 locations had been obtained (Marzluff et. al 2004, Garton et al. 2001 – Table 1.7). To identify the best model for all 16 owls, I added AIC values for all 16 individual owls. Thus I treated the individual owls as the sampling unit in an effort to identify those variables that were most important to the population. I then selected the models that had the lowest added AIC in the physical, remotely sensed and stand exam categories. I compared overall added AIC values for all models. I evaluated the synoptic models separately based on whether the original null model was based on the bivariate normal or the exponential power model.

Table 1.7 – Owl Capture Dates and Number of Locations

Owl	Sex	Capture Season	Date capture	Last Location	Days	Number of Locations	Fate or Nest
5	M	Spring	4/26/2007	8/08/2007	105	69	Nest
6	M	Spring	5/1/2007	5/3/2007	3	3	Mortality
7	M	Spring	5/3/2007	5/7/2007	4	3	Mortality
8	M	Spring	5/22/2007	7/17/2007	57	29	Nest Not Located/ Mortality
9	M	Spring	5/23/2007	8/24/2007	94	37	Nest Not Located
10	M	Spring	5/25/2007	8/23/2007	91	30	Non-Breeding?
18	M	Spring	3/21/2008	4/29/2008	40	25	Mortality
19	M	Spring	4/11/2008	6/14/2008	65	38	Nest
20	M	Spring	4/15/2008	7/2/2008	80	44	Nest not located
21	M	Spring	5/12/2008	6/4/2008	24	13	Mortality
23	M	Spring	5/21/2008	8/1/2008	73	30	Non-Breeding?
24	M	Spring	5/27/2008	8/11/2008	77	41	Fledglings observed
25	F	Summer	6/19/2008	9/06/2008	80	58	Nest (Mate - Bird 19)
26	M	Summer	7/8/2008	9/20/2008	75	39	Nest not found
27	M	Summer	7/14/2008	9/26/2008	74	63	Fledglings Observed
1	M	Fall	9/28/2006	11/22/2006	56	31	Migrated?
2	M	Fall	10/20/2006	1/16/2007	89	42	No Migration
3	F	Fall	10/27/2006	12/8/2006	43	12	Mortality
4	M	Fall	11/1/2006	11/27/2006	27	9	Migrated?
11	M	Fall	9/18/2007	9/28/2007	11	7	Mortality
12	M	Fall	9/20/2007	12/06/2007	78	38	No Migration
13	M	Fall	10/ 2/2007	12/14/2007	74	38	Mortality
14	F	Fall	10/9/2007	12/22/2007	75	10	Mortality
15	F	Fall	10/23/2007	11/26/2007	35	17	Migrated?
16	M	Winter	1/24/2008	1/26/2008	3	2	Mortality
17	M	Winter	2/14/2008	4/25/2008	72	50	No Migration

*Note there is no owl 22 – (Escape during handling)

I estimated mean selection coefficients for the population of Northern Pygmy-Owls from which the owls were sampled by simply calculating the mean and variance of selection coefficients estimated by each of the three methods. The following equation was utilized to estimate population variance (Where $\hat{\hat{\beta}}_j$ = the mean value of the selection coefficients, $\hat{\beta}ij$ = the value of the selection coefficient for owl *i* and *n* = the number of owls):

$$Var\ \left(\hat{\hat{\beta}}_j\right) = \frac{1}{(n-1)}\ \sum_{i=1}^{n}\left(\hat{\beta}_{ij} - \hat{\hat{\beta}}_j\right)^2$$

1.3.7 Nests

I located three nests during the study. Two of these nests were associated with radio tagged owls and one nest was found in 2009 after I completed radio tracking. At each nest site, I measured the diameter of the nest tree, height of the nest tree, and height of the nest cavity. Tree species and tree condition (dead or alive) were recorded for each nest tree. I recorded the average conditions at each nest site including slope, aspect, elevation, distance to the nearest stream, and distance to the nearest road. I took densitometer readings (Lemmon 1957) using a spherical densitometer in four cardinal directions at the base of the nest tree. Several photographs were taken at each nest site.

I completed individual tree plots at each nest site. I used the nest tree as plot center and counted all trees over 7.6 cm diameter breast height (DBH) on the plots. I used a 10 basal area factor (BAF) prism to identify plot trees at two nests located in mature stands and a 0.04 hectare fixed plot at one nest location that had been previously harvested. I entered all data in the Forest Vegetation Simulator (FVS – Crookston et al. 2003) and recorded current year results for stand level parameters.

1.4 Results

A total of twenty-six Northern Pygmy-Owls were captured during the study (Table 1.7), but only sixteen of those owls had a sufficient number of locations (at least 29) to evaluate seasonal home range and resource selection. The mean number of locations per owl for these sixteen owls was 42 with a standard error of 12 and a range of 29 to 69 locations (Table 1.7). The remaining ten owls were either lost to predation (all due to larger raptors) or exited the study area prior to the expected expiration date of the battery on their transmitter. Where appropriate, I discuss space use, movements and habitat use of all twenty-six owls.

1.4.1 Acoustic Surveys

I completed acoustic surveys at 241 stations throughout most of the project area (Table 1.8 and Figure 1.3). Surveys were conducted in the spring of 2006 (117 stations), the fall of 2006 (31 stations), the spring of 2007 (66 stations) and the fall of 2007 (27 stations). I could detect no significant difference (P=0.5029) in response rates for the two different spatial intervals between stations (Wilson 1927, Newcombe 1998a, Newcombe 1998b). I generally had higher response rates in the fall (Proportion = 0.328) than I did in the spring (Proportion = 0.212), and this rate was almost significant at the 10% significance level (P= 0.1036). However, these results were confounded by differences in the dates of collection of the spring data. The spring of 2007 data were collected earlier in the season (April 13th to May 19th) than the spring of 2006 data (May 19th to June 2nd). When the spring of 2006 data (Proportion 0.265) is compared to the fall data (Proportion 0.328) the differences are not as dramatic (P-Value = 0.493).

Table 1.8 – Owl Calling Station Results

	Number of Stations (Positive Response)	Proportion Positive	Spacing 1609.3 m (Positive Response)	Proportion Positive	Spacing 3218.6 m (Positive Response)	Proportion Positive
Spring 2006 (5/19/2006 to 6/2/2006)	117 (31)	0.265	117 (31)	0.265	-	-
Fall 2006 (9/20/2006 – 9/22/2006)	31 (11)	0.355	-	-	31 (11)	0.355
Spring 2007 (4/13/2007 to 5/19/2007	66 (10)	0.152	10 (2)	0.200	56 (8)	0.143
Fall 2007 (9/24/2007 to 10/2/2007)	27 (8)	0.296	27 (8)	0.296	-	-
Total	241 (60)	0.249	154(41)	0.266	87 (19)	0.218

1.4.2 - Seasonal (Home) Ranges

Using traditional methods, the home range model with the lowest CVC score was either the adaptive kernel (8 owls) or the fixed kernel (7 owls - Table 1.9). The two-mode-bivariate circle had the lowest CVC score for owl ten and was the second best model for owls thirteen and nineteen. CVC values for all three models (adaptive kernel, fixed kernel, and

Table 1.9 – Seasonal Range Model Cross-Validation Criterion (CVC) Scores (Does not include synoptic model)

Northern Pygmy- Owl Number (Number of locations)	Best Model	CVC	Next Best Model	CVC
1 (31)	Adaptive Kernel	772.2	Fixed Kernel	788.2
2 (42)	Adaptive Kernel	1236.5	Fixed Kernel	1245.3
5 (69)	Fixed Kernel	1866.8	Adaptive Kernel	1877.8
8 (29)	Fixed Kernel	741.2	Adaptive Kernel	744.0
9 (37)	Fixed Kernel	1019.7	Adaptive Kernel	1021.5
10 (30)	Two Mode Bivariate Circle	926.0	Adaptive Kernel	928.0
12 (38)	Adaptive Kernel	1072.7	Fixed Kernel	1075.1
13 (38)	Adaptive Kernel	1103.1	Two Mode Bivariate Circle	1103.9
17 (50)	Adaptive Kernel	1449.1	Fixed Kernel	1460.0
19 (38)	Adaptive Kernel	997.6	Two Mode Bivariate Circle	1006.9
20 (42)	Adaptive Kernel	1213.8	Fixed Kernel	1219.6
23 (30)	Fixed Kernel	934.7	Adaptive Kernel	934.8
24 (41)	Adaptive Kernel	1272.7	Fixed Kernel	1277.8
25 (54)	Fixed Kernel	1495.4	Adaptive Kernel	1497.4
26 (39)	Fixed Kernel	1161.1	Adaptive Kernel	1162.5
27 (63)	Fixed Kernel	1828.5	Adaptive Kernel	1836.5

two-mode-bivariate circle) were very close for owl thirteen (Range 1103.1 to 1104.1), but had a wider range (difference > 5) for owls ten and nineteen. CVC and AIC values suggested the two-mode-bivariate model was not competitive for any of the remaining owls and that there were no other competitive models (differences all exceeding 4). AIC values generally tracked well with CVC values, but could not be used for kernel methods. For example, when the two-mode-bivariate circle model was selected as the number 1 or 2 model, it always had the lowest AIC of the other competing models.

The best synoptic model as identified by the lowest total AIC for all 16 owls was model forty-nine (Table 1.6). The model formulation for this model is discussed more thoroughly in the habitat analysis section and includes the following parameters:

Model 49 - Wx = β_0 + β_1*(Aspect) + β_2*(Elevation) + β_3*(Stream Distance) + β_4*(Trees per Hectare) + β_5*(Trees per Hectare over 23 cm DBH) + β_6*(Trees per hectare over 38 cm DBH) + β_7*(Stand size class)

Synoptic model forty-nine was an improvement over the null bivariate normal model for all owls, but it did not offer any improvement over the null exponential power model for five owls (Table 1.10). The distribution of locations for these five owls had a circular pattern that was best represented by the exponential power model. AIC values for the other eleven owls were significantly lower (Delta AIC greater than 2) than the null models. In six cases the synoptic models that used the bivariate normal null model as the initial starting point had the lowest AIC (Table 1.10). The distribution of locations for these owls generally had a more linear distribution that often occurred along streamside riparian areas. Owl 19

Table 1.10 – AICs and Delta AICs of the Best Synoptic Model Compared to Bivariate Normal and Exponential Power Null Models

Owl Number	Bivariate Normal - Null (AIC)	Bivariate Normal - Null (Delta AIC)	Exp. Power - Null (AIC)	Exp. Power - Null (Delta AIC)	Synoptic BVN 49 (AIC)	Synoptic BVN 49 (Delta AIC)	Synoptic Exp. 49 (AIC)	Synoptic Exp. 49 (Delta AIC)
1	817.3	42.4	816.0	41.1	782.1	7.2	**774.9**[1]	**0**
2	1294.8	44.3	1325.1	74.6	**1250.5**[1]	**0**	1262.8	12.3
5	2170.5	188.6	2090.8	108.9	**1981.9**[1]	**0**	2103.6	121.7
8	858.7	68.9	853.1	63.3	**789.8**[1]	**0**	837.6	47.8
9	1064.1	34.5	1138.6	109.0	**1029.6**[1]	**0**	1049.3	19.7
10	951.7	14.7	**937.0**[1]	**0**	943.6	6.6	951.1	14.1
12	1122.4	34.5	1135.4	47.5	1099.8	11.9	**1087.9**[1]	**0**
13	1117.1	11.0	**1106.1**[1]	**0**	1110.0	3.9	1106.7	0.6
17	1492.2	31.5	1503.9	43.2	**1460.7**[1]	**0**	1487.9	27.2
19	1038.1	34.5	1010.6	7	**1003.6**[1]	**0**	**1003.6**[1]	**0**
20	1390.7	58.8	**1331.9**[1]	**0**	1366.6	34.7	1343.6	11.7
23	966.9	1.9	967.1	2.1	971.0	6.0	**965.0**[1]	**0**
24	1275.0	44.9	**1230.1**[1]	**0**	1270.8	40.7	1244.0	13.9
25	1728.7	10.5	1752.2	34.0	**1718.2**[1]	**0**	1766.2	48
26	1181.5	4.8	1190.2	13.5	1182.4	5.7	**1176.7**[1]	**0**
27	1821.7	14.3	**1807.4**[1]	**0**	1824.3	16.9	1810.3	2.9
Total	20291.3	640.1	20195.6	544.2	**19784.9**[2]	**133.6**[2]	19971.0	319.9

1 - Model with the lowest AIC and Delta AIC for each individual owl

2 – Model with the lowest total AIC and Delta AIC for all owls

had the same AIC value for both of the models that either started with the bivariate normal and the exponential power null models. The synoptic model that initially used the exponential power null model as a starting point had the lowest AIC for the remaining four owls (Table 1.10). Total AIC values for all 16 owls were the lowest for the models that used the bivariate normal null model as a starting point (Table 1.10).

The results from the traditional home range approaches (Best model - Mean size 275.8 ± 218.5 hectares) and the synoptic models (Mean size 306.0 ± 221.6 hectares) were similar (Table 1.11).

The different home range models predicted widely varying shapes and sizes for the seasonal home ranges. This can be seen in Figures 1.4 – 1.8 which display the results of applying different home range methods to the same distribution of locations for owl ten. While the different methods produced different distributions as illustrated by the displays for owl 10, overall model trends generally had similar patterns. For example, birds that had the largest home range with one method had the largest home range with the other methods (Table 1.11).

Horne and Garton (2006a) suggested that the “best” home range model could be selected by using an information-theoretic approach. They suggested that the Likelihood Cross-Validation (CVh) was a better method for selecting the smoothing parameter in kernel analysis than the Least Squares Cross-Validation (LSCVh) method for small sample sizes less than fifty (Horne and Garton 2006b). This investigation generally supports those conclusions (12 of 16 cases), but suggests that a great deal of caution is needed in selecting

Table 1.11 – Home Range Size in Hectares for Various Home Range Methods

Northern Pygmy-Owl Number (n)	**95% Fixed Kernel (CVh) (Ha**	**95% Fixed Kernel (LSCVh)**	**95% Adapt. Kernel (CVh)**	**95% Adapt. Kernel (LSCVh)**	**95% MCP (Area Added)**	**95% MCP (Fixed Mean)**	**Best Model (CVC and CVh)**	**95% (Synoptic Model - BVN-49)**
1 (31)	31.0	22.9	**50.9**	30.1[3]	21.4	23.1	50.9	35.9
2 (42)	309.9	104.0	**395.1**	129.5	220.1	219.8	395.1	347.9
5 (69)	**97.1**	50.3	132.6	64.9	330.1	337.3	97.1	335.1
8 (29)	**40.6**	43.2	45.2	48.2	76.7	86.2	40.6	81.7
9 (37)	**105.8**	90.1	123.7	105.6	69.9	84.8	105.8	105.6
10 (30)	900.8	301.3	1131.6	400.7[3]	402.3	482.8	**830.5**[1]	628.2
12 (38)	132.7	116.3	**141.7**	125.0	107.8	114.6	141.7	171.5
13 (38)	319.5	198.6[3]	**395.4**	278.4	138.7	170.4	395.4	221.2
17 (50)	287.9	131.5	**330.2**	169.2	149.6	149.6	330.2	228.0
19 (38)	122.6	48.4	**168.2**	73.7[3]	54.7	66.4	168.2	68.0
20 (44)	234.4	55.4	**305.5**	69.6	396.0	293.3	305.5	550.9
23 (30)	**623.5**	488.4	688.7	550.4	371.3	381.9	623.5	817.3
24 (41)	277.9 (819.6)[2]	53.0	**360.0** (918.3)[2]	68.8	166.3	166.3	360.0	502.3
25 (58)	**126.2**	35.9	147.2	42.2	126.3	133.0	126.2	269.7
26 (39)	**328.3**	280.3	368.1	325.9	180.0	192.4	328.3	350.1
27 (63)	**113.2**	67.6	120.9	74.2	92.8	87.2	113.2	182.0
Mean	253.2	130.5	306.6	159.8	181.5	186.8	275.8	306.0
Standard Deviation	228.0	127.5	277.3	150.7	126.2	127.2	218.5	221.6

1 - Best model is Two-Mode- Bivariate Circle – 95% Contour = 830.5 Hectares
2 - Effect of a single “outlier” on the home range size, smoothing factor changes from 434.635 to 148.708 when this location is dropped
3 - Models that LSCVh smoothing factors may be better than CVh smoothing factors

Bold highlights suggest the best models based on CVC Values and CVh Smoothing Factors appropriate home range model. I display one example (Figure 1.6) where the Least Squares Cross-Validation method may actually give a more reasonable estimate of home range size. In this case the distribution more tightly corresponds to the areas actually used by owl 10, and excludes larger areas that appear to have added to the distribution when the (CVh) smoothing factor is utilized (Figure 1.5). This example illustrates how kernel estimates are very sensitive to smoothing factor selection (Horne 2006b) and I found that outlying locations or shifts in areas of use can dramatically influence both the smoothing factor and resulting home range output (Table 1.11 - Figures 1.4-1.8). The synoptic model approach does not require selection of smoothing factors.

I did not have enough data to document shifts in space use by season. Winter observations only included one owl (Owl 17) and differences in seasonal range size or habitat use were not apparent. Owl 17 had a winter seasonal range of 330.2 hectares as measured by the adaptive kernel method (CVh smoothing factor) and 228.0 hectares as measured by the synoptic model. These values are comparable to seasonal ranges of the other fifteen owls that had enough radio locations to evaluate space use (See Table 1.11).

With the possible exception of non-breeding males, my observations did not suggest significant differences in space use at other times of the year (spring, summer and fall). Owls generally used similar habitats and had similar sized seasonal ranges during these seasons (Table 1.11). A few male owls (N=2) that were thought to be non-breeding did appear to have larger home ranges than breeding males (N=6) in the spring (Table 1.12), but the sample size is small. A larger sample size is needed to better test this hypothesis.

Table 1.12 – Space Use by Male Birds During the Breeding/Nesting Season (N=8)

Bird #	Nest	Home Range (Best Model -Hectares)	Used Area Breeding Season (Hectares)	Synoptic Model (Hectares)	Used Area Synoptic Model	Movement After Breeding Season
5	Confirmed	97.1	68.9	335.1	165.8	Yes – 3.2 Km
8	Suspected	40.6	33.4	81.7	49.9	Yes – 1.5 Km
9	Suspected	105.8	58.5	105.6	47.7	Yes – 1.9 Km
19	Confirmed	168.2	Same (168.2)	68.0	Same (68.0)	Unknown?? – Battery failure just prior to young fledging
20	Prey Returns	305.5	206.3	550.9	285.9	Yes -3.2 Km
24	Fledglings	360.0	Same (360.0)	502.3	Same (502.3)	Yes – Only one Location - 2..7 Km
Average – Breeding Males		**179.5**	**149.2**	**273.9**	**186.6**	**2.5 Km**
Standard Deviation		126.6	123.4	219.2	180.0	0.77
10	Non-Breeding?	830.5	Same	628.2	Same	No
23	Non-Breeding?	623.5	Same	817.3	Same	No
Average – Non Breeding Males		**727**		**722.8**		
Standard Deviation		146.4		133.7		

Figure 1.4 – Estimated Probability Distribution for Owl 10 Based on Two-mode Bivariate Circle Showing 50/75/90/95% Probability Contours with a 95 % Probability Area of 830.5 Hectares

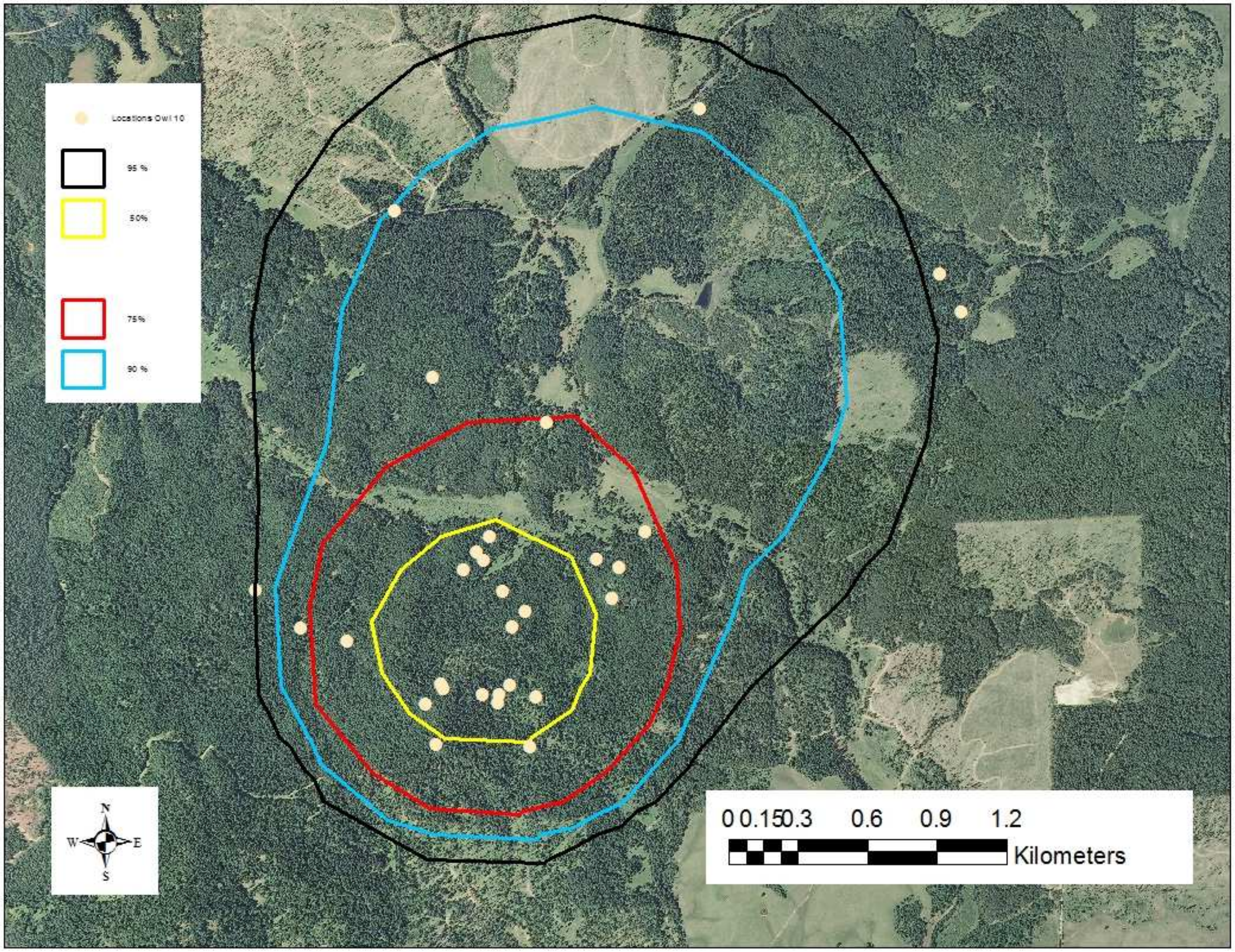


Figure 1.5 – Estimated Probability Distribution for Owl 10 Based on Adaptive Kernel (CVh) Showing 50/75/90/95% Probability Contours with a 95 % Probability Area of 1131.6 Hectares

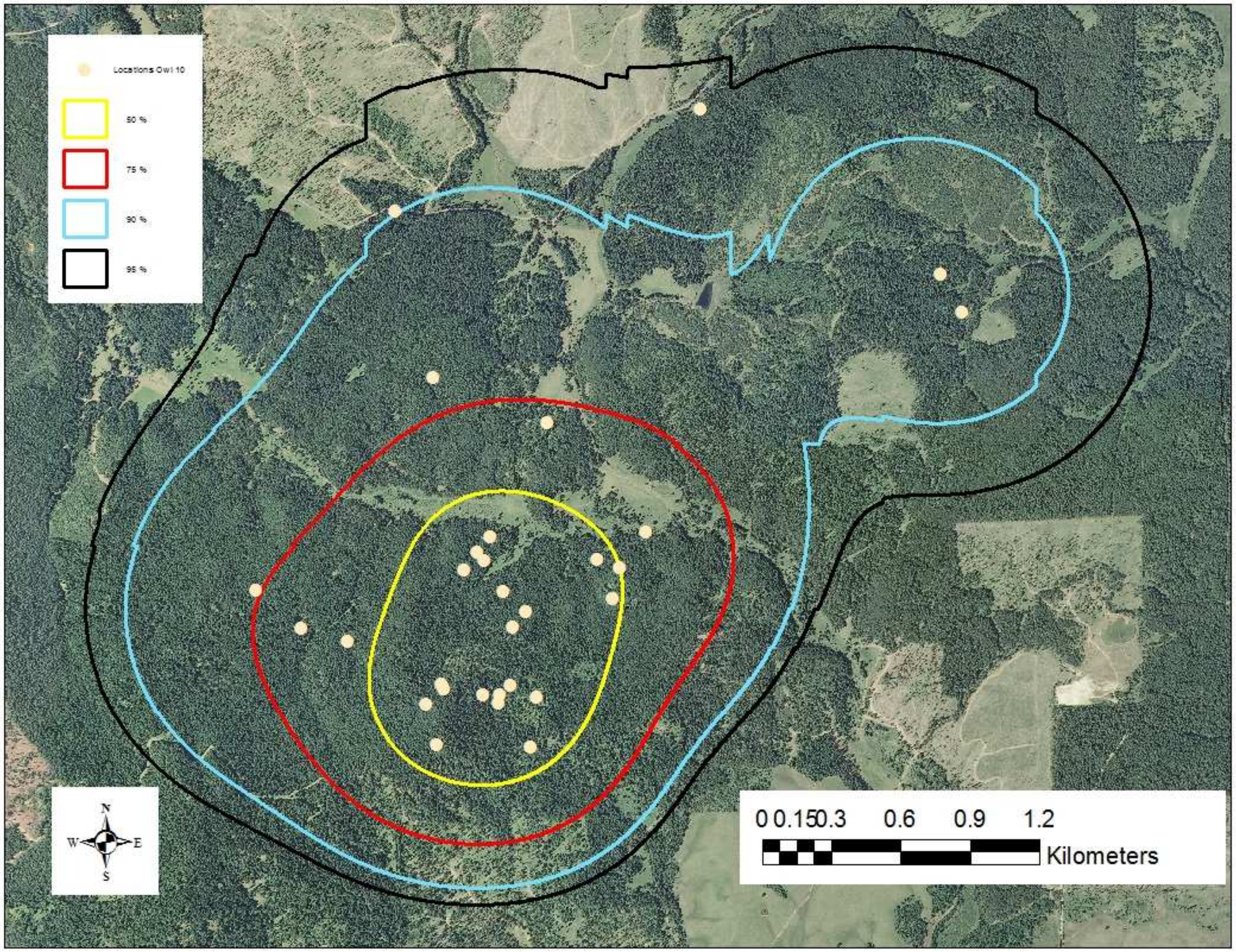


Figure 1.6 – Estimated Probability Distribution for Owl 10 Based on Adaptive Kernel (LSCVh) Showing 50/75/90/95% Probability Contours with a 95 % Probability Area of 400.7 Hectares

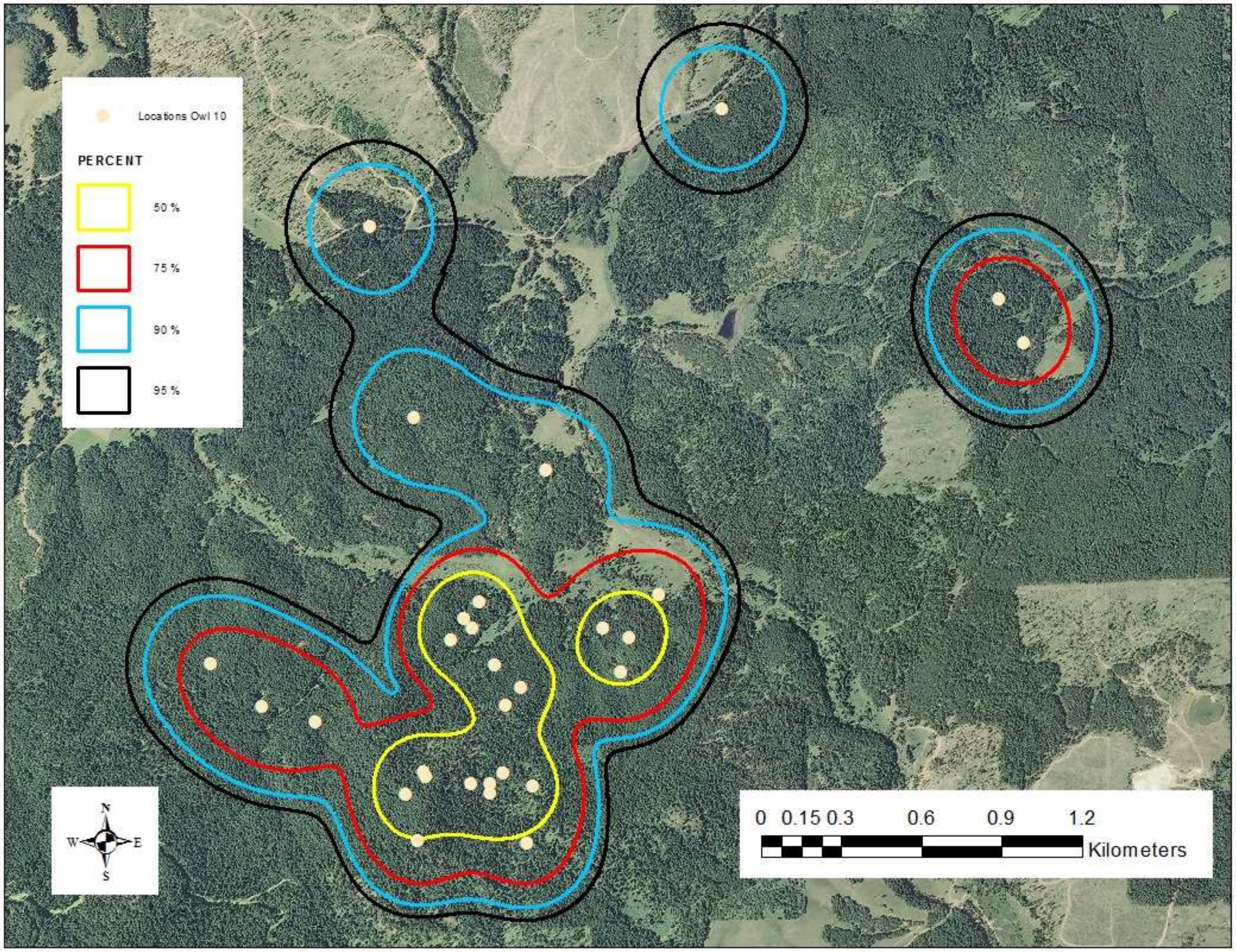


Figure 1.7 – Estimated Probability Distribution for Owl 10 Based on Minimum Convex Polygon (Fixed Mean) Showing 50/75/90/95% Probability Contours with a 95 % Probability Area of 482.2 Hectares

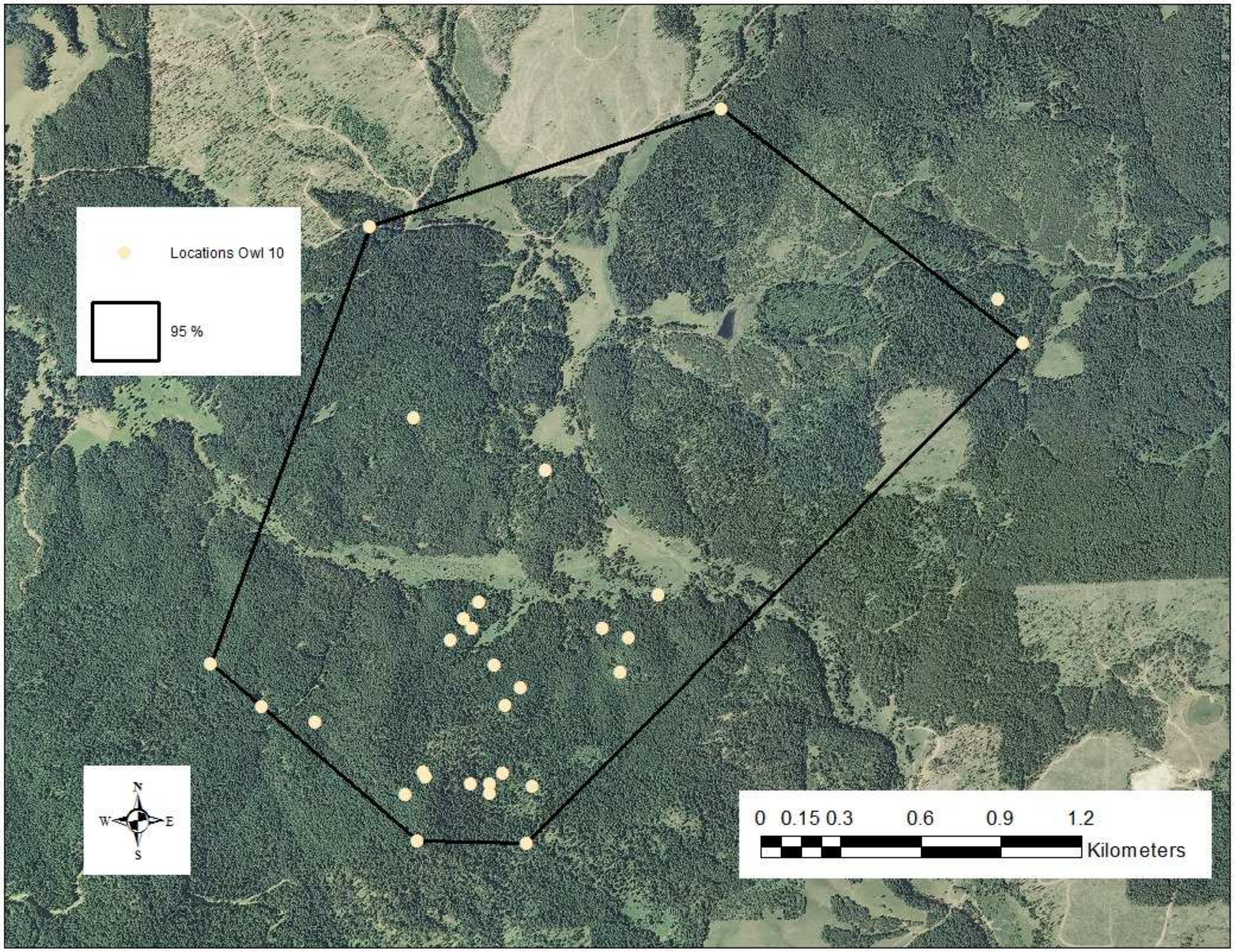
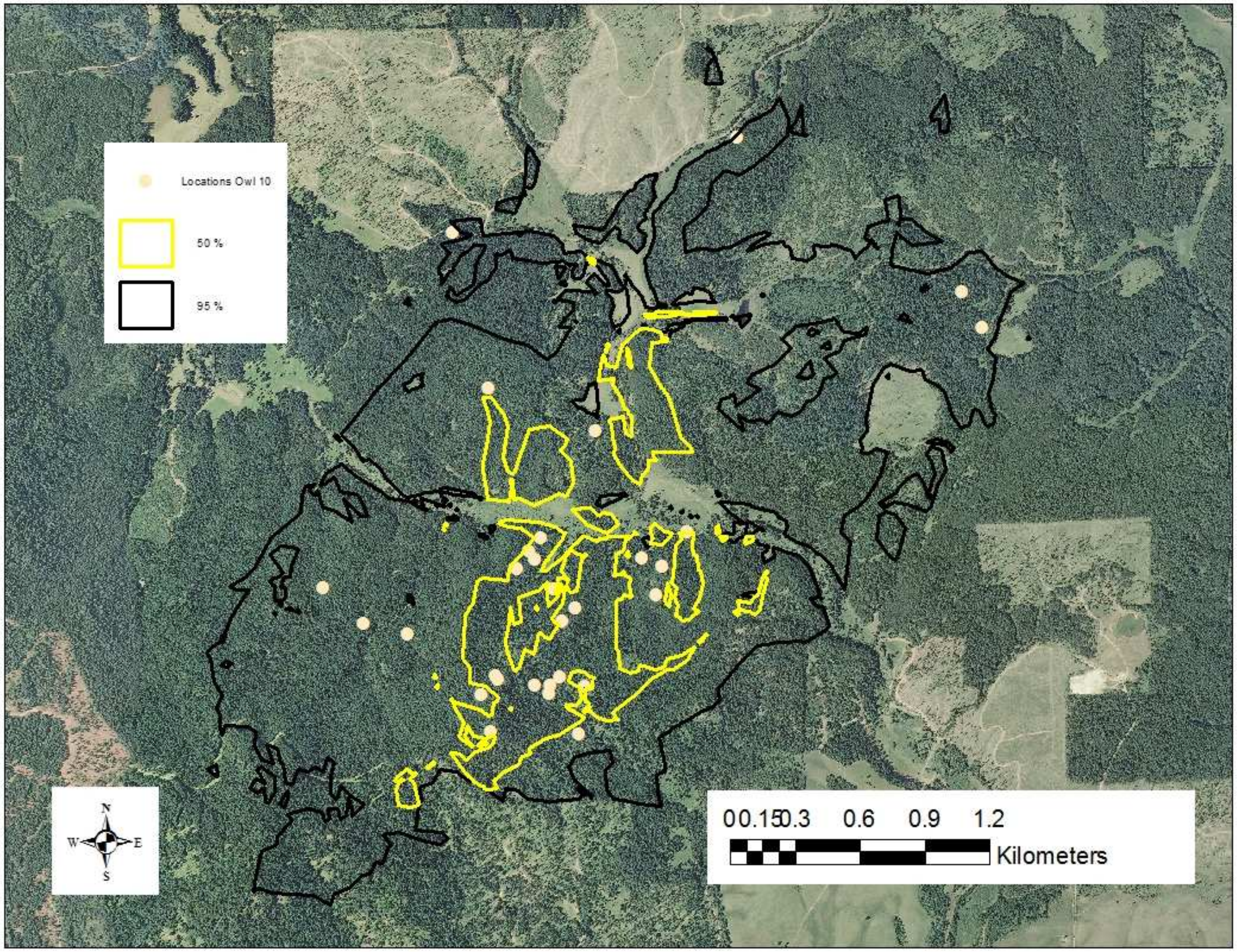


Figure 1.8 – Estimated Probability Distribution for Owl 10 Based on BVN Synoptic Model 49 Showing 50 and 95% Probability Contours with a 95 % Probability Area of 628.2 Hectares



1.4.3 Spring/Summer Movements

Twelve male owls were trapped during the spring breeding season. Three additional owls (two males and one female) were trapped in the early summer just after fledglings had left the nest (Table 1.7). I was able to measure seasonal range size for eleven of these owls. These owls generally did not make long movements over the course of the spring and summer and nine of the eleven owls had an average core use area of less than 76 hectares (as measured by the 75% contour with the best traditional home range methods). Two owls (10 and 23) appeared to be non-breeding males and both had large core use areas (average size 266 hectares as measured by the 75% contour). As has been previously discussed, these owls had the largest seasonal ranges (Table 1.11) and their location distribution included more outlying locations.

Other observations suggested that breeding male owls may be making a shift in their seasonal range after the breeding season. Of the six birds that were thought to be nesting during the study, four birds moved from their nesting territory to a completely different area following the breeding season (after dispersal of the young). A fifth bird moved on the last day he was located and just after fledgling dispersal, but only a single location was obtained on him in the new area. The average distance moved by these males was 2.5 kilometers (Table 1.12).

1.4.4 Fall/Winter Movements

In this study I captured nine owls in the fall and followed those owls into the early winter (December and January – Table 1.7). Of those owls, one was lost to another raptor prior to the onset of winter. Three others were lost to other raptors but stayed on their fall range until December when they were located as mortalities. Two remained on their fall range into December and early January when their transmitter batteries appeared to expire. Three owls either left their fall seasonal range around Thanksgiving (two in 2006 and one in 2007) or had premature battery failures. There was approximately 35 cm of snow on the ground in 2006 when the first two birds exited from their fall range. In 2007, there was only about 15 cm of snow. All three of these owls should have had several weeks of battery life on their transmitters, but despite extensive ground searching within and outside of the study area none of these three owls could be relocated. Funding was not sufficient to allow for aerial searching.

Only two owls were trapped in the winter (Table 1.7) and one of those owls succumbed to a raptor attack and was lost shortly after capture. That owl was captured in a relatively low elevation area (641 meters) which had habitat that was warmer and drier and had less accumulation of snow than most of the other capture sites. The second owl was captured in habitat that was similar to those of owls that were captured in other seasons. Locations for this owl had a mean elevation of 937 meters and ranged in elevation from 871 to 1154 meters. Non-winter capture sites had a mean elevation of 944 meters and a standard deviation of 88 meters. They ranged in elevation from 799 to 1198 meters.

1.4.5 Daily Movement Patterns

I followed several owls throughout the day and night and recorded observations on their daily movement patterns. Owls were generally most active just after dawn and late in the evening and often were heard calling at these times. I often observed movements in the early morning hours. During the day owls did not appear to move a great deal, but were observed to dive after prey when presented with an opportunity. I detected no movement of owls during the night and my observations suggest that Northern Pygmy-Owls are generally diurnal.

1.4.6 Response to Disturbance

During my monitoring of radio tagged Northern Pygmy-Owls, I noted very little reaction to my presence near the owls. While I never tried to disturb them and generally tried to minimize noise and movement, it is likely that I could be seen by some of the owls. One notable exception occurred one morning when I was tracking owl ten near an active timber sale. I was in a forested area where I could not see a great distance and had just located owl ten. It was quiet and I had not heard any logging activity that day. All of a sudden, I heard the startup of some feller-buncher logging equipment very near to my location. The noise was very loud and the crashing of nearby trees and brush made for a very notable event which scared me as much as it likely did owl ten. Both I and owl ten quickly exited the area. He made a beeline away from the logging activity and I finally located him 1387 meters away about two hours later.

1.4.7 Habitat Selection

Overall habitat characteristics of the study area are displayed in Appendix B. In this appendix I summarize several habitat variables for the portion of the study area that was considered available to Northern Pygmy-Owls and compare these data to habitat data for all used radio locations. These data are intended to give the reader a sense of the available habitat in the study area and locations being used by Northern Pygmy-Owls. A review of Appendix B should also help the reader better understand the model results described in this section the limitations of the data used to develop these models.

The results of the habitat analysis are presented in Tables 1.13 to 1.15. AIC values are displayed by the three previously described model categories and include results for both the synoptic method (bivariate normal and exponential power initial null models) and logistic regression. AIC values are shown for all 41 examined models (eight based on physical parameters – Table 1.13, sixteen based on physical and remotely sensed vegetation parameters (US Forest Service - Vmap) – Table 1.14 and seventeen based on physical and stand exam parameters - Table 1.15). Overall the top synoptic model with the lowest AIC was bivariate normal model 49. This model was based on the following physical and stand exam parameters:

Model 49 - Wx = β_0 + β_1*(Aspect) + β_2*(Elevation) + β_3*(Stream Distance) + β_4*(Trees per Hectare) + β_5*(Trees per Hectare over 23 cm DBH) + β_6*(Trees per hectare over 38 cm DBH) + β_7*(Stand size class)

Models 5 and 43 were the top logistic regression models (Note that AIC values for the logistic regression method are not directly comparable to AIC values for the synoptic method), with both models having essentially the same AIC value (Table 1:15). Models 5 and 43 include all of the same parameters as model 49, but differ by the addition of the "Slope" parameter in model 43 and both "Slope" and the species parameter "GF_C_H_WP" in model 5. Model 5 is the "full" model that includes all of the analyzed stand exam parameters.

Model 5 - Wx = β_0 + β_1*(Slope) + β_2*(Aspect) + β_3*(Elevation) + β_4*(Stream Distance) + β_5*(GF_C_H_WP) + β_6*(Trees per Hectare) + β_7*(Trees per Hectare over 23 cm DBH) + β_8*(Trees per hectare over 38 cm DBH) + β_9*(Stand size class)

Table 1.13 – Comparison of the Best Overall Physical Models for Sixteen Owls Based on Delta AIC Values for the BVN Synoptic, Exponential Power Synoptic and Logistic Regression approaches

Model	Delta AIC (Synoptic - BVN)	Delta AIC (Synoptic – Exp. Power)	Delta AIC (Logistic Regression)2	Variable 1	Variable 2	Variable 3	Variable 4
20[1](Full_Physical)	100.1	216.3	156.4	Slope	Aspect	Elev.	STRM_DIST
19	124.9	205.7	191.4	Aspect	Elev.	STRM_DIST	
18	175.9	230.6	185.0	Slope	Elev.	STRM_DIST	
16	191.3	217.9	218.9	Elev.	STRM_DIST		
17	206.8	256.2	249.8	Slope	Aspect	STRM_DIST	
15	235.9	242.4	287.2	Aspect	STRM_DIST		
14	291.3	275.5	291.6	Slope	STRM_DIST		
21	303.1	258.3	324.4	STRM_DIST			

1 - The full bivariate normal model 20 had the best AIC value of the physical models, but overall the physical models had higher AICs than the models which added vegetation variables. The synoptic models are compared to the best synoptic bivariate model 49 which had a total AIC value of 19784.9

2 -The scale of AIC values for the logistic regression models are different than those displayed for the synoptic models and should not be compared directly. Logistic regression models are compared to the best logistic regression model 43 which had a total AIC value of 1418.4

Table 1.14 – Comparison of the Best Overall Remotely Sensed Vegetation (Vmap) Models for Sixteen Owls Based on Delta AIC Values for the BVN Synoptic, Exponential Power Synoptic and Logistic Regression Approaches

Model	Syn. BVN	Syn. Exp.	Log. Reg.	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7
35	74.6	202.3	116.3	Slope	Aspect	Elev.	STRM_DIST	Vmap_Canopy	Vmap_C_GF	
33	77.3	216.5	102.0	Slope	Aspect	Elev.	STRM_DIST	Vmap_Size	Vmap_Canopy	
31	78.2	232.2	120.5	Slope	Aspect	Elev.	STRM_DIST	Vmap_Canopy		
4 (Full Vmap)	87.7	196.5	89.5	Slope	Aspect	Elev.	STRM_DIST	Vmap_Size	Vmap_Canopy	Vmap_C_GF
32	93.2	195.3	142.7	Slope	Aspect	Elev.	STRM_DIST	Vmap_C_GF		
34	95.3	197.3	96.6	Slope	Aspect	Elev.	STRM_DIST	Vmap_Size	Vmap_C_GF	
50	97.5	206.4	150.5	Aspect	Elev.	STRM_DIST	Vmap_Canopy			
51	98.0	200.3	129.3	Aspect	Elev.	STRM_DIST	Vmap_Size	Vmap_Canopy		
30	109.3	234.4	112.9	Slope	Aspect	Elev.	STRM_DIST	Vmap_Size		
6	125.7	226.5	180.6	Slope	Aspect	STRM_DIST	Vmap_Size	Vmap_Canopy	Vmap_C_GF	
8	171.5	219.5	203.2	Slope	STRM_DIST	Vmap_Size	Vmap_Canopy	Vmap_C_GF		
10	188.1	196.5	220.0	STRM_DIST	Vmap_Size	Vmap_Canopy	Vmap_C_GF			
23	224.1	246.0	274.3	STRM_DIST	Vmap_Canopy					
12	231.4	221.8	245.8	STRM_DIST	Vmap_Size	Vmap_Canopy				
24	234.5	211.1	277.2	STRM_DIST	Vmap_C_GF					
22	278.8	238.5	261.8	STRM_DIST	Vmap_Size					

Table 1.15 – Comparison of the Best Overall Stand Exam Models for Sixteen Owls Based on Delta AIC Values for the BVN Synoptic, Exponential Power Synoptic and Logistic Regression approaches

Model	BVN	Exp.	Log. Reg.	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7	Variable 8	Variable 9
49	0.0[1]	186.1	11.2	Aspect	Elev.	STRM_DIST	TPHA	TDTPHA23	TDTPHA38	HJ_Size		
43	19.1	226.3	0.0[2]	Slope	Aspect	Elev.	STRM_DIST	TPHA	TDTPHA23	TDTPHA38	HJ_Size	
47	27.3	196.7	44.3	Slope	Aspect	Elev.	STRM_DIST	TPHA	HJ_Size			
48	33.8	184.4	66.3	Aspect	Elev.	STRM_DIST	TDTPHA23	TDTPHA38	HJ_Size			
05(Full)	38.1	143.4	0.1	Slope	Aspect	Elev.	STRM_DIST	GF_C_H_WP	TPHA	TDTPHA23	TDTPHA38	HJ_Size
46	51.2	211.3	45.7	Slope	Aspect	Elev.	STRM_DIST	TDTPHA23	HJ_Size			
41	55.6	176.7	101.2	Slope	Aspect	Elev.	STRM_DIST	HJ_Size				
44	63.0	195.0	46.4	Slope	Aspect	Elev.	STRM_DIST	TDTPHA23	TDTPHA38	HJ_Size		
07	68.4	225.6	56.8	Slope	Aspect	Elev.	STRM_DIST	GF_C_H_WP	TDTPHA23	TDTPHA38	HJ_Size	
45	74.7	189.0	81.9	Slope	Aspect	Elev.	STRM_DIST	TDTPHA38	HJ_Size			
39	91.8	185.0	123.4	Slope	Aspect	Elev.	STRM_DIST	TDTPHA23				
37	95.4	207.1	158.8	Slope	Aspect	Elev.	STRM_DIST	GF_C_H_WP				
40	95.6	170.6	124.6	Slope	Aspect	Elev.	STRM_DIST	TDTPHA38				
38	104.8	196.0	104.2	Slope	Aspect	Elev.	STRM_DIST	TPHA				
27	215.9	200.5	206.5	STRM_DIST	GF_C_H_WP	TDTPHA23	HJ_Size					
28	236.4	231.7	269.9	STRM_DIST	GF_C_H_WP	HJ_Size						
29	243.7	224.2	257.9	STRM_DIST	HJ_Size							

1 - The best overall synoptic model (BVN 49) had a total AIC of 19885 for all 16 owls. Note the difference in scale between the synoptic models and the logistic regression models. AIC values for the synoptic model are generally 10 times those of the logistic regression models

2 - The best overall logistic regression model (BVN 43) had a total AIC value of 1418.4 for all 16 owls

Model 43 - Wx = β_0 + β_1*(Slope) + β_2*(Aspect) + β_3*(Elevation) + β_4*(Stream Distance) + β_5*(Trees per Hectare) + β_6*(Trees per Hectare over 23 cm DBH) + β_7*(Trees per hectare over 38 cm DBH) + β_8*(Stand size class)

In comparing the results of the synoptic analysis with the logistic regression analysis, I found that while the order of the models was different based on AIC values both methods essentially identified the same top models. For example, four out of the five top synoptic models (**49, 43, 47**, 48 and **5**) also occurred in the five top models in the logistic regression (**43, 5, 49, 47** and 46). Models are listed from lowest to highest AIC values respectively.

The physical models did not perform as well as the models that included the vegetation parameters and the stand exam models generally outperformed models based on remotely sensed vegetative data. For example the best synoptic physical model (BVN-Model 20) had a Delta AIC value of 100.1 which placed it below eight of sixteen remotely sensed vegetative (Vmap) models and all but four of the seventeen stand exam models. Model 20 (the full physical model) was also the best physical model as determined by logistic regression.

Model 20 = Wx = β_0 + β_1*(Slope) + β_2*(Aspect) + β_3*(Elevation) + β_4*(Stream Distance)

Overall the models with the lowest AIC were the models based on the stand exam information. These models generally outperformed models that were based strictly on physical parameters or remotely sensed vegetation data (Vmap). Of the 41 models that were examined in the analysis using the synoptic method the top nine models (Lowest Delta AIC) were all stand exam models (Tables 1.13, 1.14 and 1.15). This also held true for the logistic regression, where the top nine models were also based on stand exam information (Tables 1.13, 1.14 and 1.15).

The models based on the stand exam vegetation data had lower AICs than either the physical or Vmap models. For example, the best stand exam synoptic model (BVN Model 49) had a Delta AIC of 0.0 as compared to the best remotely sensed Vmap model (BVN Model 35) which had a Delta AIC of 74.6. This was a difference of 74.6 or an average of 4.66 for the individual owls. Results were similar for the logistic regression with the best stand exam logistic regression model (Model 43) having a Delta AIC of 0.0 compared to a Delta AIC of 89.5 or 5.6 per individual owl for the best remotely sensed vegetative logistic regression model (Model 4). Models with differences in AIC values greater than 2.0 are considered to be statistically significantly different at least the 0.05 level (Burnham and Anderson 2002). This suggests the stand exam models are a significant improvement over both the remotely sensed vegetative models and the physical models.

Adding remotely sensed vegetative data variables for vegetation to the physical model improved the AIC values over that of the physical model alone. The best remotely sensed synoptic model (BVN-Model 35) had a Delta AIC value of 74.6 as compared to the best synoptic physical model (BVN-Model 20) which had an AIC value of 100.1. This is an average difference of 1.6 for the individual owls. The results for the logistic regression models suggest a significant difference between the physical and remotely sensed data. The physical logistic regression model which had the lowest AIC was also Model 20 which had a Delta AIC value of 156.4. This compared to the best remotely sensed vegetative model as determined by logistic regression (Model 4) which had a Delta AIC value of 89.5. This is an average difference of 4.2 for the individual owls.

Again there were differences between the best remotely sensed models (lowest Delta AIC) as determined by the synoptic and logistic regression approaches. The best model in the remotely sensed vegetative group as determined by the synoptic approach was BVN-Model 35.

Model 35 - Wx = $\boldsymbol{\beta_0 + \beta_1}$***(Slope) +** $\boldsymbol{\beta_2}$***(Aspect) +** $\boldsymbol{\beta_3}$***(Elevation) +** $\boldsymbol{\beta_4}$***(Stream Distance) +** $\boldsymbol{\beta_5}$***(Vmap_Canopy) +** $\boldsymbol{\beta_6}$***(Vmap_GF_C)**

The best model as determined by logistic regression was model 4, which differs from model 35 by the inclusion of the term for vegetation size class.

Model 4 - Wx = $\boldsymbol{\beta_0 + \beta_1}$***(Slope) +** $\boldsymbol{\beta_2}$***(Aspect) +** $\boldsymbol{\beta_3}$***(Elevation) +** $\boldsymbol{\beta_4}$***(Stream Distance) +** $\boldsymbol{\beta_5}$***(Vmap_Size) +** $\boldsymbol{\beta_6}$***(Vmap_Canopy) +** $\boldsymbol{\beta_7}$ ***(Vmap_GF_C)**

Again there was general agreement in the remotely sensed vegetation top models as determined by synoptic model and logistic regression methods. The synoptic approach identified Models **35, 33, 31, 4,** 32 and **34** as the top six remotely sensed vegetative models (respectively). The logistic regression method identifies **4**, **34**, 30, **33, 35** and **31** as the top remotely sensed models (respectively). Added AIC values were very close for each of the individual methods. The total difference between the top six BVN synoptic models was 20.7, which is an average difference of 1.3 for the sixteen individual owls used in the analysis (Table 1.14). Similarly, the difference between the top six logistic regression models was 31.0 which is an average difference of 1.9 for sixteen individual owls used in the analysis (Table 1.7). Models with differences in AIC values less than 2.0 are considered not statistically different (Burnham and Anderson 2002).

The parameters in the top six Vmap models were very similar. All six models incorporated the four physical parameters (SLOPE, ASPECT, ELEV, and STRM_DIST) and various combinations of the three Vmap parameters (Vmap_Size + Vmap_Canopy +

Vmap_C_GF_H). Model 4 is the full Vmap model and it ranked 4th among the synoptic models and 1st among the logistic regression models. In models 30, 31, 32, 33 and 35 one or more of the Vmap parameters is dropped (Table 1.14).

The synoptic model that started with the BVN null model had the lowest added AICs for all model categories (Physical, Vmap and Stand_Exam) and generally outperformed (Lower AICs) the synoptic exponential power model for the overall population. However, this was not the case for individual owls. The exponential power model often had the lowest AIC for almost half of the individual owls. In most cases, the model that proved to be "best" could be seen by looking at the distribution of the locations prior to running the model. Several owls appeared to have seasonal ranges that were being influenced by stream courses and valley topography. In those cases, the BVN model generally had the lowest AIC. Topography and the influence of stream courses were generally less distinct for those owls where the synoptic exponential power model had the lowest AIC.

Tables 1.16-1.21 display the individual results for the best models in each category and they include the "full" model in each category. Model coefficients are shown for both the bivariate normal synoptic and the logistic regression methods. I display both the standard error and P-values for each parameter used in the individual models. I note parameters that are significant at $P <= 0.05$ and $P <= 0.01$

All of the best models of resource selection suggest that Northern Pygmy-Owls strongly select habitats near streams within the sampled range. Distance to stream was a significant parameter in all of the top models of resource selection regardless of what physical and vegetation parameters were included in the models (Tables 1:16-1:21). This parameter was generally significant at $P <= 0.001$ in all models suggesting it is an extremely important factor in pygmy-owl habitat selection within the study area. Strong selection for streamside areas was demonstrated with both the synoptic and logistic approaches.

The second most important selection parameter was forest stand size class. Northern Pygmy-Owls tended to select habitats in older more mature stands in the study area. This is consistent with past studies, (Giese and Forsman 2003, Sater et al. 2006) where researchers found greater use of older late successional forests. Stand size class was a significant parameter ($P<0.01$) in all of the best stand exam models (Tables 1:19, 1:20 and 1:21). It was also significant ($P<0.01$) in the best remotely sensed Vmap synoptic model (Model 4). The importance of this parameter appears to have overshadowed all other vegetation variables in the stand exam models, since the only other vegetative parameter to show some level of significance was trees per hectare over 23 cm DBH.

Trees over 23 cm DBH appears to have a statistically significant negative influence on Northern Pygmy-Owl habitat selection (Tables 1:19– 1:21) in the logistic regression stand exam models, but not in the synoptic stand exam models. This same negative trend is seen in total trees per acre, but this parameter is not statistically significant in any of the best models. Northern Pygmy-Owls appear to select older age class stands as evidenced by the strong selection in larger stand size classes and positive selection for trees over 38 cm DBH in all models except the logistic regression model forty-three. Logistic model forty-three has a P-level of 0.98 for this parameter and is likely not representative of the positive trend seen in all of the other stand exam models for the number of trees over 38 cm DBH. When avoidance of stands with high numbers of small trees less than 23.9 cm is coupled with the strong association with larger size classes, the results suggest that Northern Pygmy-Owls are avoiding stands with high numbers of young trees and selecting stands with more open understories and larger trees commonly associated with older stands.

The best remotely sensed vegetative models (Models 4 and 35) suggest that higher canopy closure and moister species groups like grand fir, cedar and white pine are selected in the study area. Both parameters were statistically significant at the $P < 0.1$ levels (Tables 1:17 and 1:18). The stand exam models did not incorporate crown closure since it was highly positively correlated with stand size class in the stand exam data. The addition of moister species groups did lower AIC values in stand exam model five (Table 1:19), but this parameter was not statistically significant. Moist species groups did not influence model forty-three (Table 1:20) or model forty-nine (Table 1:21). These two models were the best stand exam models and best overall models.

Topographical features such as slope, aspect and elevation were important in the physical models and when the data is analyzed with the logistic regression approach. All models suggest that Northern Pygmy-Owls are using lower elevations, more northerly aspects and steeper slopes than those currently available in the study area. These parameters are more statistically significant $P < 0.05$ in the physical and remotely sensed models and less statistically significant in the stand exam models. The comparison of random points to used points suggests an average slope of 24.9% slope for random points compared to 26.1% for used points (Appendix B).

Slope, aspect and elevation also appear to be more statistically significant when the logistic regression approach is utilized.

Table 1.16 –Estimated Coefficients (*β*) of Physical Model 20
(Best Physical Model Using the BVN Synoptic and Logistic Regression Approaches)

Parameter	BVN 20 (*β*)	BVN 20 SE)	BVN 20 P-Value	Log - 20 (*β*)	Log - 20 SE (EQ 2)	Log - 20 P-Value (EQ 2)
(Intercept)				5.1619390	4.23495	0.24170
Slope	0.028	0.693	0.96814	0.0329938	0.01063	0.00730**
Aspect	-0.556	0.381	0.16535	-0.0037698	0.00117	0.00560**
Elev.	-2.962	1.673	0.09696*	-0.0047577	0.00445	0.30230
STRM_DIST	-4.059	0.800	0.00014**	-0.0096755	0.00197	0.00020**

** Parameters in Tables 1.16 thru 1.21 which are significant at P<=0.05
*   Parameters not significant at P<=0.05 but which are significant at P<=0.1

Table 1.17 –Estimated Coefficients (*β*) of Vmap Model 4
(Full Vmap Model and Best Model Using Logistic Regression)

Parameter	BVN - 4 (*β*)	BVN - 4 SE	BVN - 4 P-Value	Log - 4 (*β*)	Log - 4 SE	Log - 4 P-Value
(Intercept)				5.193	4.25547	0.24120
Slope	0.128	0.657	0.84766	0.029	0.01045	0.01470**
Aspect	-0.519	0.332	0.13813	-0.004	0.00116	0.00450**
Elev.	-1.173	1.540	0.45805	-0.007	0.00453	0.16410
STRM_DIST	-4.106	0.895	0.00036**	-0.010	0.00255	0.00160**
Vmap_Size	0.764	0.306	0.02485**	0.317	0.32303	0.34260
Vmap_Canopy	0.476	0.271	0.09963*	0.260	0.09491	0.01510**
Vmap_C_GF_H	0.368	0.172	0.04910**	0.533	0.32929	0.12670

Table 1.18 –Estimated Coefficients (*β*) of Vmap Model 35 (Best Vmap Model Using the Synoptic Approach)

Parameter	BVN - 35 (*β*)	BVN - 35 SE (EQ 2)	BVN - 35 P-Value (EQ 2)	Log - 35 (*β*)	Log - 35 SE (EQ 2)	Log - 35 P-Value (EQ 2)
(Intercept)				5.469	3.97159	0.18870
Slope	0.113	0.631	0.85996	0.031	0.01012	0.00800**
Aspect	-0.398	0.356	0.28157	-0.003	0.00118	0.01460**
Elev.	-1.419	1.461	0.34675	-0.006	0.00428	0.16100
STRM_DIST	-4.154	0.840	0.00018**	-0.009	0.00197	0.00030**
Vmap_Canopy	0.596	0.230	0.02044**	0.305	0.08951	0.00390**
Vmap_C_GF_H	0.372	0.167	0.04189**	0.492	0.24255	0.0608*

Table 1.19 –Estimated Coefficients (*β*) of Stand Exam Model 5 (Full Model)

Parameter	BVN - 5 (*β*)	BVN - 5 SE (EQ 2)	BVN - 5 P-Value (EQ 2)	Log - 5 (*β*)	Log - 5 SE (EQ 2)	Log - 5 P-Value (EQ 2)
(Intercept)				3.89317	6.9692	0.5847
Slope	0.243	0.5020	0.63598	0.03357	0.0110	0.00820**
Aspect	-0.465	0.3064	0.15023	-0.00327	0.0014	0.03880**
Elev.	-1.053	2.6465	0.69624	-0.00496	0.0076	0.52570
STRM_DIST	-3.984	1.3941	0.01198**	-0.01009	0.0025	0.00130**
GF_C_H_WP	0.004	0.1512	0.98120	0.18760	0.4730	0.69720
TPHA	-0.828	1.2550	0.51945	0.00149	0.0015	0.34540
TDTPHA23	-4.977	3.5346	0.17952	-0.03396	0.0174	0.07060*
TDTPHA38	1.459	1.2341	0.25541	0.01440	0.0361	0.69530
HJ_SIZE	2.712	0.6814	0.00121**	0.65405	0.2013	0.00540**

Table 1.20 –Estimated coefficients (*β*) of Stand Exam Model 43 (Best Logistic Regression Model)

Parameter	BVN - 43 (*β*)	BVN - 43 SE (EQ 2)	BVN - 43 P-Value (EQ 2)	Log - 43 (*β*)	Log - 43 SE (EQ 2)	Log - 43 P-Value (EQ 2)
(Intercept)				4.1758904	6.43412	0.52610
Slope	0.243	0.5020	0.63598	0.0348966	0.01039	0.00430**
Aspect	-0.465	0.3064	0.15023	-0.0036094	0.00139	0.02040**
Elev.	-1.053	2.6465	0.69624	-0.0057496	0.00701	0.42510
STRM_DIST	-3.984	1.3941	0.01198**	-0.0101541	0.00212	0.00020**
TPHA	-0.828	1.2550	0.51945	0.0000322	0.00015	0.82840
TDTPHA23	-4.977	3.5346	0.17952	-0.0331500	0.01818	0.0882*
TDTPHA38	1.459	1.2341	0.25541	-0.0006765	0.02862	0.98150
HJ_SIZE	2.712	0.6814	0.00121**	0.5731479	0.14943	0.0016**

Table 1.21 –Estimated Coefficients (*β*) of Stand Exam Model 49 (Best Synoptic Model)

Parameter	BVN - 49 (*β*)	BVN - 49 SE	BVN - 49 P-Value	Log - 49 (*β*)	Log - 49 SE	Log - 49 P-Value
(Intercept)				1.87448	6.31289	0.77060
Aspect	-0.433	0.309	0.18206	-0.00303	0.00139	0.04650**
Elev.	-2.982	2.222	0.19956	-0.00265	0.00681	0.70270
STRM_DIST	-3.481	0.954	0.00238**	-0.00969	0.00196	0.00020**
TPHA	-1.245	1.152	0.29712	0.00005	0.00014	0.70710
TDTPHA23	-3.233	2.274	0.17560	-0.03736	0.02143	0.10170
TDTPHA38	0.600	0.813	0.47184	0.01390	0.02994	0.64920
HJ_SIZE	2.671	0.625	0.00067**	0.58373	0.15892	0.00230**

1.4.8 Nests

I located three nests during the course of the study (Tables 1.22 -1.24). Two nests were located in stands classified in the medium sawtimber class (DBH 38.1 – 53.2 cm - Table 1:23). The third nest was located in a selectively harvested stand that was logged around 30-40 years ago. The size class of the stand is considered to be pole (12.7-22.9 cm DBH – Table 1.23). Nesting snags/trees varied in size from 24.9 to 43.7 cm DBH. Two nests were in dead grand fir snags and the third nest was located in a live grand fir tree that has a broken top and hollow center (Table 1.22). Fledglings exited the nests between the dates of 18 June to 28 June (Table 1.22). Detailed information on post-fledgling dates, movement and behavior can be found in a previous paper (Appendix H - Frye and Jageman 2012).

Table 1.22 - Nest Snag/Tree Characteristics of Three Northern Pygmy Owl Nest Sites

Nest	Nest snag/tree Diameter (cm)	Nest snag/tree Height (m)	Nest Cavity Height (m)	Species	Tree Condition	Minimum Number Fledglings	Fledgling Date
1	24.9	13.7	8.8	GF	Dead Snag	2	18 June 2007
2	43.7	21.6	7.3	GF	Live-Broken Top	4	24 June 2008
3	35.8	8.5	6.7	GF	Dead Snag	5	28 June 2009

Table 1.23 -Nest Area Characteristics of three Northern Pygmy Owl Nest Sites

Nest Area	Slope (%)	Aspect (Degrees)	Elevation (Meters)	Stand Size Class	Plot Habitat Type	Average of 4 Densiometer readings – Percent (N, E, S and W)	Distance to nearest perennial stream (M)	Distance to nearest travelable road (M) – All Gated
1	54	68	943	Med.	THPL/ASCA	92.3	54.6	57.6
2	43	204	828	Pole	ABGR/CLUN	75.7	125.0	53.3
3	35	254	860	Med.	THPL/CLUN	87.7	314.0	110.0

Table 1.24 – Stand Characteristics at Three Northern Pygmy-Owl Nest Sites

Parameter	Nest 1	Nest 2	Nest 3
Quadratic Mean Diameter	19.3	10.4	31.0
Total Timber Volume – M^3 per Hectare	582.5	129.0	542.4
Top Height of the 40 largest trees (M)	33.8	18.3	32.9
Live Trees per Hectare (DBH 7.6-22.8 cm)	1482.6	3162.9	330.4
Live Trees per Hectare (DBH 22.9-38.0 cm)	70.9	49.4	114.9
Live Trees per Hectare (DBH 38.1-52.2 cm)	165.6	24.7	130.7
Live Trees per Hectare (DBH >53.3 cm)	22.5	0	34.6
Live Trees per Hectare (Total)	1741.6	3237.1	610.6
Snags per Hectare (DBH 7.6-22.8 cm)	0	1705.0	0
Snags per Hectare (DBH 22.9-38.0 cm)	85.3	74.1	46.2
Snags per Hectare (DBH 38.1-52.2 cm)	0	0	17.3
Snags per Hectare (DBH >53.3 cm)	0	0	8.9
Snags per Hectare (Total)	85.3	1779.1	72.40
Basal Area GF (M^2 per Hectare)	18.4	20.4	36.7
Basal Area C (M^2 per Hectare)	32.7	0	0
Basal Area DF (M^2 per Hectare)	0	7.8	4.6
Basal Area L (M^2 per Hectare)	0	0	4.6
Total Basal Area (M^2 per Hectare)	51.1	28.2	45.9

1.5 -Discussion

1.5.1 Acoustic Surveys

The calling data suggest that Northern Pygmy-Owls were fairly common in the study area. I had responses about 25% of the time when I attempted calls. This number is comparable to reported values for the Western Cascades of Oregon (Sater et al. 2006) who reported calling responses at approximately 26% of calling stations (Average 3.9 birds per 15 station transect (n=37 transects)). Of the seven ecoregions examined in Oregon by Sater et al. (2006), the Western Cascades had the highest calling response rate and it contains habitat that is very similar to that found in Northern Idaho.

Lower response rates in the spring of 2007 (Proportion = 0.152) may be a function of timing or sample size rather than differences in population levels between 2006 and 2007. I collected calling data (N=117 stations) from May 19th to June 2nd in 2006 (Response rate 0.265) and from April 12th to May 19th in 2007 (N=66 stations). It may be that owls are less aggressive in the earlier time frame in the study area or just the fact that my sample size was less robust in 2007. However, Sater et al. (2006) found no significant difference in calling rates between April, May and June in their more extensive calling survey study of Northern Pygmy-Owls in Oregon. The difference in survey timing was mainly due to logistical problems as other commitments kept surveys from being started until after May 19th in 2006 and in 2007 I had actually captured several birds by May 19th. This limited the ability to conduct additional acoustic surveys after May 19th.

I would expect population numbers to be highest in the fall after the young of the year have fledged. The slightly higher response rate to the calls in the fall may reflect this and the fact that there would be a higher proportion of young owls in the population at that time. Females are more likely to respond in the fall since they are not actively nesting at this time of the year. I never captured any females during the spring, but three of nine owls captured in the fall were females (Table 1.7). Hunters often report hearing Northern Pygmy-Owls calling in the fall. E. Forsman (personal communication) suggested to me that he felt that the fall calling may be part of young birds trying to establish territories of their own at this time.

The goal of the acoustic surveys was not to establish population or trend data. More work and a more comprehensive strategy similar to that described by (Sater et al. 2006) would be needed to meet this goal. Although it is possible that a few owls may have been double counted in the acoustical surveys, I made every effort to avoid this problem including the lengthening the survey interval and testing for differences in response rates. Acoustic surveys merely established that Northern Pygmy-Owls were fairly common in the study area and that habitats here may be equivalent to similar high quality habitats in other locations. Trapping efforts further support these findings. I made several additional unreported calls during my trapping efforts and had similar response rates to those reported here. Finding birds was not the main problem in capturing owls, but actually luring birds to the net required a great deal of time and patience.

1.5.2 Space Use and Movements

There are a number of problems with traditional methods of determining space use of animals. Minimum convex polygon, bivariate normal and exponential power methods do a good job of portraying the total area utilized by animals, but they do a poor job of displaying areas of concentrated use within the home range. Kernel methods do a better job of portraying areas of concentrated use, but they are very sensitive to smoothing factors (Horne and Garton 2006a). Minimum convex polygon and kernel estimates are very sensitive to outlying locations that skew model results (Horne and Garton 2006a). None of the traditional methods rely on the existing underlying habitat conditions that are influencing the observed patterns of space use. In contrast, the synoptic model helps to alleviate some of these problems by incorporating the underlying habitat distribution into the analysis.

In conducting the analysis of space use by Northern Pygmy-Owls, I found a great deal of variation in results based on the home range model that was used for the analysis and the actual locations of the individual birds. Traditional home range methods appeared to be very sensitive to outlying locations and shifts in home range use. For example, the removal of a single location changed the smoothing factor in the Animal Space Use program from 434.6 to 148.7 for owl twenty-four. This in turn resulted in a 95% home range size that went from 918.3 hectares to 360 hectares (Figures 1.9 and 1.10). Outlying locations and shifts in home range use seemed to be common in the data as pygmy-owls often appeared to take exploratory flights away from their core area of use. I noted shifts in core use areas, particularly, with male birds following the breeding season.

I suspect similar range shifts occur with some birds during the winter when resources grow scarce on their usual ranges. These shifts, likely, occur when birds are using areas with deep winter snow accumulations. I was unable to document winter movement in this study, but was able to confirm that three owls either left the study area when confronted with deep snow or had radio transmitter failures. Five owls captured in the fall remained on their home range into the early winter, but three of these owls were lost to predation by other raptors. The short battery life of the radio transmitters and the inability to recapture owls

Figure 1.9 – Estimated Probability Distribution for Owl 24 Based on Adaptive Kernel (CVh –All Locations) Showing 50/75/90/95% Probability Contours with a 95 % Probability Area of 918.3 Hectares

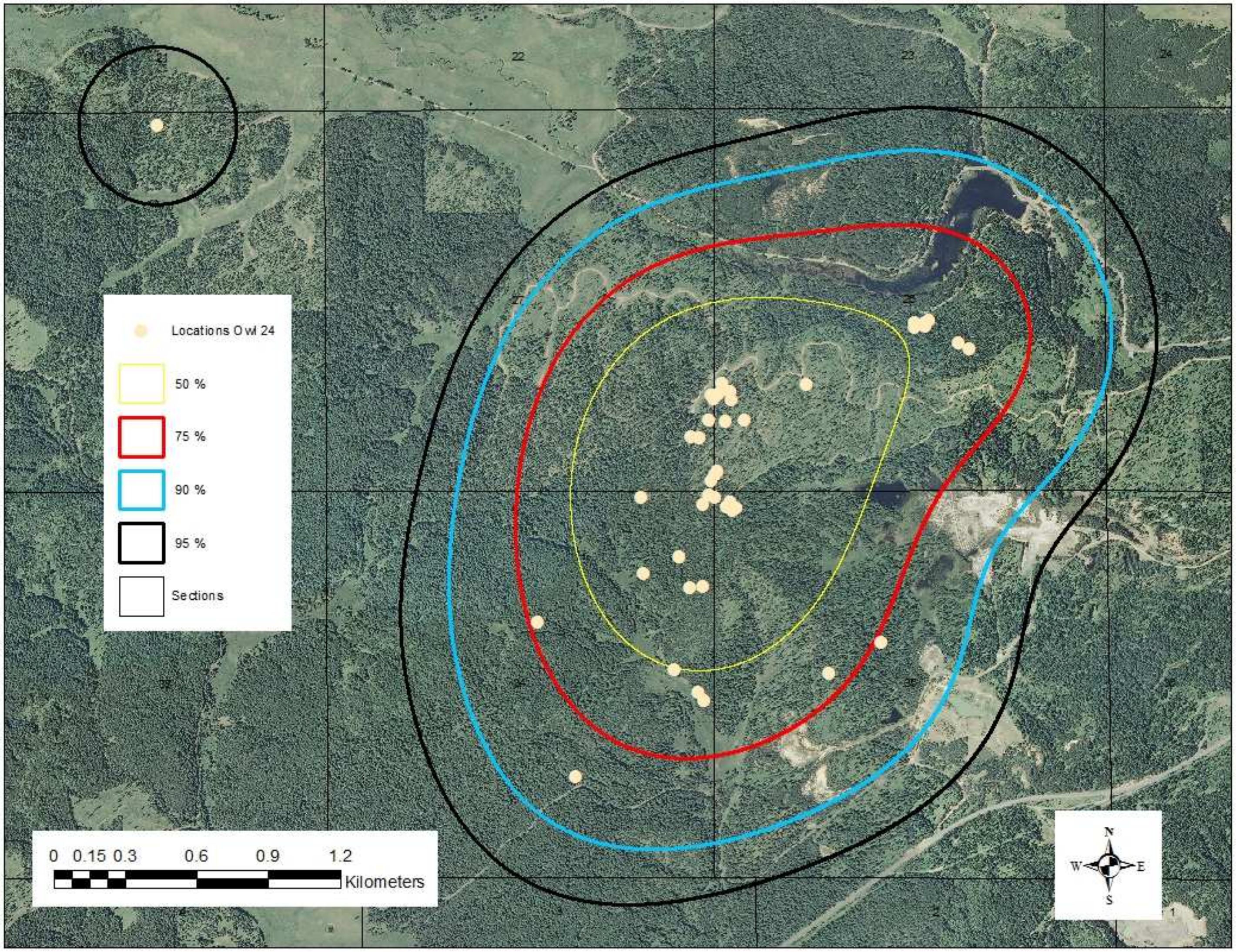
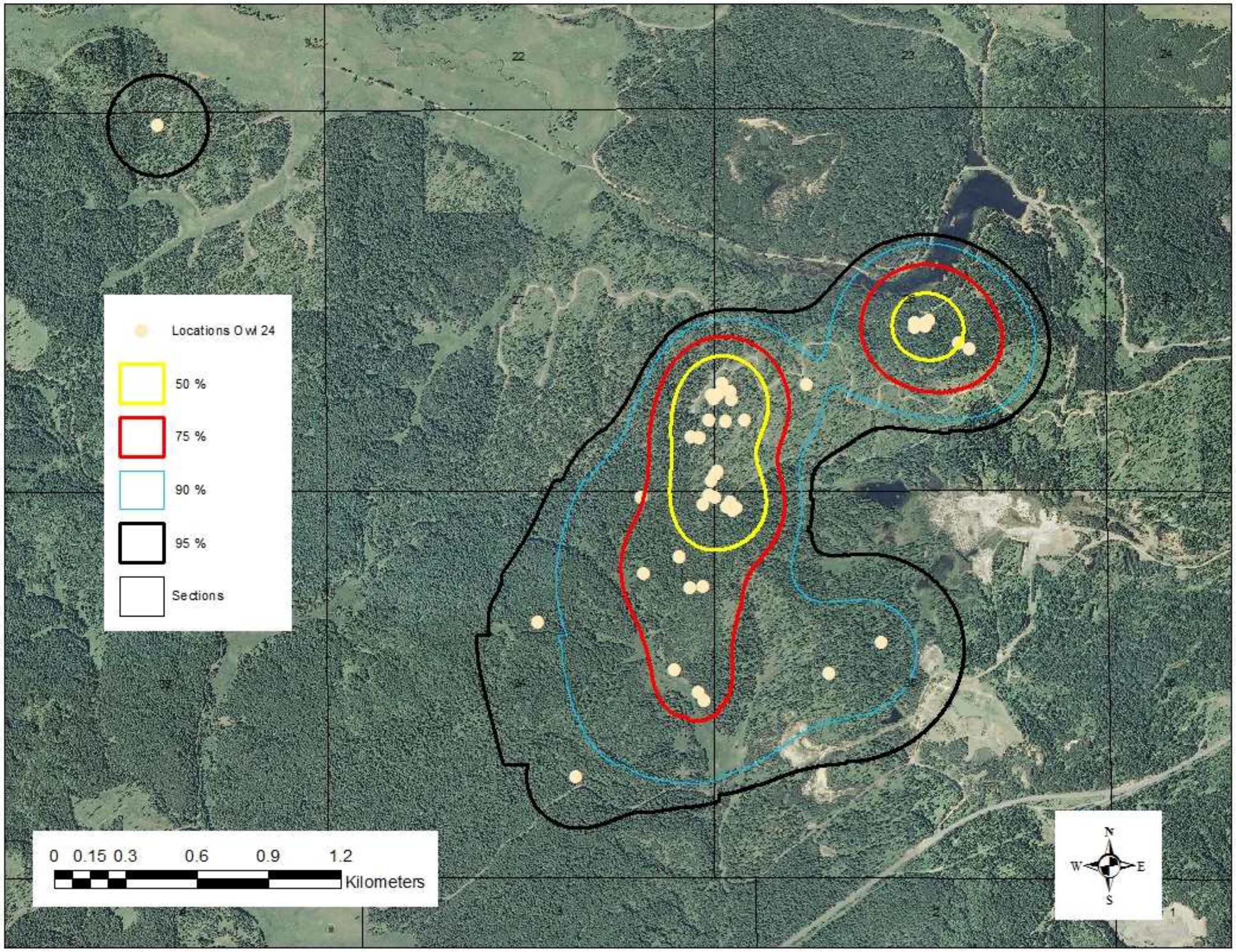


Figure 1.10 – Estimated Probability Distribution for Owl 24 Based on Adaptive Kernel (CVh – Minus Outlier) Showing 50/75/90/95% Probability Contours with a 95 % Probability Area of 360.0 Hectares



did not allow me to document if these birds remained on their home range during the entire winter.

In trying to trap birds in the winter, I found that some birds still remained on the study area, but it was more difficult to find birds in the usual areas where I captured them in the spring and fall. I captured two birds in the winter, and one of these birds remained on the capture range all winter in an area that was similar (elevation 881 meters) to where I caught birds in the spring and fall. Despite, snow depths of 60-90 cm on this bird's seasonal range it did not leave the area. The other bird was lost to predation shortly after capture, but its capture location was much lower in elevation (647 meters) and included drier habitat types (more openings and more ponderosa pine) than were present on the seasonal ranges of the other owls. The area is known to have less snow accumulation than locations where the other owls were captured.

Holt and Petersen (2000) suggest that Northern Pygmy-Owls are generally non-migratory, but they will move to lower elevations in response to snow and cold weather. They report (page 5) that, "the species commonly descends to lower elevations during winter, bringing individuals into habitats and locations in which they often do not breed In Missoula, Montana individuals arrive in town about November 1st and stay until March." "During this time they often frequent bird feeders by day and prey on small passerines" (Holt and Kline 1989, pg. 16). Hannah (1999- pg. 6) reported that "eastern and southern movements during winter are well documented in Alberta, especially in years with high snowfall and extreme cold". Similar movements have been noted near the study area in the town of Moscow, Idaho. For example, owls have been spotted both on the University of

Idaho campus and in town during the winter (J, Aycrigg 2007 and J. Manning 2007 – personal communications).

There are no studies in the literature that have actually documented the winter movements of Northern Pygmy-Owls with radio telemetry, but G. Frye of the Rocky Mountain Front Institute has documented a winter movement of approximately 20 kilometers by an owl along the eastern front of the Rocky Mountains near the town of Choteau, Montana (unpublished data and personal communication 2006). In Frye's study, he found that birds generally moved east from higher elevation sites in the Rocky Mountains to lower elevation sites in the foothills and neighboring lowlands.

The synoptic model produced improved probability distributions that were responsive to underlying habitat distributions. An example of this can be seen in Figures 1.11 and 1.12. In this case I first display the adaptive kernel home range estimate (CVh Smoothing Factor). Note how the kernel estimate (Figure 1.11) is unresponsive to the cutting units in the northern part of the range and the meadow area in the southern part of the range. In contrast we can see in Figure 1.12 how the synoptic model excludes cutover areas in the north and more tightly conforms to forested areas in the south. The synoptic model also tightly conforms to the streamside riparian area which can best be seen in the 50% probability distribution. Seasonal range size and variation was similar between traditional methods and the synoptic model. For example, when the seasonal range size was larger than average with traditional methods it was larger than average with the synoptic model.

Figure 1.11 – Estimated Probability Distribution for Owl 2 Based on Adaptive Kernel (CVh) Showing 50/75/90/95% Probability Contours with a 95 % Probability Area of 395.1 Hectares

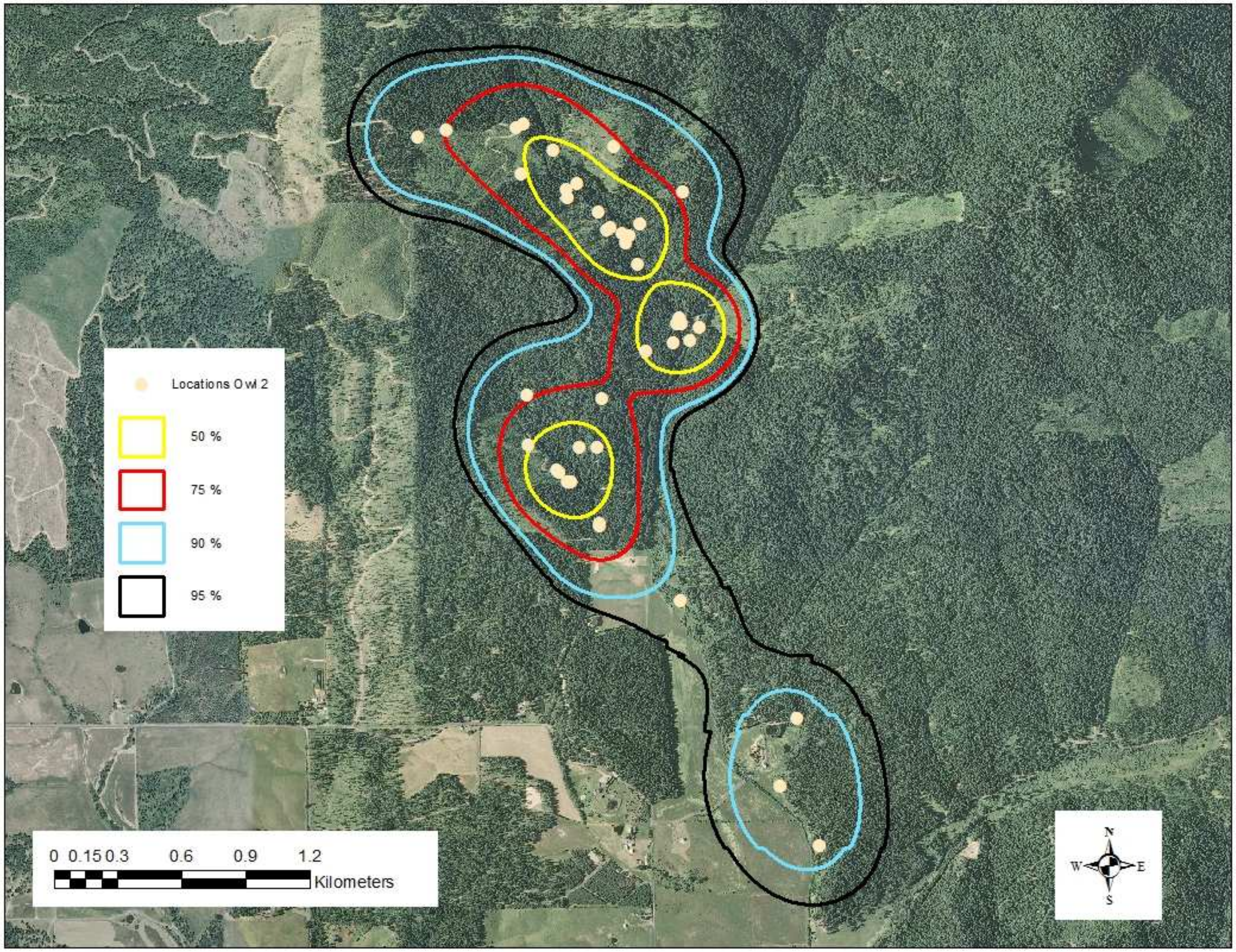
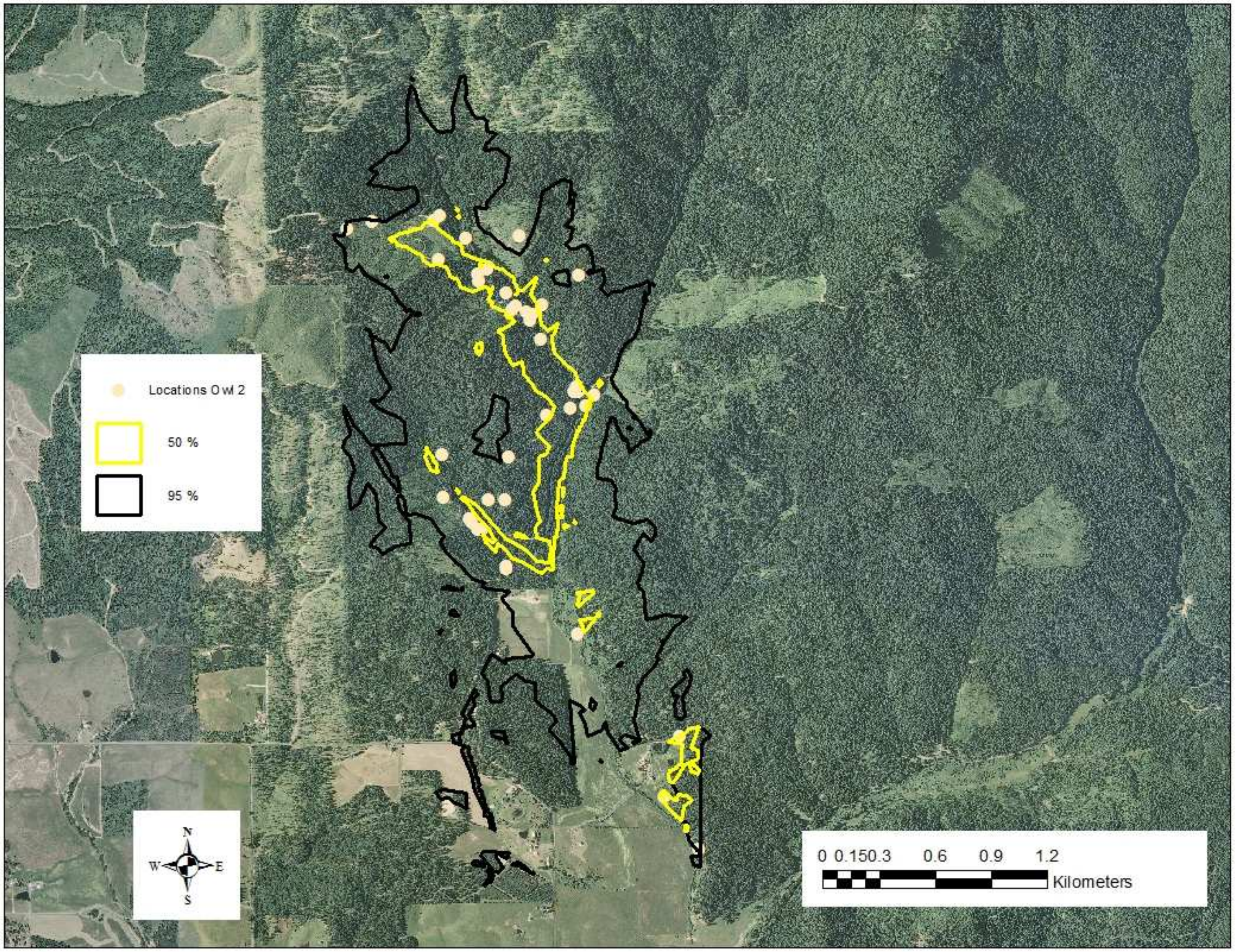


Figure 1.12 – Estimated Probability Distribution for Owl 2 Based on BVN Synoptic Model 49 Showing 50 and 95% Probability Contours with a 95 % Probability Area of 347.9 Hectares



I know that some of the data included serially correlated locations, but this did not seem to influence the analysis as much as outlying locations. I found that Northern Pygmy-Owls often sit and wait for hours at a time when they are searching for prey and that they often do not move large distances from day to day. When relocating birds I would often find birds very close to the previous day's location. Following and observing owls for periods as long as 22 hours allowed me to make observations on daily movement patterns and hunting techniques that I could not have made otherwise.

I found that information theoretic methods provide an objective method for determining the best home range (Horne and Garton 2006a), but that the presence of outliers influenced which model is selected as the "best" model. I found that many of the home range models were sensitive to outlying locations, but it proved very difficult to objectively remove locations that appeared to cause the most problems. Owls, likely, made exploratory flights and shifts in core use areas for a reason and these movements are important components of survival. For example, they allow the birds to find new sources of food or mates. Such movements may serve to reduce competition between adult and juvenile birds as the young birds start to gain independence and establish home ranges of their own.

I found that non-breeding males appear to have larger seasonal ranges than breeding males and that there is a difference in the pattern of locations between breeding males and non-breeding males. Non-breeding males appeared to have more outlying locations in their seasonal range during the breeding season and then gradually reduce their core use as the nesting season progressed and the chances of finding a mate were reduced. These birds continued to use the same smaller core area after the nesting season. However, my sample size is small (Non-breeding - N=2 and Breeding – N=6) and these conclusions need more investigation in future studies.

In contrast, breeding male birds had smaller home ranges during the nesting season and then shifted use to a completely different core area after the breeding season. It may be possible that male birds are moving to nearby female home ranges during the nesting season and then returning to their own home range after breeding. This could not be confirmed due to the battery life of the radio transmitters used in the study, but one female bird that was trapped just before fledging of her chicks, remained on her home range for the life of her transmitter (approximately 11 weeks). Another male (# 20) had a few locations in an area approximately 3.2 km from his core use area prior to the nesting season and then returned to this area after his nest appeared to fail in mid-June (Tables 1.12 and 1.13).

My observations confirmed previous observations that Northern Pygmy-Owls are diurnal and that these owls are most active in crepuscular periods (Holt and Peterson 2000, Frye and Jageman 2012). I spent the entire night near roosting owls on five occasions and none of them appeared to move from their roost tree. Similar observations have been made in Montana (Frye and Jageman 2012).

I could not document much response to human disturbance by Northern Pygmy-Owls. I frequently called and trapped owls near open roads and had numerous locations that were near open roads. In one instance, I did document an avoidance response to active logging equipment, but the noise level and amount of activity was fairly excessive compared to other activities that were occurring in the study area. However, Northern Pygmy-Owls were often very cautious in approaching during trapping operations. It usually required several hours to lure owls to the net and I had some owls that would sit observing the live mice lures for as long as two hours before they would attempt to take the prey. During trapping efforts, many owls would actively respond to my calls, but then they could not be lured closer than 100 meters to my location.

1.5.3 Habitat Analysis

Based on lower AIC Values, I believe the data generated from the stand exam plots, ocular interpretation of satellite imagery and nearest neighbor projections (Crookston et al. 2002) were of superior quality to that which I obtained from remotely sensed Vmap (Vmap 2013) projections and similar efforts like Landfire (Landfire 2013) and Idaho Gap Analysis (Idaho Gap Analysis 2013). Models built from the stand exam data generally had lower AICs than similar models that relied on remotely sensed Vmap data. The stand exam data also allowed for inclusion of detailed information like trees per acre and stand diameter. However, obtaining this information was much more time consuming, costly and labor intensive than remotely sensed data. Even when I had a considerable amount of data for a large portion of the study area (USFS lands in this case), I still had to do a considerable amount of work to extrapolate the data to unsampled areas. I hope that new approaches like LIDAR may help to alleviate problems of obtaining accurate and timely information in the future. However, these types of data were not available for the study area. I suggest that without accurate landscape level data there is a high risk of making erroneous conclusions on wildlife habitat selection regardless of the method used to analyze that data.

For example, the remotely sensed Vmap models placed greater emphasis on canopy closure and tree species than the stand exam models. While I agree these are important descriptors of Northern Pygmy-Owl habitat selection, I suspect that the lack of resolution in the remotely sensed data elevated the importance of these factors. Stand size class was highly positively correlated with crown closure in the stand exam models and stands with larger diameters were often found on moister cedar and grand fir growing sites in the study area. It is likely that the resolution of crown closure and species were better in the remotely sensed data than stand size class which can be difficult to determine with remotely sensed methods.

The best model in the analysis (BVN Synoptic Model 49) suggests that two parameters (Successional Stage and Distance to Stream) are the most important parameters for predicting habitat selection by Northern Pygmy-Owls. Both of these parameters were statistically significant ($P<0.5$) with both the synoptic and logistic regression methods (Table 1:21). I found that Northern Pygmy-Owls are more likely to be found in older stands with larger tree sizes and that they are more likely to be found closer to streams than randomly selected points in the logistic regression or available habitats as defined in the synoptic model. These results agree with the findings of Giese and Forsman (2003 pg. 117) who suggested that “structurally diverse and older forests were most heavily used” by Northern Pygmy-Owls.

There have been historical references that Northern Pygmy-Owls often utilized riparian areas. For example, the following quotation was attributed to James Moffitt of Mendocino County, California and reported in 1938 by A.C. Bent in his book on the Life Histories of North American Birds of Prey (Bent 1938 pg. 432). “The owls that frequented my camp seemed to range in the trees immediately bordering the creek for a distance of about 400 yards along the watercourse, but apparently they seldom, or never, extended their range far from the sides of the creek, as their calls were never heard in the hillside trees bordering the stream at a distance farther than 100 yards from it." This study documents similar findings (at least for this study area) based on radio telemetry and on the ground observations. In Northern Idaho, radio marked owls routinely selected riparian habitats in preference to upslope areas.

I speculate that Northern Pygmy-Owls utilize older forest stands and riparian areas for two main reasons. First, because of their small size they are particularly vulnerable to predation themselves. Ten out of twenty-six radio marked owls were lost to predation by other raptors in this study and no other cause of death was observed. Interestingly, high turnover rates of individual Northern Pygmy-Owls were reported in an extensive study of a 2145 hectare park in Portland, Oregon (Deshler and Murphy 2012). That study included an extensive effort to find and band all known nesting pairs within the park over three different years. In that study, the park was estimated to support 9-12 pairs of nesting owls and the same nesting territories generally had different nesting owls in subsequent years. No birds banded as fledglings (N=26) were ever recaptured as adults in the Portland study. As sit and wait predators and relatively slow fliers compared to many other raptors, I believe Northern Pygmy-Owls seek out forested stands for protection.

I believe forested stands support the "ambush" type approach to hunting that these owls utilize. Observations of Northern Pygmy-Owls suggest they will sit for hours watching and waiting for unsuspecting prey, and that they make quick dives from upslope perches to finally make their kill. I believe older forests and riparian areas likely support higher prey densities and facilitate their hunting style (Gomez and Anthony 1998, Lock and Naiman 1998). Besides having lower prey densities, the obstructions in young dense forests would make their style of hunting more difficult. Northern Pygmy-Owls need to be able to see their prey and descend quickly for the kill. Older stands with open understories facilitate this type of hunting by offering protection in the dense upper canopy together with open understories where owls can observe and easily capture prey.

The results of the Vmap models tend to support the findings of the models based on the stand exam data. Like the stand exam models, all of the Vmap models identify distance to stream as a significantly important variable (Tables 1.17-1.18). The remotely sensed Vmap models also suggest that stands in larger size classes and those with closed canopies are preferred by Northern Pygmy-Owls (Tables 1.17-1.18). However, P-values are generally lower for size class in the remotely sensed Vmap models. High canopy closure is highly positively correlated with size class in the stand exam data. I speculate that crown closure and species groupings are not as important to Northern Pygmy-Owls as stand structure. The study area is dominated by relatively moist habitat types and most of the larger diameter (DBH) stands occur in these groupings. Crown closure is likely important in the remotely sensed Vmap data as it can be determined fairly accurately with these methods. On the ground field data that was collected for the stand exam models incorporate important structural components into the model and therefore factors like crown closure and species mix are less likely to show up as important model parameters.

Stands with grand fir, cedar and hemlock (moister sites) appear to be preferred and of significant influence according to remotely sensed Vmap models 4 and 35, but not the stand exam models. Size class appears to overshadow any importance of species composition in the stand exam models. Based on my fieldwork, I agree that species composition is less important than the structural complexity of the stand. However, I found many of the most structurally complex stands were located on moister sites and in close proximity to streams and was not surprised by this finding from the remotely sensed Vmap models. Also, overall use and availability data support this conclusion and are consistent with field observations (Appendix B4 and Appendix B7).

I speculate that the physical parameters of slope, aspect and elevation are important in determining vegetative characteristics and that more accurate vegetative information overshadows these variables in the stand exam and Vmap models. Slope and aspect appeared to have a significant influence ($P < 0.05$) in most of the logistic regression models, but not in synoptic models. Northerly aspects and steeper slopes were generally preferred according to the logistic models (Tables 1.16 – 1.21). Northerly slopes and lower elevations likely support larger diameter stands and riparian areas are going to occur at the lowest elevations of each owl's home range. The selection of more northerly aspects makes sense given field observations that owls often utilized larger sized stands that occurred on northerly aspects.

I am somewhat perplexed by the finding that steeper slopes are preferred. Significant P-values < 0.05 were generally associated with the logistic regression analysis and the physical models. Slope was generally not statistically significant in the synoptic models and models that included stand exam data. I suspect this may be a data anomaly of the random points that were selected for the logistic regression. I did notice, for example, that the random slope points for owl two only averaged 19.5% slope as compared to the average slope of 28.0% for the points that owl two actually utilized. The synoptic model makes use of the entire slope surface when determining significance and is less likely to be influenced by a few random points or the effects of an individual owl. I suspect the optimization approach used in the synoptic model is less likely to be influenced by individual points than the logistic regression. The probability density function for slope, aspect and elevation includes thousands of points rather than just comparing an equal number of points as is done in the logistic the regression. The likelihood that individual points can cause significant differences to show up is more probable with the logistic regression approach. Slope in the locations utilized by all radio tagged owls (mean 26.1%) was not that much different than available habitat slope (24.9%), and I did not notice any significant difference in the slope of radio locations compared to that of the general topography in my fieldwork. I believe the synoptic model results are likely more accurate for the relatively gentle topography of the study area and that slope is not a major factor here. Other studies in steeper topography may find different results as I did not have that many steep slopes in the study area.

Elevation was shown to be significant at the 90% level in the synoptic physical model 20, but dropped out as being a significant variable when remotely sensed Vmap or stand exam vegetation elements were added in remotely sensed Vmap models 4 and 35 and stand exam models 5, 43 and 49 (Tables 1.16-1.21). However, the addition of elevation improved AIC values of most models and suggested that Northern Pygmy-Owls prefer lower elevations. This makes sense in light of the fact that streamside areas would generally occur at the lowest elevations of an owl's seasonal range. However, the range of elevations in the study area is limited to moderate elevation sites (644.1 to 1540.5 meters) and may not be representative of pygmy-owl habitat across the species range. In the study area, I don't think elevation is a major factor.

The only other variable that showed up with some significance ($P< 0.1$) was trees per hectare over 22.9 cm DBH. This variable was important ($P<0.1$) in models 5 and 43, and just over P=0.1 in model 49 under the logistic regression method. The parameter did not show up as important with the synoptic method (Tables 1.19-1.21). The logistic regression model suggested this parameter was negatively associated with Northern Pygmy-Owl habitat selection. This would make sense if such stands included a large number of small diameter trees that made hunting difficult for Northern Pygmy-Owls. However, stands in this size category are likely in transition and I did observe a considerable amount of use in stands with average diameters between 22.9 and 38.1 cm as long as the stands contained open understories.

None of the other model variables such as trees per hectare and trees per hectare over 38.1 cm were considered to have a significant ($P < 0.05$) influence on the various models. However, the addition of these parameters generally lowered model AIC values.

1.5.4 Nests

I only discovered three nests in this study, but my observations were generally consistent with the literature (Giese 2003). Two of the nests were located in non-harvested older structurally diverse stands and one occurred in cutover pole-sized stand that had retained a large diameter broken topped grand fir tree which was utilized as the nest (Tables 1.23-1.24). Giese (2003) found that 7 of 8 nests occurred in older structurally diverse stands and that one nest "was in a relatively young, mixed patch of coniferous and deciduous trees that had regenerated naturally following logging." One nest in this study (Table 1.22) was in a smaller diameter snag (24.9 cm) than those reported by Giese (2003). Snags selected for nesting as reported by Giese (2003) varied in size from 31 to 96 cm DBH (mean 55.7 cm) and were all located in dead snags. The nest in the pole sized cutover stand was located in a broken topped live grand fir tree (DBH 43.7 cm) and appeared to be a cull tree that was not removed during the original logging operation.

Nest two and nest three were located very close together (Approximately 190 meters), but were found in two different years (2008 and 2009). The owls using nest three in 2009 were not the same owls that were observed in 2008 (both banded and radio tagged) and any relationship between them is unknown. The nesting pair at nest three was not radio tagged. Interestingly, similar observations were made by Desheler and Murphy (2012) who found that there was a high turnover in individuals occupying nesting territories in subsequent years. In a study of 22 nests, they found some individuals (4 females and one male) returning to the same nesting area, but did not find any instance of the same mated pair nesting in a subsequent year.

Northern Pygmy-Owl fledglings in this study exited the known nests between the dates of 18 June to 28 June (N=3). Fledgling dates for two additional nests (never located) were estimated as 1 July based on the date and size of the fledglings when they were first observed (Frye and Jageman 2012). In Montana, Frye reported that fledglings exited the nest between 28 June and Aug 5 (N=11, Frye and Jageman 2012). In western Washington (Olympic Peninsula), Giese and Forsman (2003) reported Northern Pygmy-Owls fledging between 14 June and 17 July (N=9). Deshler and Murphy (2012) working in Portland, Oregon reported fledglings first exiting nests between 6 June and 27 June in three different years (N=22). Detailed information on post-fledgling dates, movement and behavior can be found in a previous paper (Frye and Jageman 2012).

1.6 Management Implications

As a cavity nester and forest predator on small birds and mammals, it is likely that management recommendations for the Northern Pygmy-Owl will have implications for a wide variety of species. Northern Pygmy-Owls in this study preferred riparian habitats and stands with larger tree sizes and higher crown closures. These findings are in agreement with previous studies (Giese and Forsman 2003 and Sater et al. 2006). It is important to maintain older forests and intact riparian areas across the landscape in order to maintain Northern Pygmy-Owls. Wide buffers greater than 100 meters in width that are associated with nearby intact stands would be preferable for this species. If buffers are too narrow they are likely to increase vulnerability to predation by larger raptors.

I did not find that Northern Pygmy-Owls need the largest and most pristine forests for reproduction and survival. While I only located three nests, all were successful and located in relatively small diameter snags (24.9 - 43.7 cm DBH). One nest was located in a stand with previous timber harvest. I observed habitat use in stands that were relatively young (80-90 years) that would be considered small sawtimber by most foresters. However, such stands generally had open understories and some form of structural diversity. A complex overstory where owls could find security was a common feature of most stands where I observed Northern Pygmy-Owls. Very young stands with dense understory tree stocking were commonly avoided by Northern Pygmy-Owls.

I found that partially cut timber stands were often utilized by Northern Pygmy-Owls, but caution land managers in relying on extensive partial cut strategies to provide habitat for Northern Pygmy-Owls. Most habitat use was observed in unharvested older aged stands with intact canopies. As reported by Irwin et al. (2012) for the spotted owl, I found that Northern Pygmy-Owls have the ability to find small patches of structurally complex habitat in stands that may be categorized as relatively uniform in human habitat classification systems. My observations suggest that these patches often have characteristics we commonly associate with older structurally diverse forests such as large trees, open understories and the presence of snags and downed wood. Nest two is a good example of how Northern Pygmy-Owls are able to find and select these microsites.

I suggest that managers consider leaving complex structural components in harvested timber stands. Retention of snags, broken topped trees, down logs and non-uniform spacing should be considered in harvest units. Protection of riparian areas and leaving unharvested clumps should be considered. I have some evidence that owls may be particularly vulnerable in fragmented landscapes which I discuss in Chapter 2. Thus, I caution against leaving isolated patches such as uncut buffer strips surrounded by new clearcuts. Northern Pygmy-Owls may be particularly vulnerable to predation by other raptors in such situations. I suggest less abrupt transitions with retention of leave trees on upslope areas.

In this paper I examined the potential home range size of pygmy-owls and how this home range size may change over the course of a year. These numbers have implications for determining how much habitat is required by the species and how these owls might distribute themselves across the landscape at various times of the year. Seasonal ranges averaged approximately 300 hectares and I believe it prudent to maintain landscapes that have some relatively intact forested areas of at least this size scattered across the landscape. Forested stands of at least the small timber size class (22.9-38.0 cm DBH) should be included in these blocks.

I believe that larger intact forested blocks are important for post-fledgling survival. My work suggests that Northern Pygmy-Owls are very vulnerable in the post-fledgling period when they can be easily located by the food begging calls they make to their parents. I found Northern Pygmy-Owls are typically fed by parents for 30-35 days after leaving the nest and that they occupy areas from 35 to 95 hectares in size during that time (Frye and Jageman 2012). Larger forested blocks would decrease chances of detection by other predators during this critical time period.

I suspect that winter habitat may be a critical life history component for this species as owls move to lower elevations to avoid deep snows. Typically, such sites are drier and more open than areas where we might expect to find Northern Pygmy-Owls during the rest of the year. Vulnerability may be particularly high during this time frame as evidenced by the quick loss of the one owl I did manage to capture in this type of habitat. All of the recommendations I suggest for Northern Pygmy-Owls during the rest of the year are likely important on wintering areas. Given the fact that such areas have reduced forest cover naturally, retention of forest cover may be even more important in such locations.

Chapter 2

Intraguild Predation of Northern Pygmy-Owls in a Fragmented Landscape

2.1 Abstract

As part of the habitat and space use study of Northern Pygmy-Owls described in Chapter One, I experienced the loss of several owls to intraguild predation by larger raptors. Ten of twenty-six owls succumbed to larger raptor predation and no other sources of mortality were observed. Northern Pygmy-Owls utilizing more fragmented landscapes were more vulnerable to predation loss. When a 1000 meter radius circle was placed around the centroid of known radio locations, the percent of forested stands that exceeded an average DBH of 22.9 cm within that circle proved to be a good predictor of survival ($P< 0.001$). I selected this circle size (314.2 hectares) based on my previous work with Northern Pygmy-owls (Chapter 1), where I found that owls had seasonal ranges which averaged 276 to 306 hectares. As the amount of forested stands with an average DBH exceeding 22.9 cm increased beyond 60%, it appeared that Northern Pygmy-Owls were less vulnerable to intraguild predation. This finding is consistent with findings from several other studies on intraguild predation in different raptor species.

2.2 Introduction

Numerous studies have examined the effect of forest fragmentation on bird nest predation and fledgling survival (Lloyd and Marsden 2008, Sperry et al., 2008, Renjifo 1999, Tewksbury et al. 1998, Andren 1992). These studies have generally focused on passerine species and the effect of losses of eggs or young to a variety of non-guild predators such as rodents, other small and medium sized mammals, snakes and non-guild avian species such as corvids (crows and jays) or raptors. Few studies have examined the effects of intraguild predation (predation on species that utilize similar resources for their survival). I became interested in this aspect of bird and raptor ecology after experiencing the loss of several radio-tagged Northern Pygmy-Owls to larger raptors during the habitat and space use study of this species described in Chapter One. The focus of this chapter is to report my findings and to examine the current literature on intraguild predation in raptors and the effect of fragmentation on that phenomenon. I was interested in how productivity and adult survival are being affected by fragmentation of continuous forest cover and if that might be contributing to population declines, habitat avoidance or changes in habitat selection by different raptor species.

Because of the good growing conditions and high value of the forest stands in the study area, there has been a long history of forest management. This has led to varying degrees of forest fragmentation across the study area. Some areas have had relatively little recent harvest (particularly on National Forest lands) while other areas have had extensive management activity. This has made the study area an ideal location to study the effects of forest fragmentation on a species like the Northern Pygmy-Owl.

2.3 Methods

I trapped and radio-tagged twenty-six Northern Pygmy-Owls as part of the study described in Chapter One. Owls were trapped in various seasons and included both males and females (Table 2.1). I trapped and fitted owls with radio-transmitters following methods outlined by Giese and Forsman (2003). Owls were captured in mist nets or balcha-tri traps and live pet store mice were utilized as bait. I lured owls to the general trapping location by utilizing acoustic calls. Transmitters were attached using the crisscross backpack method (Smith and

Table 2.1 – Survival of Northern Pygmy-Owls

Owl	Sex	Capture Season	Date capture	Last Location	Days	Fate
5	M	Spring	4/26/2007	8/08/2007	105	Live
6	M	Spring	5/1/2007	5/3/2007	3	Mortality
7	M	Spring	5/3/2007	5/7/2007	4	Mortality
8	M	Spring	5/22/2007	7/17/2007	57	Mortality
9	M	Spring	5/23/2007	8/24/2007	94	Live
10	M	Spring	5/25/2007	8/23/2007	91	Live
18	M	Spring	3/21/2008	4/29/2008	40	Mortality
19	M	Spring	4/11/2008	6/14/2008	65	Live
20	M	Spring	4/15/2008	7/2/2008	80	Live
21	M	Spring	5/12/2008	6/4/2008	24	Mortality
23	M	Spring	5/21/2008	8/1/2008	73	Live
				5/26/2009	(371)	**Observed Again**
24	M	Spring	5/27/2008	8/11/2008	77	Live
25	F	Summer	6/19/2008	9/06/2008	80	Live
26	M	Summer	7/8/2008	9/20/2008	75	Live
27	M	Summer	7/14/2008	9/26/2008	74	Live
1	M	Fall	9/28/2006	11/22/2006	56	Live (Migrated)
2	M	Fall	10/20/2006	1/16/2007	89	Live
3	F	Fall	10/27/2006	12/8/2006	43	Mortality
4	M	Fall	11/1/2006	11/27/2006	27	Live (Migrated)
11	M	Fall	9/18/2007	9/28/2007	11	Mortality
12	M	Fall	9/20/2007	12/06/2007	78	Live
13	M	Fall	10/ 2/2007	12/14/2007	74	Mortality
14	F	Fall	10/9/2007	12/22/2007	75	Mortality
15	F	Fall	10/23/2007	11/26/2007	35	Live (Migrated)
16	M	Winter	1/24/2008	1/26/2008	3	Mortality
17	M	Winter	2/14/2008	4/25/2008	72	Live

*There is no owl 22 – (Escape during handling)

Gilbert 1981) and were secured with 80 pound test Teflon-coated Dacron braided fishing line. I was unable to re-trap any owls during the study. The battery life of the transmitters varied from 11 to 14 weeks depending on the weight and model of the transmitter (1.4-1.8 gm Holohil Systems Ltd., Carp, ON, Canada -Model BD-2).

For each owl I placed a 1000 meter radius circle around the centroid of known radio locations for that particular owl. I selected this circle size (314.2 hectares) based on my previous work with Northern Pygmy-owls (Chapter 1), where I found that owls had seasonal ranges which averaged 275.8 hectares based on traditional home range methods (Rodgers et al. 2005) or 306 hectares based on the newer synoptic model methods (Horne et al. 2008).

Inside of the circle, I identified three different stand conditions based on previous habitat delineations (Chapter 1) using Clearwater National Forest Stand Exam Data (http://www.fs.fed.us/r1/clearwater/gis/vegetation/clw_inventory– cstands_combo090825) and manual interpretation of NAIP satellite imagery (INSIDE IDAHO 2012). The first category included natural openings and stands in young age classes (seedlings and saplings <= 12.6 cm DBH), the second category included pole sized stands (12.7-22.8 cm DBH) and the third category included forested stands exceeding the small sawtimber size class (>= 22.9 cm DBH). I calculated area in hectares, percentage of coverage and edge length for each of the three classes and estimated the contagion value for the entire circle with the program Fragstats 4.1 (McGarigal et al. 2012, see Appendix D1). Contagion value is a measure of aggregation of the various classes. High contagion values near 100% suggest an aggregated pattern and low contagion values near 0 suggest a dispersed pattern.

I examined the correlation coefficients of these metrics using Pearson, Kendall and Spearman methods in program R. Percent young forest (<=12.6 cm DBH) and percent older forest (>= 22.9 cm DBH) were highly negatively correlated (-0.90). Area and percentage values were highly positively correlated (Appendix D2). These variables and others, with correlations greater than 0.60, were eliminated from the analysis (Appendix D2). Pole stands were not well represented in the data and were also eliminated. This resulted in three variables being carried forward in the analysis: length of open forest edge <= 12.6 cm DBH, percent older forest greater than 22.9 cm DBH and the contagion value. These variables were all calculated within a 1000 meter radius circle around the centroid of each individual owl's actual radio locations.

I used the Kaplan-Meier (Kaplan and Meier 1958, Klein and Moeschberger 2003) and Cox Proportional Hazard methods (Cox 1972, Klein and Moeschberger 2003) to test for differences in survival. The Kaplan-Meier method estimates survival rate based on the following formulation:

$$S(t_i) = \prod_{t_i \leq t} \left(1 - \frac{d_i}{n_i}\right)$$

Where S (t_i) is the probability of survival to time t_i, n_i is the number of individuals at the start of time interval t_i and d_i is the number of individuals who die in time period t_i.

The Cox Proportional Hazard method is considered a semi-parametric method to estimate hazard rate (mortality) as follows:

$$\boldsymbol{h_i(t) = h_0(t) exp(\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_i X_i)}$$

where hazard probability, $h_i(t)$, at time t is equal to hazard probability at time zero, $h_0(t)$ times the antilog of the sum of the parameter estimates times predictive variables $\beta_i X_i$.

To avoid highly correlated or poorly represented variables (Appendix D2), I limited the analysis to the following five basic predictors (Owl gender, Owl capture season, Length of young forest edge <= 12.6 cm DBH, percent forest >= DBH 22.9, and contagion for the entire circle).

2.4 Results

I could not detect any difference in survival or hazard (mortality) based on gender (Figure 2.1) or the season which the owl was captured (Figure 2.2) in my sample of owls. Therefore, I combined all owls into one sample for the remainder of the analysis. Differences in survival based on gender (Female = 4, Male =22) were not significant according to the log rank test (Mantel 1966, Peto and Peto 1972) conducted under the Kaplan-Meier approach (P=0.74). Similar results regarding hazard rate occurred with the Cox Proportional Hazard Method. All statistical tests for differences in hazard (mortality) based on gender (Likelihood ratio (Wilks 1938), Wald (Diggle et al.1994, Draper and Smith 1998) and log rank) had high P-values at or near 0.75 when this method was utilized.

Similar results occurred for the capture season variable. Capture season (Spring = 12, Summer = 3, Fall = 9 and Winter = 2) did not significantly influence survival or hazard rates. The log rank test for capture season based on the Kaplan-Meier approach had an overall P-value of 0.488. Overall tests for influence of capture season on mortality for the Cox Proportional Hazard method were P=0.28 for the likelihood ration test, P=0.92 for the Wald test and P=0.48 for the log rank test. When individual seasons were compared to the fall capture season, values were also not significant (Spring (P=0.844), Summer (P=0.999) and Winter (P=0.577)).

Figure 2.1 - Survival Rate of Northern Pygmy-Owls Based on Gender (Female (N =4), Male (N=22)) as Estimated by the Kaplan-Meier Method (P=0.74) Displayed are the 95% Confidence Intervals.

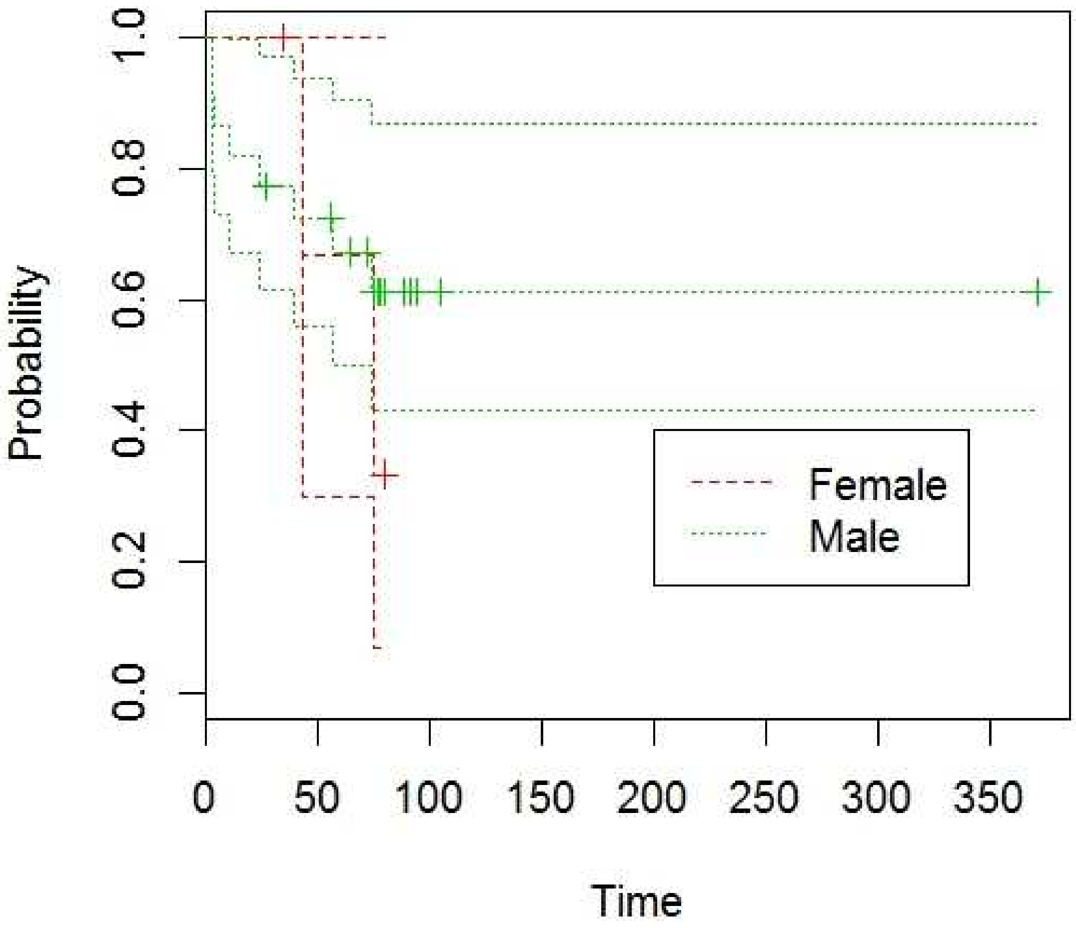
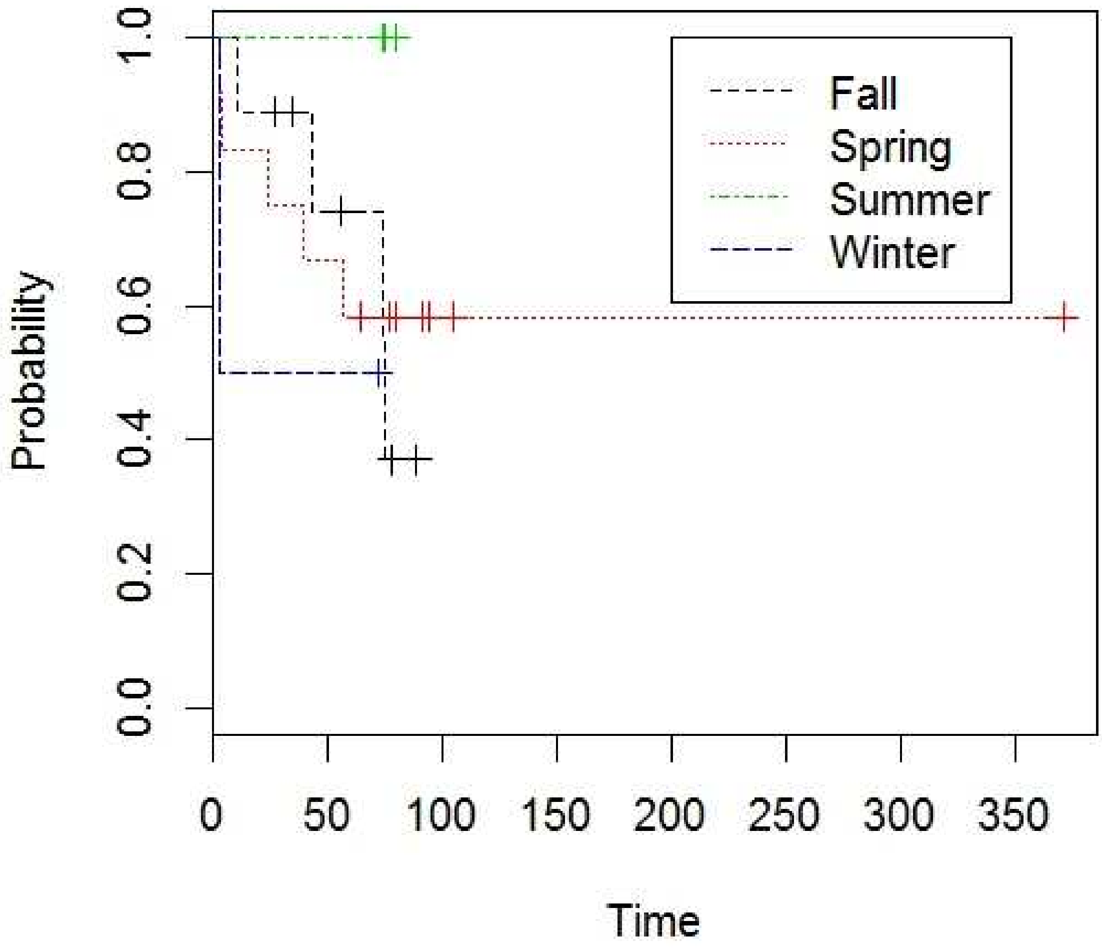


Figure 2.2 – Survival by Capture Season (Spring (N=12), Summer (N=3), Fall (N=9) and Winter (N=2)) as Estimated by the Kaplan-Meier Method (Pvalue = 0.488)



In contrast to the non-significant results for gender and capture season, the Fragstat metric of the percentage of forest cover that exceeded an average DBH of least 22.9 cm within a 1000 meter radius circle around each owl's known locations proved to be a good predictor of owl survival. As the amount of cover decreased mortality increased significantly. The following model, which is based on the Cox Proportional Hazard method, represents the importance of the continuous variable of percent forest cover over 22.9 cm DBH to survival of Northern Pygmy-Owls. This model was highly significant at $P \leq 0.001$ as measured by the likelihood ratio, Wald and log rank tests.

$$\mathbf{Mortality_{(t,\ \%Forest)} = Mortality_{(t0)} * exp\ (-0.10287 * (\%\ Forest))}$$

Percent of forest stands over 22.9 cm DBH within a 1000 meter circle around the centroid of individual owl locations was also evaluated with the Kaplan-Meier method. This method does not allow the use of continuous variables. In this analysis I compared survival of owls with less than 60% forest cover to those with more than 60% forest cover in the 1000 meter circle. Owls in the under 60% group had a significantly lower survival rate of 0.231 with standard error of 0.135 for 75 days as compared to owls in the over 60% group which had a survival rate of 0.923 with a standard error of 0.739 for 24 days (Figure 2.3, log rank test P=0.002).

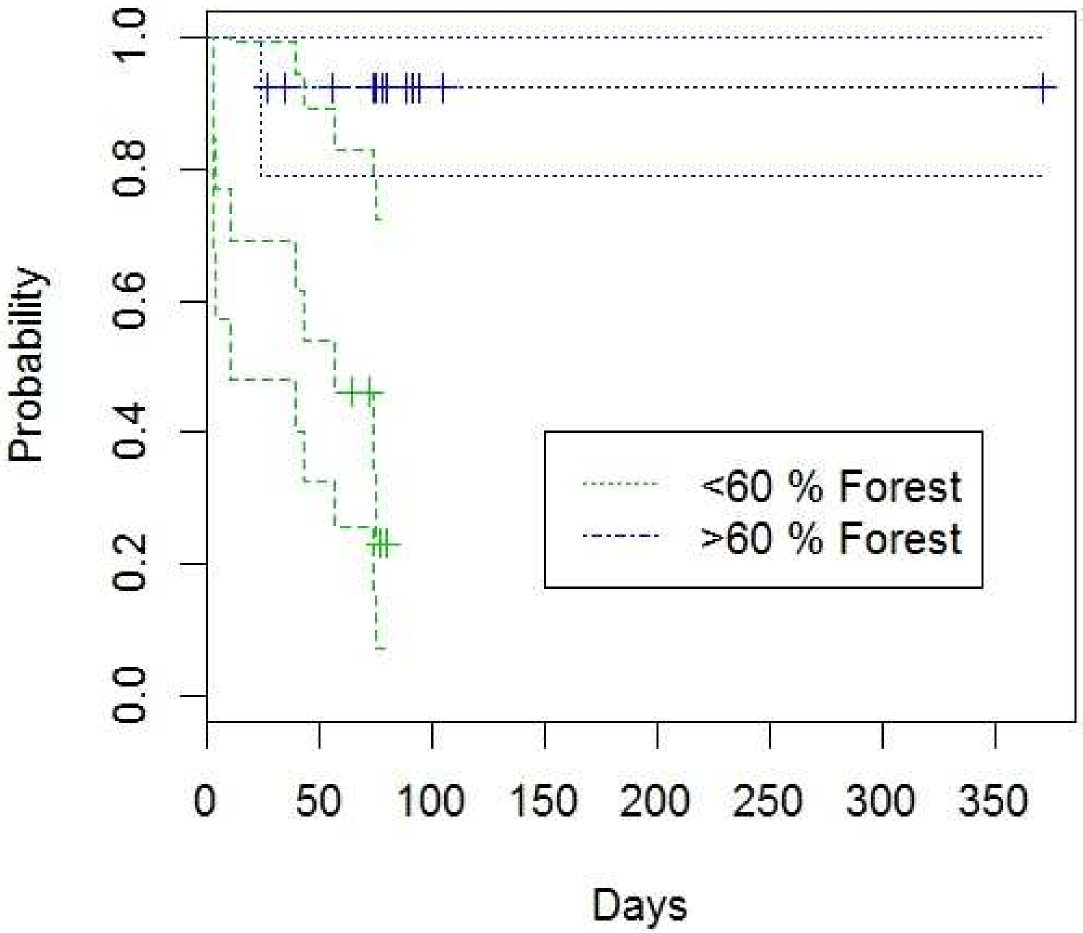
The average amount of forest cover exceeding an average DBH of 22.9 cm in the less than 60% group was 44.6% with a standard deviation of 12.6%. The range of the data in the under 60% group was 11.0 to 57.6% forest cover. The average amount of cover in the over 60% group was 74.7% with a standard deviation of 8.0%. The range of the data in the over 60% group was 63.0 to 91.3% cover.

Owl numbers were equally divided between the two groups (13 in each stratum), but owl deaths were disproportionally found in the group with less forest cover (9 of 10 owl deaths occurred in the under 60% strata). Review of the data suggested all owls (5 of 5) died when forest cover was less than 41%. When forest cover was between 46 and 58% (4 of 8 owls died) and as previously stated only one owl died when forest cover values exceeded 60%. No owls died in the over 60% group after the first owl died at 24 days after initial capture. Most owls in the over 60% group remained alive for at least 60 days. Eighty-one days was the average radio tracking duration for owls that did not die or appear to migrate from the study area. One surviving owl was observed on his same seasonal range 371 days after capture. Interestingly, the average forest cover value in the 1000 meter circle around this owl’s locations was 91.3%.

I also evaluated the under and over 60% group with the Cox Proportional Hazard model. When stands over 22.9 cm DBH composed over 60% or more of the 1000 meter radius evaluation circle there was significantly less mortality ($P=0.0157$ for the Wald test and $P<0.002$ for the log rank and likelihood ratio tests).

$$\mathbf{Mortality_{(t,\ \%Forest)} = Mortality_{(t0)} * exp\ (-2.5614 * (>60\%\ Forest))}$$

Figure 2.3 – Survival of Owls Based on the Percentage of Forest Stands with an Average DBH of 22.9 cm or Larger within a 1000 Meter Radius Circle of the Centroid of Each Individual Owl's Known Radio locations (N=13 Owls <60% Forest and 13 Owls > 60% Forest). Displayed are the 95% Confidence Intervals as Measured by the Kaplan-Meier Method (P=0.002)



+ Indicates when censored owls (live owls whose fate is unknown) were removed from the analysis

The other metrics (Appendix D1 - Open edge length and Contagion) suggested that increasing open edge length and more dispersed patterns (contagion values closer to zero) were also associated with increasing mortality, but these metrics were not significant at the P=0.05 level. Increasing length of open edge was associated with increasing mortality (Wald Test P=0.0806) and dispersed contagion values were associated with increasing mortality (Wald Test P=0.152).

2.5 Discussion

2.5.1General Concepts

Studies on predation and fragmentation tend to support the general finding that fragmentation increases predation rates and reduces survival of the young once they leave the nest (Lloyd and Marsden 2008, Sperry et al., 2008, Renjifo 1999, Tewksbury et al. 1998, Andren 1992). However, findings aren't always consistent and some studies have produced varying results that are often dependent on the species being studied, the location of the study area, the hierarchical scale of the examination and the fragmentation matrix (Chalfoun et al. 2002). Studies conducted in fragmented landscapes where forest patches are found in agricultural landscape matrices often show greater rates of nest predation than when the fragmented matrix consists of older forest patches scattered among younger stands (Chalfoun et al. 2002). Studies conducted in the Eastern United States often produce different results than those conducted in the Western United States. For example, Tewksbury et al. (1998) actually found higher rates of nest predation on passerine species in unfragmented Montana forests than they did on nearby fragmented forest and agricultural land. They attributed this to higher densities of red squirrels (*Tamiasciurus hudsonicus*) in the unfragmented forests and less dramatic increases in corvids in fragmented areas than is common in Eastern North America or in Andren's (1992) study area in Sweden.

Differences in Western and Eastern U.S. may be due to differences in the nature of fragmentation in the two areas and how human populations are distributed in the two areas. Human populations in the West are commonly found in lower elevation areas along major waterways and human populations in the East are more scattered and there is less influence due to elevation. Higher percentages of public land in the West and differences in forest types (coniferous verses deciduous) may also play a role.

Extraneous factors can sometimes influence results. In Ohio, Doherty and Grubb (2002) found that bird survival was much higher in fragmented forest patches where local residents maintained a nearby bird feeder. In Alaska, an unexpected result occurred in an examination of predation rates in two different sizes of buffer strips (Sperry 2008). In that study, the distance to productive nearby intertidal zones influenced predation rates much more than buffer strip width. Predators were attracted to the intertidal zone because of the prey abundance, and this overwhelmed the finer scale buffer width issue.

Another aspect of fragmentation that has received much less attention than nest predation and fledgling survival is adult survival. In the previously mentioned 5-year study by Doherty and Grubb (2002) it was found that there were higher rates of adult survival in larger patches for three resident species (White-breasted nuthatch (*Sitta carolinensis*), Carolina chickadee (*Poecile carolinensis*) and downy woodpecker (*Picoides pubescens*)). Survival of a fourth species, the Tufted- titmouse (*Baeolophus bicolor*) appeared to be affected by snow levels rather than patch size.

2.5.2 Intraguild Predation in Raptors

Historically, intraguild predation was considered more of a curiosity than a population concern. However, after the concept was formalized by Polis et al. (1989) investigators started to understand that it might be an important regulating mechanism for raptor populations and that it may affect habitat selection and resource partitioning of members of the raptor community. The idea behind intraguild predation is that larger predators within the guild (in this case raptors) control the number and distribution of smaller members by preying upon them. This may be because smaller members compete directly with larger members for scarce food resources or that they merely are preyed upon as a food resource (Sergio et al. 2008).

Sergio (2008 et al.) completed a review of studies that have been conducted on intraguild predation in raptors. He reviewed 39 studies and found that intraguild predation reduced occupancy, breeding success and survival in many of the depredated species. These species responded by spatial avoidance of the predator species, habitat selection that helped them avoid the predator, reduced vocalizations when the predator species was nearby or by using habitats at different times. For example, night activity may help owls avoid diurnal predators. Listed below are a few examples of the papers reviewed by Sergio et al. (2008) and some of their findings.

A study in Britain may be one of the first to document a larger species actually controlling the population size of a smaller guild member (Petty et al. 2003). In that study, common kestrels (*Falco tinnuncuius*) were relatively common within Keilder Forest, along the Scotland and England border. There were three other raptor species (Short-eared owl (*Asio flammeus*), Long-eared owl (*Asio otus*) and the Tawny Owl (*Strix aluco*)) that utilized field voles (*Microtus agrestis*) for food. All four of these species utilize different habitats or are active at different times of the day so there is little direct conflict between them. In 1973, several goshawks (*Accipiter gentilis*) were released by falconers and soon established themselves in the Keilder Forest. Over the next 23 years the population of goshawks increased and the population of kestrels declined. A regression analysis of the number of kestrel pairs compared to the number of goshawk pairs showed a negative linear relationship ($r^2 = 0.70$, $P<0.001$) over this time period. Kestrels were thought to be particularly vulnerable to goshawk predation because of their diurnal activity and their habit of hovering while hunting. The findings of Petty et al. (2003) are important because it is one of the few studies that had enough long-term information on populations of both predator and prey species to actually document population effects due to intraguild predation. It is unique in the fact that a comparison could be made between populations of prey species with and without the presence of the predator species.

To further substantiate their findings the authors conducted some additional analyses. First they looked at goshawk diet as their numbers approached their peak near the end of the study, and found that kestrels composed approximately 2.6% of the prey items taken by goshawks. At this rate, they estimated that 20 pairs of nesting goshawks (the estimated population level) would kill approximately 115 kestrels per year. This value was higher than the estimated springtime population of kestrels, so the authors concluded that the goshawks were creating a population sink for kestrels in the Kiedler forest. Short-eared owls, another diurnal species, where found to decline in numbers after the introduction of goshawks, but because of more temporally fluctuating populations that were related to prey abundance, a statistically significant relationship between the number of short-eared owls and the number of goshawks could not be established. No population declines were noted for long-eared owls and tawny owls. These species were expected to be less vulnerable to goshawk predation because of their nocturnal habits.

2.5.3 Intraguild Habitat Use

Hakkarainen et al. (2008) found that yearlong survival of male Tengmalm’s (Boreal – USA - *Aegolius funereus*) owls (n=209) in Finland increased as the percentage of old forest (>152 m^3/ha and approximately 80-100 years of age) increased within a 314 ha (1000 meter radius) circle located around the bird’s nest. However, the amount of old forest in all of these circles was relatively low, ranging from a low of 2% to a high of 37% (mean approximately 12%). Data were reported for five years and survival in any given year was dependent on the vole (*Microtus spp*.) population. Annual survival varied from year to year. Survival was low in two years of declining vole populations regardless of the old forest cover value. In the other three years of increasing vole abundance, survival varied and was highest in 1988-1989. Birds using nest areas with over 20% old forest survived at rates of 100% in that year. In 1994-1995, there was a dramatic linear decline in survival rates, ranging from a high of approximately 75% in nest circles with the maximum old forest cover value (37%) to only about 10% in nest circles with minimal old forest cover values (2%). Differences were not as pronounced in 1991-1992 and ranged from about 60% in nest circles with the maximum old forest cover value (37%) to about 50% in nest circles with minimal old forest cover values (2%). No configuration metrics were reported for any of the nest circles.

Sonerud (1985), working in Norway, examined predator relationships of three owl species (Hawk owl, *Surnia ulula*, weight 270-380 grams, Tengmalm’s owl or Boreal owl, weight 126-194 grams and the Eurasian Pygmy-Owl, *Glaucidium passerinum*, weight 67-83 grams. He found that the smaller pygmy-owls generally nested in dense spruce forests, while the other two species nested in more open areas. These observations are consistent with previous observations of Northern Pygmy-Owls (Giese and Forsman 2003, Sater et al. 2006) and results from this study. In all three studies, pygmy-owls were found to prefer older structurally diverse forests.

Individual trees, in clearcuts or open areas, were often used for nesting by the hawk owl and the Tengmalm's owl. In Sonerud's study area, the pine marten (*Martes martes*) was a major nest predator of the hawk owl and Tengmalm's owl, but the marten did not bother nesting pygmy-owls because the nest diameter hole used by the pygmy-owl was too small (usually between 43-55 mm) for the marten to enter. Pine martens had no trouble entering the larger diameter nest holes of the other two species.

Pine martens are known to favor dense spruce habitats and in Sonerud's (1985) study area there was a significant overlap in habitats used by pygmy-owls and pine martens. Sonerud (1985) speculated that this was a great advantage for the smaller pygmy-owl because while it was vulnerable to predation by the other two owl species, it was not threatened by the marten. By utilizing the denser habitats the risk of predation by the other owls was much lower since these species avoided the denser forested areas inhabited by the marten. It is likely the additional fragmentation would negatively affect both the marten and pygmy-owl in this system.

Another study on eagle owls (*Bubo bubo*) and black kites (*Milvus migrans*), in Italy, showed that black kites generally avoided nesting near eagle owl nests (Sergio et al. 2003). No kites successfully fledged young within 1 km of an eagle owl nest. Because kites and eagle owls favored similar habitats for nesting it appeared that either kites were spatially avoiding the eagle owl nests or that owls were selectively removing them from the habitat surrounding their nest. In either case, kite nests tended to end up on the periphery of the core areas used by eagle owls and often were located between eagle owl home ranges.

Sunde et al. (2003) investigated diurnal behavior of Tawny owls and were interested in mortality due to diurnal raptors (mostly goshawks). Tawny owls are generally active in the night and roost during the day in dense foliage where they are less exposed to predation. However, diurnal raptors were still responsible for 73% of natural owl deaths of radio tagged birds (n=15). The authors found that most of these losses occurred during the breeding season and were often associated with fledglings in their first five months of life. During this time, the young owls tend to be found closer to the ground and in more exposed areas. The authors speculated that this might help the less experienced owls capture prey, and that they may need to forage more in the day to meet their needs.

Parent owls often adopt more exposed roosting sites during the post-fledgling season; presumably to watch for predators and help with fledgling defense should a predator appear. The authors found that both adults and juveniles were more vulnerable to predation during this time period. They speculated that adults were more vulnerable due the exposed roosting locations and juveniles were just more vulnerable due to poor flight ability, begging behavior and inexperience. Based on the number of radio days that they tracked various age groups and the number of mortalities the authors estimated vulnerability in different time periods of the year. What they found was that breeding adults were two and a half times as likely to be killed during the first 45 days after juvenile fledgling as they were during the remainder of the year. During this time, the adults remain with the juveniles and used more open areas for roosting.

Juveniles were killed at high rates (6 times the adult non-breeding season rate) in the time period from 45 days after fledging until they stop begging for food at 55 to 83 days after fledging. Several factors, likely, influence this situation: 1) the act of begging may attract other predators 2) juvenile birds have poor flight abilities and reduced ability and experience in avoiding predators and 3) their lack of experience in hunting may require them to use more open habitats were foraging is less difficult or require them to hunt more during the day than more experienced adults. In the two months after they stop begging (considered as evidence of independence in the study) vulnerability is reduced to 4 times the adult non-breeding rate and finally by the fourth month after independence, vulnerability is reduced to a level similar to that of adults.

2.5.4 Fragmentation Effects

Studies on the effect of fragmentation on raptors are relatively rare in the literature and it does not appear that anyone has made a direct link between habitat fragmentation and an increase in intraguild predation in raptors. Olson et al. (2004) compared spotted owl survival and fecundity based on habitat variables calculated within three different sized circles (scales) around the nest tree (600-meters – approximate size of core use areas around the nest, 1500-meters - approximate home range for spotted owls during the nesting season and 2400-meters – a size thought to incorporate most winter spotted owl movements). Their models suggested that survival and productivity were often tied to factors other than habitat including factors like the age of the breeding pair, precipitation during the spring nesting season or winter weather. They were disappointed to find that the habitat factors they measured only accounted for 14% of the variability in survival rates and only 3% of the variability in rates of productivity. Although, they calculated a variety of metrics for the landscapes they were examining with Fragstats, their best model for survival suggested that survival was tied to the amount of old and mid-seral forest within the 1500-meter circle. This relationship was non-linear with survival peaking at approximately 70% and declining as the amounts of old and mid-seral forest either increased or declined. In contrast, they found that productivity (mean number of young per pair) was best estimated by the amount of edge between old and mid-seral forest and other types (mostly young forest - clearcuts or natural openings). This relationship was linear with increasing productivity being tied to the amount of edge habitat measured in meters.

Grossman et al. (2008) conducted a study on the effects of fragmentation on three owl species (Great Horned Owl (*Bubo virginianus*), Barred Owl (*Strix varia*) and Northern Saw-whet Owl (*Aegolius acadicus*). They examined owl abundance of the three species in 95 – 3-km x 5-km “landscapes”. These “landscapes” were located in an agricultural area of southern Alberta, Canada and arranged so that no two “landscapes” were within 2 km of each other. This distance was selected to be larger than the average radius of Barred owl home ranges, which was the widest ranging species in their study.

Owl abundance was determined by placing five calling stations within each 3-km by 5-km landscape. Calling was done at night and stations were uniformly distributed over each landscape so that they were separated by 1.6 km. Under this configuration the five stations fit nicely within the 3-km by 5-km landscape and calls would reach most areas within the landscape.

Landscape metrics were developed for each of the 95 landscape areas using two classes (forest and agriculture/other). Landscapes were selected prior to the owl surveys to give a wide range of variation in the amount of forest cover. Six classes, based on the amount of forest cover, were utilized in the selection process: 0-15%, 16-25%, 26-35%, 36-50%, 51-65%, and 65-100%. Metrics that were analyzed in Fragstats included: percent forest edge, forest edge length, forest mean patch size, standard deviation of mean patch area, mean distance between forest patches and forest contagion.

Saw-whet Owls were the most abundant species in the 95 landscapes (mean 2.3, standard deviation 1.68, range 0-8.0), Great-Horned owls were the second most abundant (mean 1.8, SD 1.95, range 0-9.5) and Barred owls (mean 0.25, SD 0.56, range 0-2.0) were least abundant. At least one owl species was found in 90 of the 95 landscapes. All three species were affected by the amount of forest cover. Barred owls were most common when the amount of forest within the landscape exceeded 65%, Great-Horned owls were most common when the amount of forest was between 36 and 65%, and Saw-whet owls appeared to be the most versatile being present in 90% of all landscapes with over 15% forest cover.

Landscape configuration appeared to be important in explaining the variability of abundance of the three species. All models were evaluated with Akaike’s information criterion (AIC). Great Horned owls were shown to be most abundant in heterogeneous landscapes. In addition to forest cover, increases in forest patch area standard deviation and in the length of forest edge proved to be useful variables for predicting the abundance of this species. High contagion values along with higher forest cover values were most important in predicting the abundance of Saw-whet owls. These owls appeared to be able to survive in landscapes with less forest cover, but they needed more clumped habitat distributions to be successful. The authors speculated that because of their smaller home range size these owls were able to use smaller patches of habitat than the other two species. Barred owls were most common in landscapes that had the largest mean patch size and most cover, and indicated that this species tended to avoid fragmented agricultural landscapes.

2.6 Conclusions

Intraguild predation appears to be an important aspect of raptor ecology, but testing how this aspect of predator ecology affects raptor populations is a difficult process. Intraguild predation is dependent on the particular species that are involved and small species like the Northern Pygmy-Owl are likely to be most affected. However, sorting out how intraguild predation is influencing overall population responses and how forest fragmentation is influencing this relationship is a difficult process. It is likely that much higher sample sizes than are currently available will be required to sort out this relationship for the Northern Pygmy-Owl.

In this study, Northern Pygmy-Owls that did not succumb to intraguild predation generally utilized habitats that appeared to have less fragmentation. Survival was significantly related to the amount of forest cover exceeding 22.9 cm DBH around known locations and increased significantly as the amount of forest cover increased. Owls with areas of use that had over 60% older forest cover (stands with average diameters exceeding 22.9 cm) had survival levels exceeding 92%, while only 50% of the owls with intermediate levels of forest cover between 46 and 58 percent survived. All owls with less than 41% older forest cover around their area of use were lost to intraguild predation in this study. Open edge length and contagion values appeared to be less significant predictors of survival.

Some birds survived and successfully produced young in areas that had fragmentation levels that were greater than or equal to those observed for owls that were lost to intraguild predation. One female, that survived and successfully raised four fledglings, had only 47% older forest cover exceeding 22.9 cm DBH in the 1000 meter circle around her known locations. In contrast, another male owl survived for at least one year (the longest period in this study) and his area of use (as defined by the circle around his radio locations) was composed of large proportion of older forest (greater than 22.9 cm DBH) exceeding 91.3%.

Olson et al. (2004) found that many other factors such as age, prey availability, weather, impacts of non-guild predators and prey abundance all affect population responses. In this study of Northern Pygmy-Owls, the data suggests that intraguild predation and habitat fragmentation may be playing a role. However, the sample size is small (n=26) and the relationship between mortality and fragmentation was not clear. For example, all owl mortalities (n=10 of 26 birds) were due to intraguild predation and all of these mortalities appeared to occur in habitats that had some degree of fragmentation. However, the amount of fragmentation varied for the different birds. Some birds were lost in areas that had moderate levels of fragmentation and others were lost in areas that were considered heavily fragmented. In some areas, mortality appeared to be associated with riparian leave strips in landscapes that were heavily harvested. There were no other causes of mortality in the study.

My data is consistent with other previous studies of Northern Pygmy-Owls. For example, Giese and Forsman (2003) and Sater et al. (2006) found that Northern Pygmy-Owls generally utilized older structurally diverse forests. I found similar habitat use patterns (Chapter One) and believe that older forests play an important role in preventing intraguild predation on this species.

My findings on the high rate of mortality of Northern Pygmy-Owls are consistent with work by Giese and Forsman (2003) and Deshler and Murphy (2012). Deshler and

Murphy (2012) reported high turnover in Northern Pygmy-Owl populations. In a three year examination of the same 10-12 nesting territories, they found that nesting territories were seldom occupied by the same birds. Although a few male owls returned to the same nesting territory in subsequent years, female owls were generally different. No banded fledglings (n=26) were ever observed as breeding adults in subsequent years. Like this study, no previously marked owls were ever re-trapped by Giese and Forsman (2003).

2.7 Management Implications

This study suggests that Northern Pygmy-Owls survive and successfully breed in managed landscapes. However, the maintenance of non-fragmented areas with forested stands that have an average DBH exceeding 22.9 cm is important to Northern Pygmy-Owls. I believe it is important to maintain a significant portion of the landscape in older stands and suggest that some of those patches be at least 300 hectares in size. This patch size would accommodate the territory size of most Northern Pygmy-Owls. Longer timber rotations would likely better achieve objectives for Northern Pygmy-Owls. My analysis suggests that landscapes that support greater than 60% forest cover in stands that have a minimum DBH of 22.9 cm reduce mortality significantly. Wider buffers along streams also appear to be important for Northern Pygmy-Owls and reducing the number and distribution of narrow buffer leave strips is likely to decrease mortality. Management actions that integrate upslope areas with significant forest retention in upslope areas are more likely to be more successful than strategies that allow intensive management of upslope areas and minimal narrow buffer strip protection. I suggest rotations and patch sizes that are closer to natural disturbance events.

Chapter 3 –Assessment of Genetic Differences in Northern Pygmy-Owls (*Glaucidium gnoma*) Using DNA Microsatellites, and the Use of DNA Analysis to Sex Northern Pygmy-Owls

3.1 Abstract

I examined five polymorphic microsatellite loci to determine genetic variation in 33 Northern Pygmy-Owls (*Glaucidium gnoma*) from Idaho, Montana, and British Columbia. I also tested two DNA primer sequences to evaluate their utility for determining sex on this monomorphic species. I found no genetic differences or clustering in samples from Idaho, Montana, or British Columbia. I found no unique alleles in either Montana or British Columbia that distinguish them from Idaho birds, despite these populations being 300-500 kilometers (km) from the Idaho population. Thus, the results did not corroborate the current subspecies status of *G. g. swarthi* of British Columbia and *G. g. pinicola* of Idaho and Montana. Genetic analysis accurately (100%) assigned gender to birds of known sex and in most other instances was congruent with the "projected" gender that was assigned by owl weight and behavior prior to DNA analysis.

3.2 Introduction

The Northern Pygmy-Owl (*Glaucidium gnoma*) is a small owl species found in Western North America. Its range extends from southeast Alaska to northern Mexico along the West Coast and down the Rocky Mountains from British Columbia to northern Mexico. The Northern Pygmy-Owl is commonly associated with forested areas and is generally thought to prefer areas of older mature forest (Giese and Forsman 2003). The Northern Pygmy-Owl is considered to be non-migratory. However, Northern Pygmy-Owls are known to move to lower elevations during winter in response to increasing snow depths (Hannah 1999). G. Frye (Rocky Mountain Front Institute, pers. comm.) documented a winter movement of approximately 20 km by an owl along the eastern front of the Rocky Mountains near the town of Choteau, Montana. Frye found that Northern Pygmy-Owls generally moved east from higher elevation sites in the Rocky Mountains to lower elevation sites in the foothills and neighboring lowlands during winter.

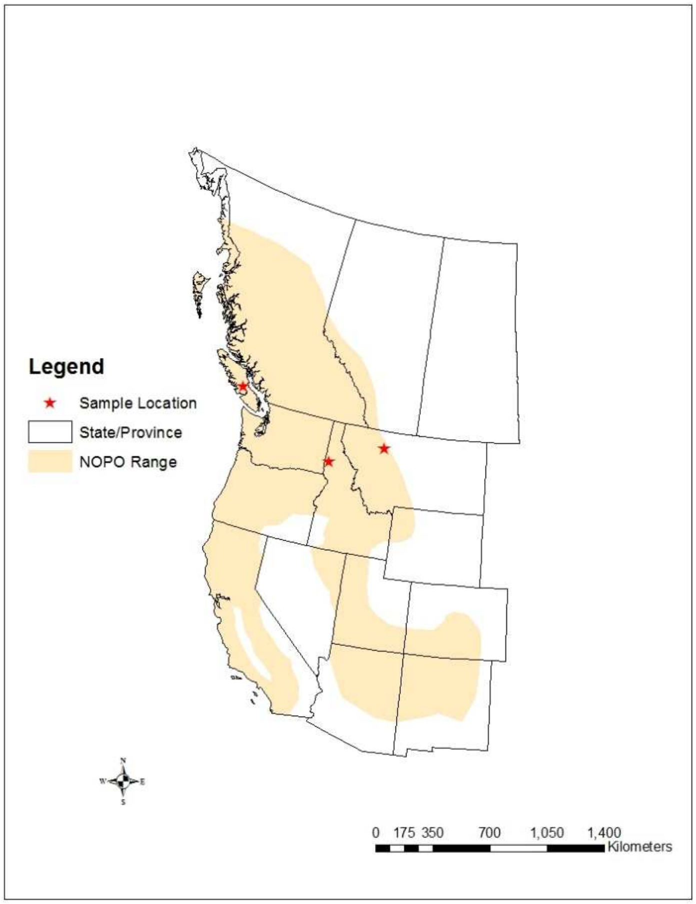
Since Northern Pygmy-Owls are generally non-migratory except for possible winter altitudinal shifts, I hypothesized that genetic differences may exist between populations or geographic areas. The second objective was to determine if genetic methods could be used to accurately assign gender to Northern Pygmy-Owls. It is difficult to accurately sex this species in the field. For this study, I used bird weight to assign gender. Bird behavior, i.e., female birds remain in the nesting cavity during most of the nesting season and are fed by male birds during that time (Holt and Peterson 2000), was also used to determine sex. I hypothesized genetic analysis would be a much more accurate method of determining gender of Northern Pygmy-Owls than just using body mass and/or behavior-based predictions in the field.

A few studies have done some genetic testing on a few Northern Pygmy-Owls as part of investigations of other owl species. For example, (Proudfoot et al. 2005) examined four Northern Pygmy-Owls as part of their work on Ferruginous Pygmy-Owls (*Glaucidium brasilianum*). In trying to establish owl family relationships (Wink and Heidrich 2000, Wink et al. 2009) also examined Northern Pygmy-Owls. To my knowledge, this work is the first review dedicated strictly to Northern Pygmy-Owl population genetics.

3.3 Study Area

To test these hypotheses I obtained blood and feathers from owls in northern Idaho (within 80 km of Moscow), Vancouver Island, British Columbia and the Rocky Mountain Front Area (Choteau vicinity) of western Montana (Figure 3.1). According to Holt and Peterson (2000), the Vancouver Island population is considered a different sub-species (*G. g. swarthi*) than Idaho and Montana populations (*G. g. pinicola*). Samples of the Vancouver Island population were collected at least 530 km from the Idaho study area, and Montana samples were collected at least 325 km from the Idaho study area.

Figure 3.1 – Northern Pygmy-Owl Species Range and Genetic Sampling Locations



3.4 Methods

I examined tissue of 33 Northern Pygmy-Owls from populations in Idaho and Montana in the United States and Vancouver Island, British Columbia in Canada. Most of the samples (n = 25) were collected in northern Idaho from wild trapped Northern Pygmy-Owls. The Rocky Mountain Front Institute provided two feather samples from western Montana and the Pacific Northwest Raptors, Ltd. in Duncan, British Columbia provided seven feather samples, but two of these birds were known siblings and proved to have the same allele signature at all five loci. The sample from one sibling was not used in the microsatellite analysis, but I did determine gender of this bird with DNA methods.

I extracted DNA using a DNeasy kit from Qiagen, Valencia, CA. I followed extraction protocols developed by Bush et al. (2005) for avian blood and body-contour feathers, but changed protocols slightly for both blood and feathers. I modified the blood protocol by mixing all of the blood samples with lysis buffer (Longmire et al. 1988) immediately after the sample was collected in the field. The lysis buffer was then substituted for the initial buffer described by Bush et al. (2005). From that point, I followed the Bush et al. (2005) protocol exactly. Samples were kept in a cooler for transport and frozen as soon possible upon return from the field.

For feather samples I followed the Bush et al. (2005) protocol as written, except that I used tips of approximately 5-6 plucked body feathers. Northern Pygmy-Owl body feathers are very small and delicate and I felt additional feathers would assure successful extraction. Feathers from Idaho birds were placed in coin envelopes and each envelope was placed in a plastic bag with a small amount of granular desiccant. The samples were transported from the field in a cooler and kept frozen until just prior to extraction. Exact treatment of the British Columbia and Montana feathers is unknown, but most were from frozen or recent collections. These feather samples were sent by mail to the Idaho laboratory and no special precautions were made to keep them cool during transport. Because of CITES requirements, transport of British Columbia samples took over two weeks to reach Idaho.

I completed DNA analysis on 25 Northern Pygmy-Owls from Idaho. The Idaho samples were assayed using blood (n = 10), feathers (n = 10), or both blood and feathers (n = 5). I did not analyze blood from Northern Pygmy-Owls of British Columbia or Montana, the analysis of owls from these areas is based entirely on feathers.

I conducted a limited investigation into possible microsatellite DNA and sex determination primers that could be utilized for this species, based on previous work of Proudfoot et al. (2005), Kahn et al. (1998) and Fridolfsson and Ellegren (1999). I used five primers that Proudfoot et al. (2005) developed for Ferruginous Pygmy-Owls and later tested for cross-species amplification. The cross-species amplification tests revealed polymorphic loci among four Northern Pygmy-Owls. Kahn et al. (1998) and Fridolfsson and Ellegren (1999) developed molecular methods for sex determination in birds and tested these methods on a variety of species including some owl species, but not the Northern Pygmy-Owl.

For microsatellite analysis, I used recommended conditions for polymerase chain reaction (PCR) described by Proudfoot et al. (2005) but modified these recommendations slightly as I gained experience with the primers. I increased the size of the reactions to 20 *ul* and included the following components: 0.2 *ul* GoTaq Flexi DNA Polymerase (Promega -

Madison, Wisconsin - 5 *units/ul*), 4 *ul* manufacturer-supplied (Promega) 5X buffer, 1.2 *ul* of $MgCl_2$ (25 mM), 1.8 *ul* of dNTP (0.2 mM), 1 *ul* of fluorescently-labeled forward primer (10 pmol/*ul*), 1 *ul* of reverse primer (10 pmol/*ul*), 9.8 *ul* of ddH2O, and 1 ul of DNA template (estimated concentration, ca. 50 ng/microliter). PCR conditions were the same as those described by Proudfoot et al. (2005), except that I used 39 cycles for Primer FEPO_25 and slightly different locus specific temperatures: "initial denaturation at 94 ^{o}C for 4 min, followed by 35 [39 for FEPO_ 25] cycles of denaturation for 30 seconds at 94 ^{o}C, annealing for 30 s at locus specific temperatures (Appendix E1), and an extension of 30 s at 72 ^{o}C. A final extension at 72 ^{o}C for 4 min succeeded the last cycle."

For sex-identification I used a 7*ul* PCR reaction originally developed for greater sage-grouse (*Centrocercus urophasianus*) at the University of Idaho Laboratory for Conservation and Ecological Genetics, which included the following: "3.5 *ul* Qiagen Master Mix (2X), 0.70 *ul* Q-Solution (5X) – (Qiagen, Valencia, CA, USA), 0.1 *ul* (10*u*M) fluorescently-labeled primer (Kahn et al. 1998), 0.4 *ul* (10 *u*M) fluorescently-labeled primer (Fridolfsson and Ellegren 1999), 1.3 *ul* ddH2O and 1.0 *ul* of DNA template. PCR conditions included initial denaturation at 95 ^{o}C for 15 minutes, followed by 8 cycles of denaturation for 30 seconds at 94 ^{o}C, annealing for 1.5 minutes at 51.5^{o}C, and extension at 72^{o}C of 1 minute, followed by 37 cycles of denaturation for 30 seconds, annealing for 1.5 minutes at 48^{o}C, and extension at 72^{o}C of 1 minute. A final elongation at 60^{o}C for 30 minutes succeeded the last cycle."

I measured amplicon size using a 3130xl ABI Genetic Analyzer (Applied Biosystems, Inc., Foster City, CA). Amplicon lengths were calculated by comparison to GeneScan^{TM} -500 LIZ 500 size standard (Applied Biosystems, Inc.) for microsatellite loci, and initially I used GeneScan^{TM} -600 LIZ 600 for sex-determination loci. However, in later sex-determination runs I only used the Kahn et al. (1998) primer set and this was compared to the GeneScan^{TM} -500 LIZ 500 size standard. I viewed base pair length and assigned alleles in program Genemapper (Version 4.1). Amplicons that did not exhibit a sufficient peak height above background, set at 100 RFU, were not scored, and PCR was repeated until I obtained at least three consistent results for each sample.

The program GENEPOP (Version 4.0.10) was used to test for Hardy-Weinberg equilibrium using Option 1 – Hardy Weinberg Exact Tests and the Sub-option 3- Probability Test (Raymond and Rousset 2011). This option produces an estimation of P-Values using the Markov chain method. I also used Option 5 –Sub-option 1 – Basic Information to calculate the number of observed and expected heterozygotes and the F-statistic (F_{IS}) which is a comparison of individual and sub-population structure (Weir and Cockerham 1984, Robertson and Hill 1984).

I used program STRUCTURE-Version 2.3.3 (Pritchard et al. 2011) to test for clusters of genetically similar individuals. I assumed three populations (Idaho, British Columbia, and Montana) for the analysis and ran the program for 500,000 iterations (burn-in) and 500,000 repetitions. I assumed default values: (Admixture Model, Allele Frequencies Correlated, and Compute Probability of Data [for estimating number of clusters – K]). I ran the initial model for three different levels of K (1-3) and also tested the Idaho population independently to see if any clustering could be seen in these samples. I initially used four different clusters (K-4) for the Idaho population which I based on groupings of capture locations. I also ran tests for all six clusters (British Columbia, Montana, and four clusters in Idaho).

3.5 Results

I was able to successfully extract DNA from all of collected samples on the first attempt except for one bird from Montana (Appendix E2). I reran this sample and extracted DNA on my second attempt, but could not get the sample to amplify at locus FEPO_25. This locus also proved difficult for some of the other samples and was the only locus that was not in Hardy-Weinberg equilibrium for the Idaho population (Table 3.1). I could detect no significant difference between feather and blood samples in regard to amplification or extraction success.

Allele nucleotide lengths (Appendix E1 and Table 3.2) generally agreed with the findings of Proudfoot et al. (2005) for the Ferruginous Pygmy-Owl. I found no unique alleles in either the Montana or British Columbia populations. All alleles observed in Montana (n = 2) and British Columbia (n = 6) were also found in Idaho (n = 25). With the exception of locus FEPO_25, observed heterozygosity was similar to expected heterozygosity in the Idaho population.

I do not report Hardy Weinberg, F_{IS} and heterozygosity (Table 3.1) results for British Columbia and Montana populations due to small sample sizes. Unreported results for all 33 samples (Idaho, British Columbia and Montana) were similar to results I report for Idaho. I found no evidence of clustering of individuals or populations using program STRUCTURE. All of the tests indicated that genotypes were equally likely to be found in all of the predefined populations. Thus when I ran the program with three pre-defined populations (K = 3) all individuals displayed equal probabilities (0.333, 0.333, 0.334) of being in each of the populations. Similar results were generated for level K-1 to K-6. Thus, when I selected two populations individual results for each owl was near the value of 0.500, suggesting that all of the owls were equally likely to be found in either predefined populations. I also ran program STRUCTURE without locus FEPO_25, but this did not result in any significant changes to the results.

I tested all 33 individual owls to determine gender and an additional sibling from Canada that was not used in the microsatellite analysis (Appendix E2). With the Kahn et al. (1998) primer set I was able to successfully determine sex of six Northern Pygmy-Owls whose sex was known prior to DNA analysis. Using the Kahn et al. (1998) primer set, I successfully predicted the sex of 18 Idaho owls whose weight at capture was known (female owls are generally 10 grams heavier than males) and five additional owls from Canada whose probable sex had been determined by personnel at Pacific Northwest Raptors, Ltd. I found a base pair length of approximately 260 nucleotides for the Z chromosome amplicon (male) and 275 nucleotides for the W chromosome amplicon (female). I was unsuccessful determining sex of Northern Pygmy-Owls using Fridolfsson and Ellegren (1999) primers.

Weights of two Idaho owls (ID_4, and ID_11) were in the mid-range of weight values making sex determination by weight questionable. DNA analysis with the Kahn et al. (1998) primer set suggested that these two owls were both males. Owl BC_34 (Sibling of Owl BC_33) was initially identified as a male by personnel at Pacific Northwest Raptors, Ltd., whereas DNA analysis suggested that it was a female. Subsequent discussion with personnel at Pacific Northwest Raptors, Ltd. suggested they were not sure about the sex of this owl. I reran these samples three times and got the same results each time. I had no prior knowledge of probable sex of the two Montana birds which were both determined to be males.

3.6 Discussion

I successfully extracted DNA from both feathers and blood of Northern Pygmy-Owls using protocols established by Bush et al. (2005). I found that five primers that had been previously identified by Proudfoot et al. (2005) for Ferruginous Pygmy-Owls also worked successfully for Northern Pygmy-Owls. However, I had difficulty (inconsistent results) with primer FEPO_25 during the investigation and samples had to be run many (5-11) times in order to make final allele determinations. Similar problems were encountered with primer FEPO_25 by Proudfoot et al. (2005) in their study of Ferruginous Pygmy-Owls (GA Proudfoot – pers. comm.). I did not have similar problems with the remaining four loci.

I had the most difficulty obtaining consistent results with heterozygote samples rather that homozygote samples for primer FEPO_25. Locus FEPO_25 had the lowest percentage of heterozygote samples of all examined loci and was out of Hardy Weinberg equilibrium according to the analysis. Proudfoot et al. (2006) also reported that this locus was out of Hardy Weinberg equilibrium in their Ferruginous Pygmy-Owl study. I found that 11 of 33 owls were heterozygous at locus FEPO_25.

At locus FEPO_25 Genemapper analysis provided unambiguous calls for twenty-three samples, but I had to redo the PCR on nine samples multiple times (5 to 11) in order to make calls. Eight of these more difficult samples were heterozygous. I generally added more DNA and/or modified annealing temperatures when I reran these samples. Heterozygous samples generally had lower peak heights (300 – 600 RFU) compared to homozygous samples (6000-8900 RFU). One sample (Owl MT-41) showed weak peaks (<100 RFU) and I did not consider the results reliable. Locus FEPO_25 exhibited high allelic dropout rates and I do not recommend it for future studies of Northern Pygmy-Owls.

Interestingly, Proudfoot et al. (2006) reported that locus FEPO_25 was out of Hardy Weinberg equilibrium in their analysis of 11 loci for the Ferruginous Pygmy-Owl.

For loci FEPO 5 and FEPO_17 there was direct overlap of all alleles between my study of Northern Pygmy-Owls and a similar study of Ferruginous Pygmy-Owls (Proudfoot et al. 2005; Table 3.2). For loci FEPO_25 and FEPO_27 I had general agreement with Proudfoot et al. (2005), but I did have slightly longer nucleotide lengths at the upper end of ranges for both of these loci. For example, Proudfoot et al. (2005) had a range from (180-216) for FEPO_25 while my range was (192-220). For FEPO_27 Proudfoot et al. (2005) had a range of (100-140) while my range was (126-146). My measurements appeared to have a two nucleotide longer size difference at locus FEPO_27 (for example 144 vs. 146). I saw the most difference between the two different species at FEPO_43. Proudfoot et al. (2005) reported a range of (163-227) while I found a range of (216-264). My measurements at locus FEPO_43 also suggested a ubiquitous 1 nucleotide longer size difference (for example 215 vs. 216). I ascribe nucleotide differences in length for primer FEPO_27 and FEPO_43 to standard variation that occurs between platforms and polymers used to determine fragment size.

A comparison of base pair length at locus FEPO_43 for Northern Pygmy-Owls and Ferruginous Pygmy-Owls (Table 3.2) suggests that allele length may be longer in Northern Pygmy-Owls. However, there still appears to be overlap between allele sizes for the two species. This was not the case for the other four loci investigated in this project, which all had near complete overlap in allele size with Proudfoot et al. 2005 (Table 3.2). It is unknown if this difference might be useful in assisting in separation of Ferruginous Pygmy-Owls from Northern Pygmy-Owls in locations where the range of these two species overlap.

I found no clustering of samples or unique alleles in Vancouver Island owls, which are currently considered a distinct subspecies. However, the analysis included very few samples and only examined five loci. Future studies may find genetic differences between the two subspecies as more owls and a greater number of loci are tested.

Success with sex determination primers was very good with Kahn et al. (1998) primers, but my initial use of the Fridolfsson and Ellegren (1999) primers was unsuccessful (Appendix E2). I suspect that this was not due to any problems with the primers, but rather due to the size standard I used in the analysis and the fact that I was dealing with an owl species. Fridolfsson and Ellegren reported that CHD1W fragment length for two owl species they tested was 1.2 kb in size and not 400 to 450 base pairs that they saw in most other species. Since the initial protocol was based on sage-grouse and I used a size standard of GeneScan^{TM} -600 LIZ, it is likely that I got inaccurate results when using Fridolfsson and Ellegren (1999) primers. After my initial unsuccessful runs with Fridolfsson and Ellegren (1999) primers, I abandoned their use in favor of the Kahn et al. (1998) primer set. I did not conduct any further testing of the Fridolfsson and Ellegren (1999) primers and understand that they have been successfully used for other owl species (GA Proudfoot –pers. comm.).

3.7 Conclusions

Contrary to my initial hypothesis, I found no genetic differences in three populations of Northern Pygmy-Owls I studied. However, the sample size and number of examined loci were both small due to limited funding and sample availability. I found that four of five loci initially identified by Proudfoot et al. (2005) for Ferruginous Pygmy-Owl also worked well for the Northern Pygmy-Owls, but one locus (FEPO 25) appeared to have high allelic dropout rates and I do not recommend it for future studies of the Northern Pygmy-Owl. The use of primers developed by Kahn et al. (1998) proved successful for determining gender of Northern Pygmy-Owls with molecular methods and accurately determined sex in all cases.

Table 3.1 - Hardy Weinberg, F_{IS} and Expected/Observed Heterozygosity Test Results

Locus (Idaho Population Only n=25)	Hardy Weinberg (P-Value)	Standard Error	Expected Heterozygotes[1]	Observed Heterozygotes	F_{IS}[2]	F_{IS}[3]
FEPO_05	0.6294	0.0146	19	20	-0.0538	+0.0157
FEPO_17	0.1107	0.0072	18.7	21	-0.1263	-0.0974
FEPO_25	0.0000	0.0000	20.4	9	+0.5632	+0.5411
FEPO_27	0.0804	0.0088	20.7	20	+0.0342	+0.1079
FEPO_43	0.7568	0.0184	22.6	24	-0.0618	-0.0488

1 Computed using Levene's correction factor
2 Weir and Cockerham 1984
3 Robertson & Hill 1984

Table 3.2 – Comparison of Allele Size Ranges and Numbers of Different Alleles For the Ferruginous Pygmy-Owl (Proudfoot et al. 2005) And the Northern Pygmy-Owl (this study)

Primer name (Proudfoot et al. 2005)	**Allele Size Range for Ferruginous Pygmy-Owls (Proudfoot et al. 2005)**	**No. of Alleles for Ferruginous Pygmy-Owls (Proudfoot et al. 2005)**	**Allele Size Range (This study)**	**No. of Alleles (This study)**
FEPO_05	237-281	13	241-269	7
FEPO_17	141-177	10	145-165	6
FEPO_25	180-216	11	192-220	8
FEPO_27	100-140	9	126-146	8
FEPO_43	163-227	16	216-264	12

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Appendix A

Habitat Extrapolation to Unsampled Stands

Characteristics of available habitat were determined from United States Forest Service (USFS) inventory data for the Clearwater National Forest and nearest neighbor projections (Crookston et al. 2002, Crookston and Finley 2008). Inventory data were downloaded from the Clearwater National Forest website (http://www.fs.fed.us/r1/clearwater/gis/vegetation/clw_inventory) accessed on 1/9/2010 and includes information from the table "cstands_combo090825". This table represents a summarization of the data from all field exams conducted on the Clearwater National Forest according to guidelines of the Region 1 – Timber Stand Management Record System (TSMRS) up to August 25, 2009. Inventory data in table "cstands_combo090825" were updated by the forest service using the Forest Vegetation Simulator (FVS – Crookston et al. 2003) model to 2009 so that all data are consistent to a common year (http://www.fs.fed.us/fmsc/fvs/).

I then worked to compute "most similar neighbor" projections for stands with missing data (Crookston et al. 2002, Crookston and Finley 2008). The goal was to predict a "USEID" for every stand in the study area and use that information to predict fine scale variables, such as, major tree species, basal area, and average diameter breast height for each unsampled stand in the project area. I wanted to match unsampled stands with the "most similar neighbor" field sampled stand in table"cstands_combo090825" and use that information to predict values for unsampled stands. The USFS data represents the most comprehensive locally collected vegetative information available for the study area and my goal was to produce an accurate map that would display these values across the entire study area.

Using the 2009 satellite imagery and the zonal statistics tool in ArcGIS 10, I calculated an average color signature for each stand polygon in the red, green and blue bands. I calculated average slope and elevation for each stand polygon using a digital elevation model (INSIDE IDAHO – National Elevation Dataset, 10m) and the “Spatial Statistics Tool” in ArcGIS 10. Average aspect for each polygon was calculated as a categorical variable in 8 categories (N, NE, E, SE, S, SW, W, and NW) because of the difficulty of averaging aspect data (i.e. Average of 360 and 0 = 180). I used the most common raster aspect value to make this determination. For example, if the most common raster aspect value was between 337.6 and 22.5, the stand polygon would be considered to have a Northerly (N) Aspect. The x and y UTM coordinates were calculated for the centroid of each stand.

These data formed the basic building blocks for running “yaImpute” program in program “R” (Crookston 2008). I, initially, used the following “X” variables: STAND_ID, x-UTM coordinate, y-UTM coordinate, Average Color Signature- Red Band, Average Color Signature – Blue Band, Average Color Signature – Green Band, Slope, Aspect and Elevation. The independent “Y” variable was “USEID” as downloaded from table “cstands_combo090825”. I then used the “foruse” command to predict the “most similar neighbor USEID” for all stands without values (i.e. State, private and the one missing data USFS stand). I made several runs with the model using the numerous available methods (raw, Euclidean, mahalanobis, ica, msn, msn2, gnn, and randomForest) and then visually compared the resulting stand maps (as determined by USEID) to my visual observations on the satellite imagery.

In the end, I saw problems with all stand maps generated in this manner, but the analysis suggested that the “raw” method using only the red, green and blue color signature gave the best results. When variables such as x or y coordinates, slope, aspect and elevation were added to the model, visual comparisons of the resulting stand maps as compared to the 2009 satellite imagery suggested that these maps were of much poorer quality than the maps produced by merely relying on the color signature of each polygon. Errors in expected size class were generally 20-30% higher as these additional variables were added to the model. Likewise, maps generated by more complex methods such as Euclidean distance had similar problems and I saw more errors in expected size class as compared to the visual observations.

Following the completion of “yaImpute” runs, I now had complete stand coverage for the entire project area. In addition, to the visual classification of stand structure and crown closure of all stand polygons; I now had a “USEID” for all stand polygons in the study area. This allowed me to make “most similar neighbor” projections for all unsampled stands based on locally collected field data.

After running the “yaImpute” program to assign “most similar neighbor” projections, I noticed there still appeared to be some errors in stand assignment. I further cross-checked the data set using ArcGIS query tools and visual inspection of predicted stand characteristics. As a result of this final process, the recommended “USEID” was modified on 1548 stands or 18.3% of the total. When a discrepancy between “USEID” and the satellite imagery was discovered, stands were modified by selecting an alternate field surveyed stand for a new “USEID”. When modifying the computer generated “USEID”, I always attempted to utilize a stand with a similar color signature and similar visual appearance on the satellite imagery to the stand in question.

Appendix B

Summary of Available and Used Habitats

The entire project area contains 87,762 hectares and is located in the western two-thirds of the Palouse Ranger District of the Clearwater National Forest in Northern Idaho. Intermingled ownership categorizes the area with approximately 49.7% of the land managed by the Clearwater National Forest. The remaining lands are primarily managed by industrial forest landowners (27.3%), the State of Idaho (7.3%) and small non-industrial landowners (15.7%).

Radio tagged owls utilized a smaller portion of the larger project area which I categorized by placing 2500 meter radius circles around known locations of individual owls. This area encompassed 34,815 hectares (Figure 1.2) and was considered available to radio marked birds. The data presented in this section is intended to give the reader an overview of available habitat conditions found in the area utilized by the radio marked owls.

It is interesting to note the difference between the stand exam data and the remotely sensed Vmap projections displayed in these tables for species composition. The remotely sensed Vmap projections display a much lower percentage of grand fir, cedar and western hemlock (33% of available habitat) than the stand exam projections (49% of available habitat). Based on my field reviews of the project area and the fact that the stand exam data is based on a much more extensive ground based inventory, I believe the stand exam data gives a more accurate picture of species composition in the project area.

Several variables were not used in the habitat analysis because they are highly correlated with the parameters that I actually used in the synoptic model and the logistic regression (Appendix B8-B13). However many of these parameters are often used in the development of silvicultural prescriptions and I felt it important to display their relationship to the parameters that were actually utilized.

I have broken down the species groupings that I used in the analysis to give the reader a better idea of the species components available in the study area (Appendix B8, B9, B12 and B13). As can be seen in the following tables, most stands on northerly slopes are dominated by grand fir and sites on southerly slopes are dominated by Douglas fir. Lodgepole pine and high elevation species like subalpine fir and spruce are minor components in the study area.

Appendix B1. – Continuous Variables (Available Habitat = 34815 Hectares, Used = 638 Radio Locations)

	Available Habitat Summary (34814.7 Hectares)				Used Habitat Summary (638 radio locations)			
	Mean	Standard Deviation	Min.	Max.	Mean Locations	Standard Deviation	Min.	Max.
Slope %	24.9	14.9	0	161.2	26.1	15.3	0.5	77.7
Elevation (m)	977.0	123.9	644.1	1540.5	941.1	99.5	711.7	1300.7
Stream Distance	151.6	127.9	0	992.7	83.6	88.3	0.1	608.7
TPHA	2226.0	4263.0	0	59755.7	2448.8	2137.6	0	19190.2
TDTPHA23	19.9	43.7	0	683.2	27.6	27.3	0	148.3
TDTPHA38	6.1	15.2	0	272.5	7.9	9.0	0	74.1

Appendix B2. - Proportions Aspect (Available = 34815 Hectares, Used = 638 Radio Locations)

	Aspect North	Aspect Northeast	Aspect East	Aspect Southeast	Aspect South	Aspect Southwest	Aspect West	Aspect Northwest	Flat	Total
Available	0.1081	0.0960	0.1195	0.1278	0.1433	0.1319	0.1409	0.1323	0.0002	1.0
Used	0.1113	0.1270	0.1567	0.1082	0.1066	0.1646	0.1348	0.0909	0	1.0

Appendix B3. – Proportions HJ_Size (Stand Exam Data - Available = 34814.7 Hectares, Used = 638 radio locations)

	HJ_Size Nonstocked	HJ_Size Seedling/Shrub	HJ_Size Sapling	HJ_Size Pole	HJ_Size Small	HJ_Size Medium	HJ_Size Large	Total
Available	0.10	0.10	0.13	0.11	0.32	0.22	0.02	1.0
Used	0.03	0.03	0.08	0.03	0.34	0.46	0.03	1.0

B4. - Proportions Major Species Groups
(Stand Exam Data - Available = 34815 Hectares, Used = 638 Radio Locations)

	Stand_Exam Non-Stocked	Stand_Exam DF_PP_L	Stand_Exam GF_C_H_WP	Stand_Exam LP_OTHER	Total
Available	0.07	0.40	0.49	0.04	1.0
Used	0.01	0.37	0.57	0.05	1.0

Appendix B5. – Proportions Vmap Size Class (Available = 34815 Hectares, Used = 638 Radio Locations)

	Vmap_Size Nonstocked	Vmap_Size DBH- 0-12.4 cm	Vmap_Size DBH- 12.5 - 25.3 cm	Vmap_Size DBH- 25.4 – 38.0 cm	Vmap_Size DBH- > 38.1 cm	Total
Available	0.16	0.09	0.14	0.42	0.19	1.0
Used	0.04	0.03	0.18	0.56	0.19	1.0

Appendix B6. – Proportions Vmap Canopy Class (Available = 34815 Hectares, Used = 638 Radio Locations)

	Vmap_Canopy Non-stocked	Vmap_Canopy 10-24.9%	Vmap_Canopy 25-39.9%	Vmap_Canopy 40-59.9%	Vmap_Canopy > 60%	Total
Available	0.16	0.28	0.04	0.19	0.33	1.0
Used	0.04	0.23	0.01	0.23	0.49	

Appendix B7. – Proportions Vmap Major Species Group (Available = 34814.7 Hectares, Used = 638 Radio Locations)

	Vmap_Nonstocked	Vmap_DF_PP_L	Vmap_C_GF_H	Vmap_LP	Total
Available	0.16	0.48	0.33	0.03	1.0
Used	0.04	0.44	0.50	0.02	1.0

B8 – Species Components of the GF_C__H_WP Parameter (Stand Exam Data)

Species	**GF**	**C**	**H**	**WP**	**Total**
Proportion	0.65	0.23	0.03	0.09	1.0

Appendix B9 – Species Components of the PP_DF_L Parameter
(Not Used in the Analysis – Negatively Correlated with the GF_C_H_WP Parameter)

Species	**PP**	**DF**	**L**
Proportion	0.20	0.58	0.22

Appendix B10 – Variables Highly Correlated with the HJ_Size Parameter

HJ_Size	**Mean HJ_CRN_CL (Crown Closure Class 0-4)**	**Mean BAM2HA (Basal Area - M^2 per Hectare)**	**Mean TOTVOLM3 (Total Volume in M3 per Hectare)**	**Mean BADBHCM (Average DBH of Basal Area Trees in cm)**	**Mean QMDCM (Quadratic Mean Diameter in cm)**	**Mean CRNCL (Average Crown Closure Percentage)**
0	0.29	2.22	15.93	12.11	3.64	6.92
1	0.70	4.64	42.87	15.58	6.04	8.37
2	2.55	6.45	38.74	17.22	6.43	23.54
3	3.44	26.2	166.98	21.31	11.91	46.44
4	3.53	40.22	402.49	34.98	16.91	47.45
5	3.60	42.80	475.28	43.53	19.61	45.79
6	3.76	48.28	606.23	60.25	22.16	43.56

Appendix B11– Variables Highly Correlated with TDTPHA23 and TDTPHA38

	RDTPHA23/TDTPHA23 – (Number Trees or Snags per Hectare over 22.9 cm DBH)	**RDTPHA38/TDTPHA38 (Number of Trees or Snags per Hectare over 38.1 cm DBH)**
Mean (RDTPHA)	8.40	1.75
Mean (TDTPHA)	19.9	6.1

Appendix B12 – Species Components of the Vmap_GF_C__H Parameter (Stand Exam Data)

Species	**GF**	**C**	**H**	**WP**	**Total**
Proportion	0.697	0.124	0.177	0.002	1.0

Appendix B13 – Species Components of the Vmap_DF_PP_L Parameter
(Not Used in the Analysis – Negatively Correlated with the GF_C_H_WP Parameter)

Species	**PP**	**DF**	**L**	**Intolerant Mix**	**Total**
Proportion	0.13	0.83	0.02	0.02	1.0

Appendix C

Nest Descriptions

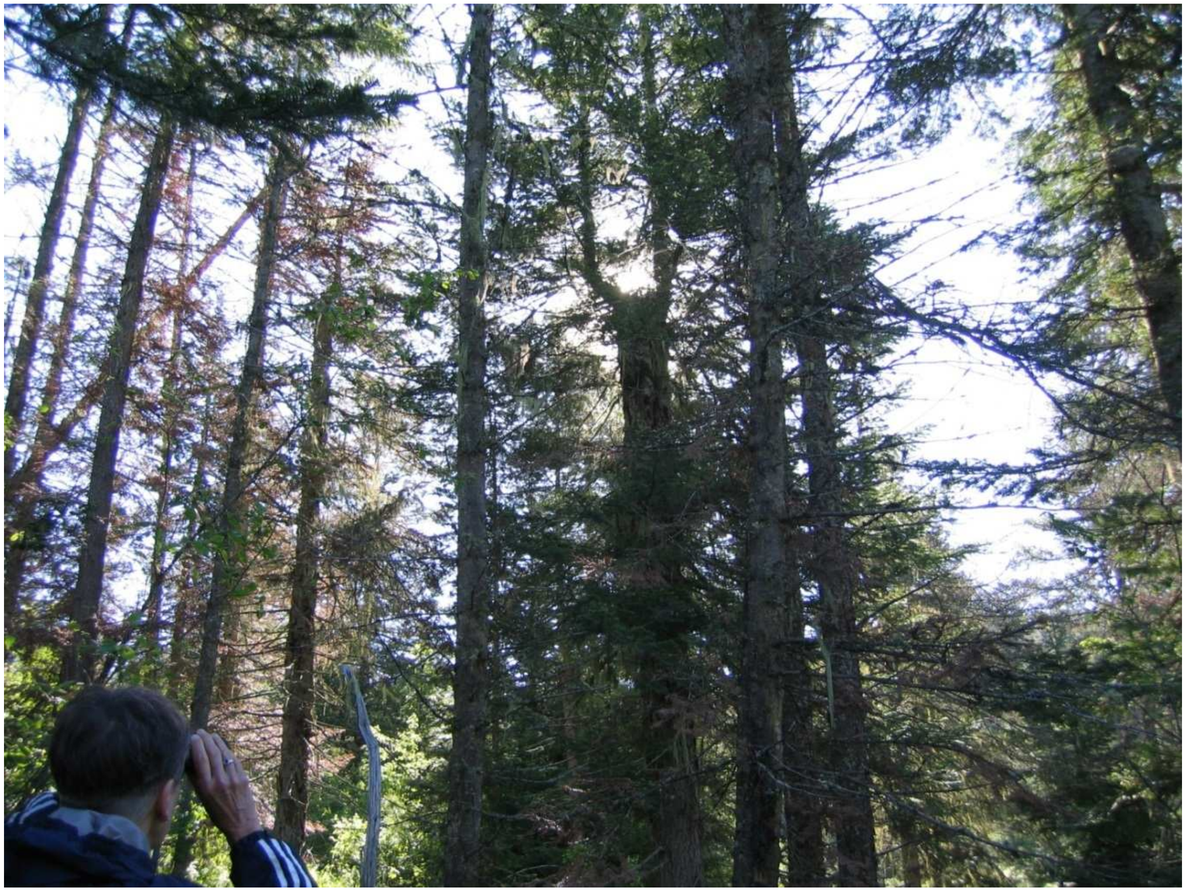
I located three nests during the course of the study. Nest one (Appendix C1) is located in a stand that is classified in the medium (DBH 38.1 – 53.2 cm) sawtimber size class by the criteria used in the analysis. The stand was mapped at 9.8 hectares, but it is bordered by many other forested stands that are either in the small sawtimber (DBH 22.9-38 cm) or medium sawtimber size classes. The extended area of all of these stands is at least 175 hectares. The nest tree is located on a uniform side slope that is approximately 55 meters upslope from a small perennial stream (width 1.5 meters). There is an old skid trail near the nest site (10 meters) that is occasionally used as an unauthorized ATV route to circumvent an existing road closure. I saw evidence of some use (tracks, cut trees, etc.), but never saw any actual use during my time at the site. I suspect most violations occur during the fall hunting season.

The second nest is located in a selectively harvested stand that was logged around 30-40 years ago. The size class of the stand is considered to be pole (12.7-22.9 cm DBH). The nest tree is a moderate sized live grand fir (43.7 cm DBH) that has a broken top and hollow center (Appendix C2 and C3). The nest tree appears to be a residual “cull” tree that was not removed during the original logging. The nest tree is located approximately 30 meters from the center of a dry side draw that runs perpendicular to a small perennial stream (1.5 meters in width) at the base of the slope. The distance from the nest tree to the perennial stream is 125 meters. An old overgrown skid trail parallels the side draw near the nest tree and is located halfway between the nest tree and the center of the draw. There is no motorized use of this skid trail.

Nest three was discovered in 2009 and is in the same general area and same dry side draw as nest two which was discovered in 2008. Nest three is located about 190 meters upslope from nest two and is in an uncut stand that borders the cutover pole sized stand where nest two was found. The stand size class is considered medium sawtimber (DBH 38.1 – 53.2 cm – Appendix C4). The stand where nest three is located is 6 hectares, but it is bordered by several other stands in the small sawtimber and medium sawtimber size classes that total over 100 hectares in size. The distance to the edge of the nearby cutover stand (where nest two was located) is 35 meters. The nest is located directly in the center of the dry side draw. An old grassed over road (untravelable) is located 24.4 meters upslope from nest tree three. The nest snag is in a broken topped grand fir snag that is 35.8 cm DBH.

Appendix C1. - Nest Stand 1 Looking Downslope From Nest Snag

Appendix C2 - Nest 2 Nest Tree (Forked Tree at the Center of the Photo)



Appendix C3 -Nest 2 stand looking downslope from the nest tree

Appendix C4 -Nest 3 – Looking downslope toward the nest snag

Appendix D

Summary of Survival Values

Appendix D1 – Fragstats Results

Owl	F[1]	O_Area[2]	O_ %[2]	O_Edge[2]	P_Area[3]	P_%[3]	P_Edge[3]	F_Area[4]	F_%[4]	F_Edge[4]	CONTAG[5]
1	L	23.24	7.4	5260	92.9	29.6	14490	198.01	63.0	16930	55.04
2	L	78.41	25.0	12420	0	0.0	0	235.83	75.0	12420	52.64
3	M	89.37	28.5	10850	70.87	22.6	4860	153.86	49.0	12410	47.11
4	L	51.29	16.3	7190	60.81	19.4	7220	202.03	64.3	10610	54.20
5	L	68.43	21.8	10930	0	0.0	0	245.81	78.2	10930	56.08
6	M	209.55	66.7	17920	0	0.0	0	104.51	33.3	17920	44.85
7	M	193.85	61.7	19220	8.17	2.6	2610	112.09	35.7	17390	58.74
8	M	146.16	46.5	9070	22.64	7.2	5030	145.28	46.3	12720	53.83
9	L	35.35	11.3	6320	43.42	13.8	5050	235.24	74.9	10710	62.24
10	L	31.69	10.1	8960	25.66	8.2	2340	256.69	81.7	9520	68.79
11	M	111.46	35.5	9860	74.37	23.7	8020	128.26	40.8	14120	44.99
12	L	23.65	7.5	4820	57.23	18.2	11950	233.25	74.3	13390	61.44
13	M	142.16	45.3	19910	15.51	4.9	3020	156.46	49.8	20610	53.77
14	M	122.93	39.1	14730	11.43	3.6	3150	179.75	57.2	13180	57.63
15	L	74.31	23.6	20940	39.28	12.5	12420	200.67	63.9	22920	50.24
16	M	244.05	77.6	12370	35.69	11.4	11920	34.56	11.0	8430	62.92
17	L	86.93	27.7	16830	46.23	14.7	10470	180.91	57.6	20200	48.21
18	M	92.43	29.4	22820	69.19	22.0	12760	152.62	48.6	21480	42.82
19	L	127.48	40.6	16420	7.82	2.5	1340	178.99	57.0	16060	58.69
20	L	62.02	19.7	9420	16.21	5.2	3820	235.91	75.1	10200	64.19
21	M	61.19	19.5	10160	4.63	1.5	1030	248.39	79.1	11190	70.18
23	L	9.99	3.2	4920	17.23	5.5	2680	286.87	91.3	7600	81.19
24	L	93.4	29.7	18020	73.8	23.5	9610	146.92	46.8	19730	43.60
25	L	144.35	46.0	18790	23.11	7.4	2680	146.63	46.7	19150	51.87
26	L	17.83	5.7	3610	44	14.0	8050	252.32	80.3	10780	67.82
27	L	39.41	12.6	8950	53.64	17.1	9530	220.91	70.4	16880	56.81

1 = Owl Fate – Mortality = M, Live= L   2 = Open (Area-Hectares, Percent, Length edge –M)   3=Pole – DBH 12.7-22.8 cm

4 = Forest – DBH >= 22.9 cm   5= Circle Contagion

Appendix D2 – Correlation Coefficients of Fragstat Coefficients

	OArea	Open%	OEdge	PArea	Pole%	PEdge	FArea	For%	FEdge	Contag
OArea	1.00	**1.00**	**0.61**	-0.33	-0.33	-0.18	**-0.90**	**-0.90**	0.25	-0.38
Open%	**1.00**	1.00	**0.61**	-0.33	-0.33	-0.18	**-0.90**	**-0.90**	0.25	-0.38
OEdge	**0.61**	**0.61**	1.00	-0.20	-0.21	-0.05	-0.55	-0.55	**0.78**	-0.59
PArea	-0.33	-0.33	-0.20	1.00	**1.00**	**0.82**	-0.12	-0.12	0.21	-0.37
Pole%	-0.33	-0.33	-0.21	**1.00**	1.00	**0.82**	-0.12	-0.12	0.21	-0.37
PEdge	-0.18	-0.18	-0.05	**0.82**	**0.82**	1.00	-0.19	-0.19	0.32	-0.26
FArea	**-0.90**	**-0.90**	-0.55	-0.12	-0.12	-0.19	1.00	**1.00**	-0.37	0.57
For%	**-0.90**	**-0.90**	-0.55	-0.12	-0.12	-0.19	**1.00**	1.00	-0.37	0.57
FEdge	0.25	0.25	**0.78**	0.21	0.21	0.32	-0.37	-0.37	1.00	**-0.70**
Contag	-0.38	-0.38	-0.59	-0.37	-0.37	-0.26	0.57	0.57	**-0.70**	1.00

Bold Values are highly correlated (>0.60)

Appendix E

Summary of Genetic Values

Appendix E1 – Characterization of Five Polymorphic Primer Pairs Originally Developed for Ferruginous Pygmy-Owl DNA (Proudfoot et al. 2005)

Primer name (Proudfoot et al. 2005)	Sequence (5'-3) – (From Proudfoot et al. 2005)	Annealing temp. (^{o}C) – (This study)	Repeats in cloned allele – (From Proudfoot et al. 2005)
FEPO_05	F-GGAGATGAATCAGCAAACCTGT	54.5	(AGAT)13
	R-AAATTTAAACTAGCCTAGAGTCAGC		
FEPO_17	F-GGAGAGTGGAATAGACAACCTC	54.5	(TATC)11
	R-TGAATATAGGCTCTGTGTGTGG		
FEPO_25	F-CCATCTCTCCTGTCCTGAGC	53	(TCTA)15
	R-CCATTCTCCTTCCTGTCATAGG		
FEPO_27	F-GCACATAATTTATAATACTG	50.3	(GATA)11
	R-GGTCTACCTGAGCACA		
FEPO_43	F-CGTGAAGGTAAGAGGAGCTGG	59.0	(GGAT)4(AGAT)10
	R-GGAGGGAGCCTGGAAATGG		AGAC(AGAT)6

Appendix E2 – Individual Owl Weight, Suspected Owl Gender Based on Weight and Behavior, Gender Identification Based on DNA and Individual Owl Alleles (Base Pair Length) at Five Examined Loci

Owl	Wt. (gm)	Suspected Sex	DNA Sex	FEPO_05		FEPO_17		FEPO_25		FEPO_27		FEPO_43	
ID-01	UKN	?	M	257	261	161	161	196	212	126	134	232	244
ID-02	60	M?	M	257	261	157	165	204	204	134	138	232	252
ID-03	68	F?	F	241	261	157	165	200	204	130	138	236	240
ID-04	63	?	M	253	261	161	161	200	212	126	126	228	248
ID-05	57	M	M	253	257	161	161	200	200	126	134	240	248
ID-06	56	M?	M	249	253	157	161	196	212	126	134	232	264
ID-07	61	M?	M	261	261	149	157	204	204	126	130	220	252
ID-08	58	M?	M	253	257	153	161	220	220	122	138	220	244
ID-09	56	M?	M	257	257	157	161	212	212	130	138	220	248
ID-10	60	M?	M	241	257	157	161	208	208	122	130	236	240
ID-11	65	?	M	257	261	157	161	212	212	126	130	248	248
ID-12	57	M?	M	261	261	157	165	204	212	126	126	224	232
ID-13	57	M?	M	253	257	149	161	200	204	118	138	224	260
ID-14	71	F?	F	261	261	161	161	216	216	122	126	236	252
ID-15	67	F?	F	253	269	157	165	212	212	122	126	224	236
ID-16	56	M?	M	253	257	157	161	208	208	146	146	240	248
ID-17	58	M?	M	261	265	145	161	208	208	122	130	224	244
ID-18	58	M?	M	253	261	149	165	192	200	118	142	220	236
ID-19	58	M	M	257	261	157	161	204	204	122	126	220	240
ID-21	57	M?	M	257	261	149	161	200	204	130	142	220	236
ID-23	57	M?	M	241	261	157	165	204	204	126	134	220	248
ID-24	56	M	M	249	249	153	161	220	220	122	134	228	260
ID-25	66	F	F	249	261	157	165	204	212	126	126	236	248
ID-26	57	M?	M	257	261	145	157	212	212	126	134	216	224
ID-27	60	M	M	253	261	149	157	212	212	122	122	224	236
BC-	UKN	F?	F	253	257	153	161	216	216	130	134	232	240
BC-	UKN	M?	M	257	257	149	157	204	204	130	130	228	236
BC-	UKN	F?	F	253	253	153	157	208	208	126	134	236	264
BC-	UKN	M?	F	N/	N/	N/	N/	N/	N/	N/	N/	N/	N/
BC-	UKN	M	M	249	257	149	161	212	212	126	134	228	244
BC-	UKN	F?	F	249	257	157	161	200	212	122	138	236	236
BC-	UKN	F?	F	249	249	157	161	200	204	122	126	236	236
MT-	UKN	?	M	253	253	153	165	N/	N/	126	130	220	236
MT-	UKN	?	M	257	261	157	161	216	216	122	130	224	224

Appendix F

Animal Care and Use Protocol

University of Idaho
Animal Care and Use Committee

Date: Wednesday, September 20, 2006
To: Edward O. Garton
From: University of Idaho
Re: Protocol 2006-60
Habitat Use and Ecology of Northern Pygmy Owls (*Glaucidium gnoma*)

Your animal care and use protocol for the project shown above was reviewed by the University of Idaho on Wednesday, September 20, 2006.

This protocol was originally submitted for review on: Thursday, June 22, 2006
The original approval date for this protocol is: Wednesday, September 20, 2006
This approval will remain in affect until: Thursday, September 20, 2007
The protocol may be continued by annual updates until: Sunday, September 20, 2009

Federal laws and guidelines require that institutional animal care and use committees review ongoing projects annually. For the first two years after initial approval of the protocol you will be asked to submit an annual update form describing any changes in procedures or personnel. The committee may, at its discretion, extend approval for the project in yearly increments until the third anniversary of the original approval of the project. At that time, the protocol must be replaced by an entirely new submission.

Brad Williams, DVM

IACUC Representative

Appendix G

Copyright Letter from the Wilson Journal of Ornithology

WJO <wjo@unl.edu>
Fri 5/2/2014 1:59 PM
To:
Jageman, Harry (jage6652@vandals.uidaho.edu);
WJO <wjo@unl.edu>;
...
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Dr. Jageman, thank you for your inquiry. As editor of the Wilson Journal of Ornithology, I am able to give you permission to include your 2013 article with Graham Frye, "Post-Fledging Ecology of Northern Pygmy-Owls in the Rocky Mountains", as an appendix to your dissertation. We do ask that you include the complete citation of the article and appropriately acknowledge the Wilson Journal of Ornithology and the Wilson Ornithological Society in your dissertation. Thanks, Mary

Mary Bomberger Brown, Editor
Melissa J. Panella, Associate Editor
The Wilson Journal of Ornithology
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Appendix H

Frye, G. G., and H.R. Jageman. 2012. Post-fledging Ecology of Northern Pygmy-Owls in the Rocky Mountains. Wilson Journal of Ornithology. 124:199-207.