AN ABSTRACT OF THE THESIS OF

Alexis Smoluk for the degree of Master of Science in Geography presented on June 8, 2011.

Title: Geographic Distributions of Prey of the Northern Spotted Owl in the Central Western Cascades, Oregon, 1988-2009

Abstract approved:

Julia A. Jones

Spatial variation in the diet of the northern spotted owl (*Strix occidentalis caurina*) influences owl home ranges, and understanding this relationship will aid managers in forest management prescriptions that influence spotted owl recovery. This study describes the spatial variation in owl diet based on 4183 prey collected at 114 owl territories in 1833 km^2 area of the Central West Cascades during 1988-2009. The study addressed two questions: (1) What are the spatial patterns of owl territories and prey in owl pellets? (2) What landscape characteristics explain the composition of spotted owl prey? Thirteen prey species/groups were identified as key prey to spotted owl diets because they appeared in 10% of owl territories, comprised 90% of the total abundance and 95% of the total biomass across all pellet samples. Northern flying squirrels (*Glaucomys sabrinus*) were the most important prey in all areas, comprising 46-64% of prey abundance and 48-75% of prey biomass. The spatial distribution of key prey species, especially red tree voles (*Arborimus longicaudus*), pocket gophers (*Thomomys mazama*), and rabbits/hares (*Sylvilagus bachmani /Lepus americanus*) was significantly related to easting, elevation, and fine-scale relief. Red tree voles were more abundant in owl diets at low elevation, with high fine-scale relief and in the western portions of the study area, whereas pocket gophers and rabbits/hares were more abundant in owl diets at high elevation, with low fine-scale relief and in the eastern portions of the study area. Owl territories exhibited a significantly dispersed spatial pattern in almost all years, but the mean nearest neighbor distance between owl territories was 2090m in the western and 3000m in the eastern portions of the study area. Differences in owl pair densities and nearest neighbor distances were related to spatial patterns in owl diet. Where red tree voles comprised a higher proportion of the diet, owl pair density was higher and owl territories were more closely packed than where pocket gophers predominated. These findings suggest that (1) differences in diet among local areas was due to differences in key prey availability, which in turn are influenced by vegetation zone and topography, (2) at high elevation spotted owl sites with abundant pocket gophers and few woodrats in the diet, owl dietary dependence on flying squirrels over the winter and early in the nesting period may require owls to occupy larger territories than owls require in lower elevations, and (3) the spatial variation in owl diets and associated variation in owl pair densities and nearest neighbor distances suggest that owl habitat requirements vary within the West Cascades physiographic province, raising questions about the use of one-size-fits-all habitat values as a management strategy. These findings may be relevant for regulatory agencies and forest managers as they work to recover the spotted owl.

Geographic Distributions of Prey of the Northern Spotted Owl in the Central Western Cascades, Oregon, 1988-2009

by

Alexis Smoluk

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 8, 2011
Commencement June 2012

Master of Science thesis of Alexis Smoluk presented on June 8, 2011

APPROVED:

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Chair of the Department of Geosciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Alexis Smoluk, Author

ACKNOWLEDGEMENTS

I would like to thank Julia Jones, for numerous reasons, not least of which being the day she plucked me out of the HJ Andrews experimental forest to become a Master's Candidate and engage in free-thinking research on northern spotted owls. Julia, as a naturally warm person, created and maintained a receptive, inspirational, work environment while guiding me through the arduous writing process. Dr. Dawn Wright, who instructed the GIS courses, helped develop my Geographic Information Science skills which was fundamental to my research. Dr. Katie Dugger provided valuable insights in the editing process. I would like to thank my committee for their patience with the short time available. I am grateful for the funding provided by the University Graduate Laurels Scholarship.

Dr. Steven A. Ackers, thank you for hiring me on to the HJ Andrews northern spotted owl demography study (HJA) in 2004 and for being a soundboard for ideas. I admire Rita Claremont, who is infectiously bubbly, for her unbridled dedication to her job as a spotted owl biologist at HJA, her uncanny ability to find owl pellets in the forest, and because she identified three-quarters of the pellet sample. Rita is also my friend and if it wasn't for her physical aversion to data entry, I would not have been so intimately connected with the pellet data. I would like to thank Dr. Eric Forsman for discovering how to study spotted owls; he inspired us all. I would like to thank my partner of six years, Lance Wyss, not only for his love and support through the entire process but for retaining his child-like wonder in the forest.

Support and encouragement from friends, family, and fellow graduate students made my research enjoyable.

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1. INTRODUCTION

The northern spotted owl (*Strix occidentalis caurina*; NSO) is intimately associated with old growth coniferous forests (Forsman et al. 1984, Franklin et al. 1990) and greater amounts of older forest, particularly near activity centers, improves survival and reproductive success (Franklin et al. 2000, Olson et al. 2004, Dugger et al. 2005). Occupancy rates of NSO are also higher on territories with more mature forest near the territory core (Forsman et al. 1984, Seamans and Gutierrez 2007). By the early 1990's timber harvest over the 20th century removed approximately 60% of NSO habitat in the United States which prompted scientific and public debate focusing on the negative impact of old-growth harvesting on the NSO and ultimately, the development of the Northwest Forest Plan (NWFP), a habitat conservation plan designed to conserve old-growth forest and the species that rely on these habitats (Anthony et al. 2006). A key component of the NWFP was an effectiveness monitoring program for NSO to track status and trends of populations as the plan was implemented (Lint et al. 1999, Anthony et al. 2006, Forsman et al. 2011).

The 1526 km^2 HJ Andrews NSO demography study (hereafter HJA, not to be confused with the HJ Andrews Experimental Forest, 62 km^2, contained within the HJ Andrews NSO demography study) is one of five demographic study areas in Oregon included in the NSO effectiveness monitoring program under the Northwest Forest Plan (NWFP) (Lint et al. 1999) (Figure 1.1). Throughout the range of the NSO, demographic studies have documented an average annual decline of 2.9% per year from 1985 to 2008 (Forsman et al. *in press*).

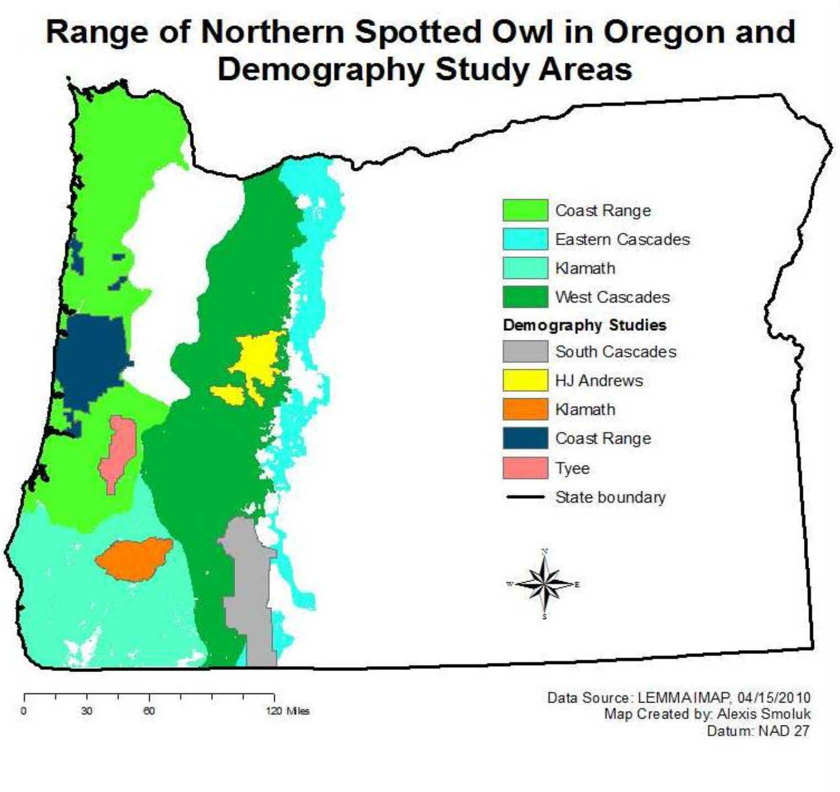


Figure 1.1: Physiographic provinces in the range of the NSO in Oregon and five associated NSO demography study areas. The HJ Andrews is in yellow and located within the West Cascades physiographic province.

The diet composition of the NSO varies within its range and has been associated with differences in home range size (Carey et al. 1992, Zabel et al. 1995, Block et al. 2005), In the central Cascades of Oregon, northern flying squirrels (*Glaucomys sabrinus*) dominated NSO diets (Carey et al. 1992), whereas in southwestern Oregon and northern California woodrats (*Neotoma fucipes* and *Neotoma cinerea*) predominated (Zabel et al. 1995, Forsman et al. 2004b). The forests of Central Oregon Cascades are mostly comprised of Douglas fir and western hemlock, and harbor a diverse assemblage of hypogeous fungi (Arora 1986), the primary food for flying squirrels (Maser et al. 1986). In southwestern Oregon the vegetation is mostly comprised of mixed-coniferous and mixed-evergreen forest associations, and home range size was inversely related to the density of woodrats (Zabel et al. 1995). Thus, variation in home range size of NSO may be related to differences in prey availability associated with differences in forest composition across the owls' range. Understanding regional variation in northern spotted owl diets may be important when evaluating space use by northern spotted owls.

Although regional patterns of NSO diet throughout the range are relatively well documented (Zabel et al. 1995, Forsman et al. 2001, 2004b), local variations in owl prey communities in Central Cascades of Oregon are less well studied. Supplemental to the flying squirrel, NSO prey in this region was mainly western red-backed voles (*Myodes californicus*), bushy-tailed woodrats (*Neotoma cinerea*), red tree voles (*Arborimus longicaudus*), pocket gophers (*Thomomys mazama*), deer mice (*Peromyscus maniculatus*), rabbits (Sylvilagus bachmani), and hares (*Lepus americanus*). Density studies of small mammals in the Central Cascades focused on flying squirrels, deer mice, and western red-backed voles (Rosenberg et al. 1994, 2003), so bushy-tailed woodrats, red tree voles, gophers, rabbits, and hares were not sampled and the role of pocket gophers in NSO diet in particular is unclear (Thomas et al. 1990, Rosenberg et al. 2003). A difference in prey abundance has been shown to affect raptor populations through mechanisms affecting reproduction and survival (Rosenberg et al. 2003). Therefore, information on spatial patterns of prey species may be relevant for management of the spotted owl.

NSO prey, such as dusky-footed woodrats (*Neotoma fuscipes*), flying squirrels, and to a lesser extent, red tree voles, have been shown to be associated with particular vegetation types. The dusky-footed woodrat was an important prey for owls in southwestern Oregon and northern California and was found in high densities in brushy pole/sapling stands (80 woodrats/ha; Sakai and Noon 1993) and edges between old stands and sapling/pole stands (Zabel et al. 1995, Ward et al. 1998). Flying squirrels were more abundant in mature and old growth stands than in second growth stands (but see Rosenberg and Anthony 1992, Witt 1992, Carey 1995, Waters and Zabel 1995, Lehmkuhl et al. 2006), and their abundance varies with the density of decadent snags and down wood (Carey et al. 1999a). Distributions of the arboreal red tree vole were inferred from studies of NSO diet (Forsman et al. 2004). Red tree voles occurred at the highest densities in the southern Oregon Coast Range, but they were common throughout the Coast Range and Central Cascades of Oregon (Forsman et al. 2004b). In the Central Cascades, the prevalence of red tree voles in NSO diets declined with increasing elevation, while the prevalence of red-backed voles and pocket gophers increased with elevation (Forsman et al. 2004).

NSO home range sizes were inversely related to prey densities (Zabel et al. 1995)**.** The largest home ranges of NSO were found where flying squirrels dominate the diet; NSO home ranges in Washington were estimated to be 1700 ha, compared to 900-1200 ha in southwestern Oregon (Carey et al. 1992). Carey et al. (1992) attributed these differences to lower densities of flying squirrels in Washington (0.5/ha, 60% of diet by weight) compared to Oregon (2/ha, 46% of diet). Even smaller home range sizes (454 ha) occur where flying squirrels and both species of woodrat co-occur (Zabel et al. 1995). In the Oregon Cascades, where flying squirrels contribute ~45 % and woodrats ~20 % of the total biomass in owl diets (Forsman et al. 2004), the spotted owl home range size was estimated to be about 1200 ha (Thomas et al. 1990).

The objectives of this study were to quantify spatial patterns of the abundance of prey item species (n=4183) identified in NSO pellets collected over the 1833 km^2 HJ Andrews NSO demography area from 1988-2009. This study addressed two specific questions: (1) What are the spatial patterns of owl territories and are these patterns associated with the spatial distribution of prey in owl pellets? (2) What landscape characteristics are associated with species composition patterns of spotted owl prey? With the answers to these questions, I discuss the relationship between spatial patterns of owl territories and species composition pattern of spotted owl prey

2. METHODS

2.1. Study Area

The study was conducted based on owl pellets collected from 1988-2009 in 1833 km^2 HJ Andrews NSO demography area (HJA) in the central Cascades of Oregon (Figure 2.1). Elevation ranges from 450m to approximately 1600m. For the purposes of this analysis the HJA was separated into the following eight watershed groups based on drainage divides, mainstem stream orientation, and study area boundary: Blue River (BLUE), East South Fork McKenzie (ESMK), Fall Creek (FALL), Lower McKenzie (LMKR), North Middle Fork of the Willamette (NMWI), South Fork McKenzie (SFMK), South Santiam, and Upper McKenzie (UMKR) (Figure 2.1) (Table 2.1).

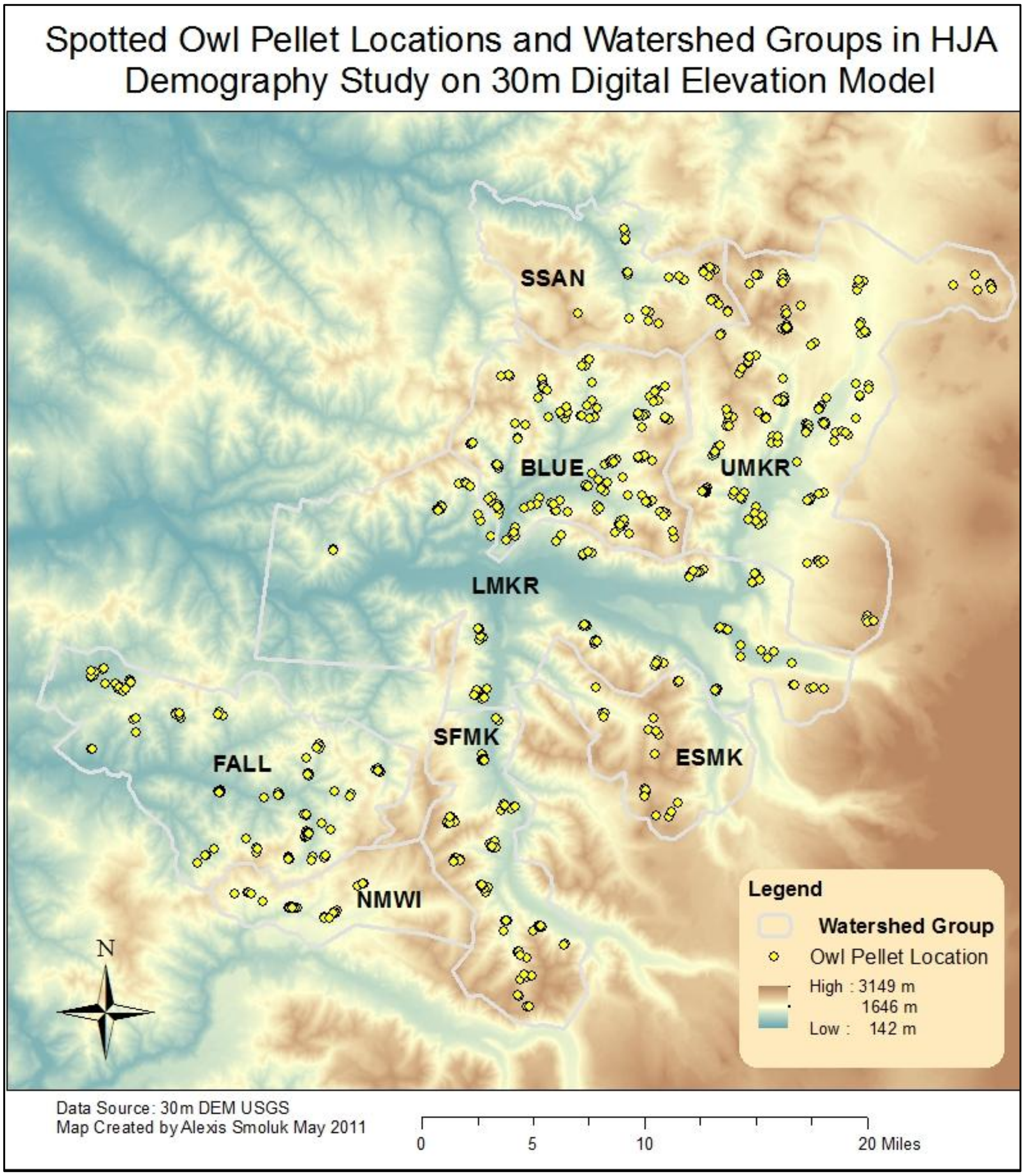
The HJA is characterized by mountainous terrain, but lithology and topography vary within and among watershed groups. The lithology in the eastern portion of Blue River, Fall

Creek and Lower McKenzie was dominated by tuffaceous sedimentary rocks and these areas were lowest in elevation (USGS Geology 2005). Highest elevation areas in Upper McKenzie and South Fork of the McKenzie River were characterized by ridge-capping basalts and the remainder of HJA is a mixture of basalt and andesite (USGS Geology 2005). Topography includes high and low relief landforms, with “high-relief” landforms deeply weathered, highly dissected, and with slopes ranging from 15˚ to 77˚ that comprise most of the study area (USGS DEM 2011). Old growth stands with no evidence of fire for >400 years were likely to be found in concave landforms that exhibit “high-relief” beneath high ridge-tops (~1200 m) (Tepley 2010). In contrast, “low-relief” landforms were little weathered, little dissected, with slopes ranging from 0˚ to 15˚ in the high-elevation sections of the study area (parts of Blue River, South Santiam, North Middle Fork of the Willamette, and Upper McKenzie) (USGS DEM 2011).

The Central Cascades region has a moist temperate maritime climate which varies with vegetation zone (Franklin and Dyrness 1973). Three vegetation zones including the Western Hemlock Zone, the Pacific Silver Fir zone, and the Mountain Hemlock zone (Franklin and Dyrness 1973) comprise the majority of the study area and boundaries between vegetation zones were not distinct. The Western Hemlock zone (150-1000m at 45°N) is dominated by *Pseudotsuga menziesii, Tsuga heterophylla* and *Thuja plicata. Abies amabilis* is common near the altitudinal limit (Franklin and Dyrness1973). The western hemlock zone accounts for almost the entire Fall Creek and most of the Lower McKenzie, Blue River, South Fork McKenzie, the northwestern portion of the South Santiam, and northwestern portion of the East South Fork of the McKenzie River watershed group. The Pacific Silver Fir Zone (1000-1500m) is wetter and cooler than western hemlock zone and receives more precipitation in the form of snow (Franklin and Dyrness 1973). Winter snowpack is generally 1 to 3 meters deep. This vegetation type occurs in all watersheds, but in Fall Creek this zone is limited to the highest ridges (Tepley 2010). Typical tree species were *Abies amabilis, Tsuga heterophylla, Abies procera, Pseudotsuga menziesii, Thuja plicata, Abies grandis, Picea engelmanii,* and *Pinus contorta* (Franklin and Dyrness 1973). The Mountain Hemlock zone (1300 – 1700 m) is the wettest and coldest of the forested zones in western Oregon and annual precipitation ranges from 1600 to 2800 mm (Franklin and Dyrness 1973). This includes 400-1400 cm of snowfall which accumulates up to 7.5 m deep, so relatively few tree species were found as dominants (Franklin and Dyrness 1973). This zone was found in

Upper McKenzie, East South Fork of the McKenzie River, eastern portion of the South Santiam, highest ridges in Blue River and Lower McKenzie River, and the southern portion of the South Fork of the McKenzie.

In the HJA, spatial use of habitat by NSO prey species can be characterized as aerial (occur primarily in the air), arboreal (occur primarily in trees), scansorial (adapted for climbing), and terrestrial (occur primarily on ground). NSO consume high proportions of arboreal and scansorial prey suggesting that owls spend a disproportionate amount of time foraging in the forest canopy (Forsman et al. 2001). However, scansorial prey such as bushy-tailed woodrats builds stick nests on talus slopes and they are found both in trees and on the ground (Carey et al. 1999b). Terrestrial prey (i.e. red-backed voles, pocket gophers, rabbits, hares, and deer mice) are primarily found on the forest floor; yet, arboreal and scansorial prey forage for food such as hypogeous fungi which grows on the forest floor (Maser et al. 1978, Arora 1986). These NSO prey species consume a variety of foods, including fungi, lichen, insects, seeds, roots, tubers, and surface vegetation (Maser et al. 1978, Gashwiler 1979, North et al. 1997, Wilson and Ruff 1999). The wet, mild climate found within the Western Hemlock Zone is well suited for fungal and lichen growth and more than 1000 kinds of mushrooms form mycorrhiza with Douglas fir (Arora 1986). Hypogeous Basidiomycetes are the primary fungal component consumed by both the flying squirrel (arboreal) and western red-backed vole (terrestrial) in the Cascade Range. In the winter these mycophagists consume alectorioid lichens which were found in the highest proportions in forested stands >140 years old (Peck and McCune 1997). Other spotted owl prey species, which are terrestrial, were known to consume fungi to a lesser extent: Trowbridge's shrew, vagrant shrew, pika, chipmunks, pocket gophers, creeping vole, brush rabbits, woodrats, and deer mice (Maser et al. 1978). The herbivorous snowshoe hare is found most often in open meadows, thickets, bogs, and coniferous lowlands (Kurta 1995, Wilson and Ruff 1999). Open meadow mosaics are ideal for the fossorial pocket gopher which feed largely on roots, tubers, and surface vegetation (Witmer et al. 1996). All spotted owl prey (except red tree voles) spend a portion of time on the ground either foraging or traveling. In the Central Cascades spotted owls consume higher proportions of terrestrial prey than other regions in Oregon (Forsman et al. 2004b). There are three hypotheses for this behavior: (1) in response to lower numbers of alternate prey such as the arboreal red tree vole at higher elevations, owls switch to the terrestrial red-backed vole, (2) terrestrial species are easier for owls to capture in the Cascades because there is relatively less dense brush on the forest floor than in areas such as the Coast Range, (3) spotted owls are not selecting for certain kinds of prey, but are simply preying opportunistically on prey that are easier for owls to capture given the particular morphological attributes of the owl and structural attributes of the dense forests (Forsman et al. 2004b).


Spotted Owl Pellet Locations and Watershed Groups in HJA Demography Study on 30m Digital Elevation Model

Data Source: 30m DEM USGS
Map Created by Alexis Smoluk May 2011

Figure 2.1: Locations where northern spotted owl pellets were collected within the 8 watershed groups in HJ Andrews (HJA) Northern Spotted Owl Demography Study on a 30m digital elevation model. Watershed groups include the Blue River (BLUE), East South Fork of the McKenzie River (ESMK), Fall Creek (FALL), Lower McKenzie (LMKR), North Middle Fork of the Willamette River (NMWI), South Fork of the McKenzie River (SFMK), South Santiam River (SSAN), and Upper McKenzie (UMKR).

Table 2. 1: Geographic information about HJA and 8 watershed groups. In parentheses is the # of owl sites with pellet data included in the pellet analyses. Areas with * have been extended to include owl territories in analyses that fall outside the HJA study area boundary for use in spatial analysis (g-function and nearest neighbor). Territories were included to reduce edge effects.

	BLUE (23)	ESMK (6)	FALL (19)	LMKR (17)	NMWI (4)	SFMK (11)	SSAN (7)	UMKR (27)	Total (114)
Area (km^2)	211	114	272	452*	88*	159	151	387*	1833*
Min elevation (m)	509	863	455	508	853	564	618	587	508
Max elevation (m)	1161	1353	1049	1333	1066	1482	1342	1511	1511
Relief Min	0.658	0.742	0.793	0.705	0.823	0.772	0.620	0.600	0.600
Relief Max	0.722	0.779	0.835	0.768	0.839	0.837	0.648	0.706	0.839
% Western Hemlock Zone	53	25	85	85	31	40	37	27	52
% Pacific Silver Fir Zone	36	36	14	14	52	30	47	52	32
% Mountain Hemlock Zone	11	39	1	4	17	30	16	21	14

2.2. Field methods

Data from annual summary reports and northern spotted owl pellet data from the HJ Andrews (HJA) northern spotted owl demography study were used in this study.

2.2.1 Spotted owls: Nest status and owl locations

Data on nesting status (whether a pair was breeding or not each year) which was used to determine “owl locations” from HJA annual reports were used in this study. Owl locations were determined in the following hierarchical way: (1) locations of nest trees, (2) location of juveniles. If nesting did not occur, then (3) pairs located during the day between April 15 and May 15, (4) pairs located outside of those dates, (5) females located during the day, (6) pairs located at night only, (7) males located during the day, and finally, (8) males located at night were used to determine “best” owl locations annually. The nesting status of owl pairs was determined from April 1 through May 31 following a standard protocol (Lint et al. 1999). A pair was considered to be nesting if any of the following were observed: (1) female with a brood patch, (2) female discovered sitting on the nest, (3) male/female delivered food to nest tree or juveniles, or (4) juveniles were located. If none of these were documented before June 1, the pair was defined as "non-nesting" for that year.

Owl location data has some inherent problems: owls are not perfectly detectable, owl locations do not always reflect nest locations, and the survey type at HJA influences the amount of forest surveyed every year. Differences in weather conditions, habitat, survey observers, time of day, season, and year may all affect detectability of owls (Olson et al. 2005). Nesting owls are more likely to be detected because they actively defend the nest (territorial), which can add biennial bias because owls exhibit a biennial nesting cycle (Anthony et al. 2006). Owls that nest this year may not have nested the year before, but probably nested two years ago. In high nesting years approximately 70% of owl pairs nest, while in low nesting years only 30% nest (Anthony et al. 2006). Nest locations are important because they are undoubtedly the center of activity for that year, whereas night detections and owls found late in the year (after July 1st) do not provide information on the center of activity and may be random. Low nesting years are likely to have more random owl locations than high nesting years. Late-season detections are normal for high elevation watersheds such as East South Fork of the McKenzie (ESMK) due to logistical problems associated with persistent snow-pack. Another potential problem is the type of survey at HJA, which is a territorial study area (TSA)(Anthony et al. 2006). It is sufficient in a TSA to visit historic site centers (historic nest trees and locations) and systematically survey from there when no owls are found. When owls are located the survey stops. HJA survey type can cause bias due to under-sampling in high nesting years and potentially miss other territorial owls; however, the bias is similar across watershed groups (except ESMK). Low nesting years and late-season detections cause bias when calculating spatial statistics such as the "nearest neighbor" by adding random locations. Statistical attempts to resolve this problem use the "g-function".

Owl locations are determined with a GPS inside loosely defined "owl territories". Owl territories are a small geographic sub-basin determined by proximity to other active owl territories. The HJA has 200 owl territories; all are not occupied at the same time.

2.2.2 Pellets and pellet data

An owl pellet is a mass of undigestible material egested by all owls that contain bones, hair, scales, and insect parts. Pellets are often found under daytime roosts and near nest trees. Owl pellets were collected during daytime visits to owl territories during the breeding season (March-August) from 1988 to 2009 following a standardized survey protocol each year associated with the NWFP effectiveness monitoring program (Lint et al. 1999). Nesting owls require more site visits to reach protocol and the odds of encountering pellets greatly increases. Eighty percent of the pellet sample comes from nesting owls. All pellet samples encountered in the field (n=2255) were collected, air-dried, tagged, and transported to the lab at the USDA Forestry Sciences Lab at Oregon State University for identification. Pellets were air-dried and separated such that prey species in each pellet could be identified, and numbers of individuals of each prey species could be counted (Forsman et al. 2004). The number of each prey type in each pellet was estimated by taking the highest count of the number of skulls, mandibles, bones of the appendicular skeleton, or pieces of exoskeleton (Forsman et al. 2004). Dichotomous keys and a reference collection of bird and mammal skeletons were used to identify remains in pellets. Biomass was estimated by multiplying the estimated number of each species by the mean biomass of the species, or by estimating and summing the mass of each prey item in the sample (Forsman et al. 2004b). The latter method was used for large prey such as snowshoe hare (*Lepus americanus*), brush rabbits (*Sylvilagus bachmani*), and mountain beaver (*Aplodontia rufa*) because these prey items were predominately represented by juveniles and applying the mean mass from museum skeletons would grossly overestimate mass (Forsman et al. 2004). Mean mass was estimated by comparing bones of specimens with known mass to those within samples, making the assumption that body mass is linearly correlated with the mass of bones in pellets (Forsman et al. 2004b). The pellet location and elevation was assigned to the nearest owl location.

Pellets samples were collected from 153 owl territories during 1988-2009, the time period with the most consistent survey effort associated with the HJ Andrews NSO demography study. Collected pellet samples reflect a spatial aggregation of regurgitated, undigestible prey parts, and it is not known if the sample collected included the entire pellet, or even multiple pellets, but we considered each pellet sample a single sample unit and abundance and biomass for each prey species were estimated for each sample (Forsman et al. 2004). Following Forsman et al. (2004), we only included sites with pellet samples containing at least 10 prey items, as less was considered inadequate for analysis. Thus, my analysis was based on samples from 114 owl territories (hereafter known as owl sites) with a total prey item sample size of 4183.

Of the 63 different prey species or species groups identified in pellet samples, 13 were chosen as key species/groups because they: (1) occur in at least 10% of the 114 owl sites, (2) comprise 90% of the total abundance, and (3) represent 95% of the total biomass collected across all samples. Two groups of species were lumped into their generic group because it was difficult to distinguish species using available bones (Forsman et al. 2004). All shrews within the *Sorex* genus were considered a single key prey group, and included the following species: Trowbridge's shrew (*S. trowbridgii*), the vagrant shrew (*S. vagrans*), and other, unidentified shrews of the *Sorex* genus. Moles were also not distinguished by species, but rather grouped by the genus *Scapanus*. Brush rabbits (*Sylvilagus bachmani*) and snowshoe hares (*Lepus americanus*) were lumped together for analysis as the "rabbit/hare" group, because they represented a single key prey group that could be characterized by large biomass and terrestrial habitat use. The 13 key species groups (hereafter "key prey species") were: (1) red tree vole (*Arborimus longicaudis*) (ARLO), (2) great grig (*Cyphoderris monstrosa*) (CYMO), (3) northern flying squirrel (*Glaucomys sabrinus*)(GLSA), (4) rabbits/hares (LAGO), (5) creeping vole (*Microtus oregoni*)(MIOR), (6) moles (MOLE), (7) western red-backed vole (*Myodes californicus*)(MYCA), (8) bushytailed woodrat (*Neotoma cinerea*)(NESP), (9) pika (*Ochotona princeps*)(OCPR), (10) deer mouse (*Peromyscus maniculatus*)(PEMA), (11) shrews (SOSP), (12) Townsend's chipmunk (*Tamias townsendii*)(TASP), and (13) pocket gopher (*Thomomys mazama*) (THSP) (Table 2.2).

Table 2. 2: Acronyms for key prey species. Scientific name, common name, average estimated mass (g), taxonomic Class, activity period (ACT), and activity zone (ZONE). Activity period: nocturnal (NOCT), diurnal (DIUR), and both nocturnal and diurnal (BOTH). Activity zone (ZONE): arboreal (ARBO), scansorial (SCAN), and terrestrial (TERR).

prey	Genus species	common name	Mass (g)	TYPE	ACT	ZONE
ARLO	*Arborimus longicaudis*	red tree vole	26	MAMMAL	NOCT	ARBO
CYMO	*Cyphoderris monstrosa*	Great Grig	2	INSECT	NOCT	SCAN
GLSA	*Glaucomys sabrinus*	northern flying squirrel	130	MAMMAL	NOCT	ARBO
LAGO	*Lepus americanus* *Sylvilagus bachmani*	snowshoe hare brush rabbit	50-1400	MAMMAL	BOTH	TERR
MIOR	*Microtus oregoni*	Creeping vole	20	MAMMAL	NOCT	TERR
MYCA	*Myodes californicus*	western red-backed vole	23	MAMMAL	NOCT	TERR
NESP	*Neotoma cinerea*	bushy-tailed woodrat	284	MAMMAL	NOCT	SCAN
OCPR	*Ochotona princeps*	pika	171	MAMMAL	BOTH	TERR
PEMA	*Peromyscus maniculatus*	Deer mouse	22	MAMMAL	NOCT	TERR
MOLE	*Scapanus spp.*	Mole species	56	MAMMAL	NOCT	TERR
SOSP	*Sorex spp.*	*trowbridgii* or *vagrans*	5	MAMMAL	NOCT	TERR
TASP	*Tamias spp.*	Chipmunks	83	MAMMAL	DIUR	SCAN
THSP	*Thomomys mazama*	Mazama pocket gopher	95	MAMMAL	NOCT	TERR

2.2.3 Fine-Scale Relief

“Fine-scale relief" was calculated for all owl locations, based on the surface area and the planar area of a standard 800 m circle (hereafter referred to as “core” area; USDI FWS 2008) surrounding each owl location. The 800 m core size was based on NSO telemetry studies and landscape occupancy models (USDI FWS et al. 2008).The surface area was calculated using the core area projected on a 10m DEM (1/3 arc second) and rounded to the nearest integer [Integer (surface area + 0.5)]. This study defined fine-scale relief as the percent difference of the surface area over the planar area, which is similar to rugosity. Rugosity or surface roughness is calculated by taking the ratio of the surface area to planar surface (Jenness 2003), but for the purposes of this study that value was too cumbersome. Fine-scale relief is also a measure of surface roughness, simply, the amount of up-and-downiness within an owl site. High fine-scale relief could indicate a steep, deeply wrinkled core that pitches the forest floor up into the canopy. The effect provides greater surface area within the standard planar area possibly harboring greater densities of prey while making terrestrial prey more available to owls by bringing the forest floor up towards the tree tops. Low fine-scale relief could indicate a relatively flat core which usually occurs in owl sites of two types: high elevation flat areas or sites close to wide rivers and streams. Fine-scale relief would be low in owl sites with wide rivers and streams because a portion of the core includes the river or stream bed. Calculated values of fine-scale relief could range from 0 to 100%, where 0 is a perfectly flat surface and 100 is a surface whose area is twice that of the plane on which it is projected. Calculated values of fine-scale relief were small in this study and ranged from 0.5995% to 0.8393%. Fine-scale relief was used in logistic regression and community analysis.

$$Fine - Scale\ Relief = \frac{(surface\ area - planar\ area)}{planar\ area} * 100\%$$

2.2.4 Community Analysis

Direct gradient analysis is used to describe the prey community according to measurements of environmental factors within the owl core (McCune and Grace 2002) and requires two matrices: species matrix (primary) and environmental matrix (secondary). The species matrix was composed of key prey counts (natural log transformation) for 114 owl sites. The environmental matrix consisted of 16 quantitative and categorical variables based on remotely sensed data (GLOVIS 2010) and Gradient Nearest Neighbor (LEMMA IMAP 2005) data. These data were used to describe NSO prey species distributions and patterns of NSO prey communities in relation to environmental gradients and factors within and across watershed groups. In order to distill 22 years of data into one location and derive the appropriate set of environmental variables in both space and time, a single “ideal” location for each site (n = 114) was identified based on year and the owl location when and where the greatest number of prey items was collected. This was important for owl sites that have been altered by harvest or wildfire, where prey communities could be erroneously associated with harvested stands (i.e. sites: Upper Smith, Smith River, Upper Kink Creek, and Lost Lake). The ideal location was buffered at the standard core area. The core was used to calculate an estimate of fine-scale relief, the percentage of the circle in each of four stand age categories, and five tree species categories. The stand age categories were grouped using pre-defined tree size classes (LEMMA IMAP 2005): non-forest (reservoirs and highways, but not lava flows), regenerating stand (2.5-25 cm), young (25-37.5 cm), mature (37.5-50 cm), and old (>50 cm). Defining more than four broad classes for forested habitat would degrade map accuracies (Cohen et al. 1995). A ten-meter Digital Elevation Model (USGS NED 2009) was used to derive elevation and main-stem stream orientation. These data were used for the environmental (second) matrix in Nonmetric Multidimensional Scaling. See Appendix F for details surrounding environmental matrices.

2.3. Statistical Analyses

2.3.1. Univariate statistics

Owl location data (whether or not pellet data were collected at this location) was used to define the spatial pattern (whether clustered, dispersed, or random), scale of spatial pattern, and mean nearest neighbor distance for each year from 1988-2009. The Welch's two-sample t-test was used to determine if there was a difference in mean nearest neighbor distance among watershed groups. All analyses performed in R version 2.10.1 (2009-12-14).

The G-function helps to determine the spatial pattern of owl locations; patterns are either Poisson (random) or dependent. Dependent owl locations exhibit an interaction and can be either clustered or dispersed (Baddeley and Turner 2005). The owl locations were confined to an approximately rectangular window to reduce edge effects. The G-function was used (R: spatstat) to define the cumulative distribution function of the nearest-neighbor distance for typical owl locations in the dataset for each year from 1988-2009. Goodness-of-fit was tested using Monte Carlo methods based on 39 simulations to create a 95% simulation envelope. Observed values ($\hat{G}$(r)) of $\hat{G}$(r) > G_{pois}(r) indicate that nearest neighbor distances in the point pattern were shorter than for a Poisson process (G_{pois}(r); random), suggesting a clustered pattern (above the envelope); while values of $\hat{G}(r)$ < G_{pois}(r) suggest a dispersed pattern (below the envelope) (Baddeley and Turner 2005). Years where observed values fell within the 95% simulation envelope were not included in mean nearest neighbor analysis because locations were determined to be no better than randomly located. Ecologically, years with random owl location patterns suggest that more owl locations can fit within the defined window during that year and the study for that year was under-sampled. Those years were excluded from further analysis. The resulting graphs were also used to determine the scale at which the pattern occurs. Although summary statistics such as the G-function were intended for exploratory purposes, it is also possible to use them as a basis for statistical inference (Baddeley and Turner 2005).

The nearest neighbor distance was determined by calculating the distance between an owl location and its closest neighbor in space using owl locations each year from 1988-2009. Nearest neighbor analysis was used to determine (1) how closely owl territories were spaced to one another, and (2) if there is a difference in mean nearest neighbor distance among selected watershed groups. The spatstat package (Baddeley and Turner 2005) in R was used to determine nearest neighbor distance for each owl territory independent of nest status in space for each year, 1988-2009. The analysis was repeated for three selected watershed groups that were chosen based on number of consistent owl territories (> 20 locations on average) and shape (rectangular) to reduce edge effects. These groups were Blue River, Fall Creek, and Upper McKenzie. For the purposes of this analysis, Lower McKenzie was omitted because it exhibits edge effects that could not be circumvented. For example: the nearest neighbor in Boone Creek is Slide Creek which is located in the South Fork of the McKenzie and O'Leary Mountain's nearest neighbor is Horsepasture Mountain which is located in East South Fork of the McKenzie. Furthermore, in the Lower McKenzie the McKenzie River channel would create disproportionately large nearest neighbor distances. Welch's t-test was used to determine if the mean nearest neighbor distances are different among selected watershed groups.

2.3.2. Bivariate statistics

Owl pair density, defined as the number of owl pairs per square km^2, was calculated for selected watersheds by year, and for the entire study period. The HJA is a territorial study area (TSA), therefore, it is sufficient in a TSA to visit historic site centers (historic nest trees and locations) and systematically survey from there. One major concern is that all territorial owl pairs may not be found within the watershed group. However, this bias is understood to be similar across years and all watershed groups (except ESMK due to high elevation). A one-way analysis of variance was used to test differences between mean owl pair density (natural log transformed) among watersheds. Watershed groups were selected based on consistent annual survey effort and mean count of owl pairs located (>8 pairs) over the study period 1988-2009. The selected watershed groups were: Blue River, South Fork McKenzie River, Upper McKenzie River, and Fall Creek. Lower McKenzie was omitted based on presence of the wide McKenzie River, which is non-habitat, and discontinuous survey effort. The number of owl pairs in selected watershed groups was tabulated for a given year and divided by the surface area of the defined watershed group.

Occurrences (presence/absence) of key prey species at owl sites (dependent variable) using pooled sample data from 1988-2009 were related to landscape gradients (dependent variables: easting, northing, fine-scale relief, elevation) using logistic regression. Logistic regression (special case of generalized linear model using the "logit" link function in R) is a probability model in which the mean of a response (π) is related to explanatory variables through a non-linear regression equation and assumptions of linear statistics such as normality, linearity, and equal variance do not apply (Ramsey and Schafer 2002). The binary responses for key prey at each site may have different detection probabilities which can cause overdispersion or extra-binomial variation (Ramsey and Schafer 2002), and testing each site for consistent detection probabilities was not possible because small mammal survey data was unavailable for prey species across the HJA. Overdispersion was apparent for pocket gophers and quasibinomial models were used to account for overdispersion by increasing standard error estimates (R MASS library) (Ramsey and Schafer 2002). Of the 13 key prey, only 4 were statistically significant with landscape gradients: red tree voles, pocket gopher, bushy-tailed woodrat, and rabbits/hares. The same model (lowest AIC values) (Ramsey and Schafer 2002) shows the fit of a logistic regression model to the red tree vole, pocket gopher, and bushy-tailed woodrat, where π represents the probability of prey presence:

$$logit\ (\pi) = \ \beta_0 + \beta_1(elevation) + \beta_2\ (fine - scale\ relief)$$

The model with the lowest AIC for rabbits/hares included only fine-scale relief.

2.3.3. Multivariate statistics

In order to determine if the communities of 13 key prey differed within and among watershed groups, Multi-response Permutation Procedure (MRPP) was performed using the Sørensen (Bray-Curtis) distance measure (statistical package: PC-ORD 5.19). The Sørensen (Bray-Curtis) distance measure is found to be appropriate with ecological data because it produces near-linear ordination results compared to absolute Euclidean, city-block distance, correlation, the Jaccard coefficient, Malhalanobis' D (Beals 1984). Samples were coded by watershed group (Figure 2.1). Statistical significance of MRPP analyses was determined with a p-value and an A-statistic. The p-value assesses how likely it is that an observed difference is due to chance. The agreement statistic, *A*, describes within group homogeneity or “effect size”, compared to the random expectation (McCune and Grace 2002). When all items were identical within groups the A-statistic equals one, the highest possible value for $A = 1$. If heterogeneity within groups equals expectation due to chance, then $A = 0$. In community ecology values for *A* are commonly below 0.1, while a value of > 0.2 is considered high (McCune and Grace 2002).

To describe the pattern of prey communities within owl sites, Nonmetric Multidimensional Scaling (NMS) was performed using PC-ORD 2.19. I used NMS ordination to analyze pellet samples because this approach is well suited to data that are non-normal, arbitrary, discontinuous or otherwise of questionable scales (McCune and Grace 2002). Pellet data are considered: non-normal because prey are counts (left-skewed), arbitrary due to pellet collection effort through space and time, and questionable scales because each prey experiences the landscape at a different scale, although viewed through the coarse scale experienced by NSO (owl core). Sørensen (Bray-Curtis) distance measure was used to describe owl prey communities because it produces near-linear ordination results compared to others stated previously using landscape gradients and vegetation characteristics (Beals 1984).

3. RESULTS

3.1. Overview of owl prey in pellets

Flying squirrels were the most abundant large prey (body mass > 100g), with pocket gophers, bushy-tailed woodrats, rabbits/hares, and pika the next most abundant large prey (Table 3.1.1). In general, small prey (body mass <100g) contributed relatively little to the overall proportion of biomass found in pellets, although some species occurred at high abundances (i.e., voles and deer-mice; Table 3.1.1). Prey density maps of selected key prey are in Appendix I and show the spatial distribution of pooled counts of prey at each owl site from 1988-2009.

Table 3.1.1: List of prey species identified in pellet samples (n=4183) for 114 owl territories collected from 1988 – 2009 at HJ Andrews. The activity zone, abundance, estimated mass, total biomass (abundance* estimated mass), percent abundance, and percent estimated biomass included for each species. Key prey were identified with an *. Note: this is a combined list, although 63 species groups were identified animals such as birds, bats, and insects were combined.

Prey	Zone	abundance	Mass (g)	Biomass	% abundance	% Biomass
Bats	AERI	13	10	122	0.3	0.0
Birds	AERI	138	8-600	10419	3.3	2.4
Chipmunks*	SCAN	67	83	5561	1.6	1.3
Creeping Vole*	TERR	58	20	1160	1.4	0.3
Deer Mice*	TERR	125	22	2946	3.0	0.7
Douglas Squirrel	SCAN	13	221	2873	0.3	0.7
Flying Squirrel*	ARBO	1847	130	241174	44.2	55.0
Great Grig (insect)*	SCAN	58	2	137	1.4	0.0
Ground Squirrel	TERR	1	169	169	0.0	0.0
Insects	LZUN	23	0.2-1	54	0.5	0.0
Microtus sp.	TERR	24	30	1224	0.6	0.3
Moles*	TERR	40	56	2240	1.0	0.5
Mountain Beaver	TERR	4	100-550	1400	0.1	0.3
Mustelids	TERR	12	55	660	0.3	0.2
Pika*	TERR	50	171	8550	1.2	2.0
Pocket Gopher*	TERR	253	95	23980	6.0	5.5
Rabbits/hares*	TERR	170	50-1400	54855	4.1	12.5
Red Tree Vole*	ARBO	272	26	7072	6.5	1.6
Red-backed vole*	TERR	533	23	12256	12.7	2.8
Shrew mole	TERR	7	9	63	0.2	0.0
Shrews*	TERR	67	5	431	1.6	0.1
Unknown Mice	TERR	17	37	638	0.4	0.1
Unknown Vole	LZUN	126	20	3160	3.0	0.7
Unknown Vole/Mouse	LZUN	67	20	1376	1.6	0.3
Bushy-tailed Woodrat*	SCAN	198	284	55739	4.7	12.7
Total		4183		438259	100.0	100.0

3.2. Differences in key prey by watershed

Abundance and biomass of key prey (n=3746) in owl pellets varied among watershed groups. Flying squirrel biomass ranged from a minimum of 48% in Lower McKenzie to a maximum of 75% in Fall Creek (Tables 3.2.1 and 3.2.2). Biomass of rabbits/hares ranged from a minimum of 3% in Fall Creek to a maximum of 16% in Lower McKenzie. Biomass of woodrats ranged from a minimum of 6% in East South Fork and South Fork McKenzie to a maximum of 22% in Lower McKenzie and South Santiam. Biomass of pocket gopher ranged from a minimum of 0% in Fall Creek to a maximum of 11% in East South Fork and South Fork McKenzie (Table 3.2.2).

Table 3.2.1: Percent of key prey (n=3746) abundance in diets of NSO in HJA study area and 8 watershed groups, 1988-2009 with sample size (number of owl territories with ≥10 prey items) in parentheses. Key prey were species that occur in at least 10% of owl territories, comprise 90% of the abundance, and 95% of estimated biomass. HJA is the average**.**

Key Prey	**BLUE (23)**	**ESMK (6)**	**FALL (19)**	**LMKR (17)**	**NMWI (4)**	**SFMK (11)**	**SSAN (7)**	**UMKR (27)**	**HJA (114)**
Red tree vole	10	1	27	7	4	5	0	1	7
Great Grig	0	5	0	2	3	1	2	3	2
Flying squirrel	47	46	53	44	64	47	50	50	49
Rabbits/hares	5	2	0	6	5	4	7	5	5
Creeping vole	1	4	0	3	1	2	0	2	2
Moles	1	1	1	1	2	1	1	1	1
Red-backed vole	18	16	8	12	8	18	16	13	14
Woodrat	5	2	3	9	7	5	10	3	5
Pika	1	1	1	1	0	1	2	2	1
Deer Mice	3	7	3	6	2	3	2	3	3
Shrews	1	1	2	1	2	1	0	3	2
Chipmunks	2	2	2	2	0	2	0	2	2
Pocket gophers	4	11	0	6	2	9	8	11	7

Table 3.2. 2: Percent estimated biomass of key prey (n=3746) in diets of NSO in HJA study area and 8 watershed groups, 1988-2009. Sample size (number of owl territories with ≥10 prey items) is in parentheses. Key prey were species that occur in at least 10% of owl territories, comprise 90% of the abundance, and 95% of estimated biomass. HJA is the average.

Key Prey	BLUE (23)	ESMK (6)	FALL (19)	LMKR (17)	NMWI (4)	SFMK (11)	SSAN (7)	UMKR (27)	HJA (114)
Red tree vole	2	0	8	2	1	0	0	0	2
Great Grig	0	0	0	0	0	0	0	0	0
N. flying squirrel	57	60	75	48	68	60	51	60	58
Rabbits/hares	15	13	3	16	12	13	15	13	13
Creeping vole	0	1	0	1	0	1	0	0	0
Moles	1	0	0	0	0	0	0	1	1
W. red-backed vole	4	4	2	2	2	4	3	3	3
Woodrat	14	6	8	22	16	6	22	8	13
Pika	1	2	1	2	0	2	3	3	2
Deer Mice	1	1	1	1	0	1	0	1	1
Shrews	0	0	0	0	0	0	0	0	0
Chipmunks	2	2	2	1	0	2	0	1	1
Pocket gophers	3	11	0	5	1	11	6	10	6

The activity zone of key prey species (i.e., aerial, arboreal, scansorial, terrestrial, and unknown) also varied among watersheds (Table 3.2.3). Although prey in all watersheds were dominated by arboreal prey (≥48%), the abundance of scansorial and terrestrial prey varied markedly among watersheds (Table 3.2.2). Abundance and biomass of arboreal prey were greatest in Fall Creek (76% of individuals and 70% of biomass), while both the Upper McKenzie and South Fork of the McKenzie had similar proportions (45% of individuals and 56% of the biomass; 47% of individuals and 53% of the biomass, respectively). Abundance and biomass of scansorial prey ranged from a minimum of 9% of individuals and 4% of biomass in Fall Creek to a maximum of 12% of individuals and 23% of biomass Lower McKenzie (LMKR). Abundance and biomass of terrestrial prey ranged from a minimum of 10% of individuals and 16% of biomass in Fall Creek to a maximum of 30% of individuals and 39% of biomass Upper McKenzie. Aerial prey (birds and bats) comprise only 1-4% of the total biomass. Prey with unknown activity zones comprises only 1-2% of the total biomass and were represented by unidentified voles, mice, and insects.

Table 3.2.3: Percent biomass and abundance of all prey (n=4183) by activity zone (aerial, arboreal, scansorial, terrestrial) in diets of NSO in HJA study area and 8 watershed groups, 1988-2009. Sample size (number of owl territories with ≥10 prey items) is in parentheses. Values contributed by the unknown activity zone (Zone unknown) were from unidentified voles and insects.

	BLUE (23)	**ESMK (6)**	**FALL (19)**	**LMKR (17)**	**NMWI (4)**	**SFMK (11)**	**SSAN (7)**	**UMKR (27)**	**HJA (114)**
% Biomass									
Aerial	2	2	3	2	1	2	3	4	3
Arboreal	58	59	76	48	67	53	49	56	57
Scansorial	15	7	9	23	15	14	21	9	14
Terrestrial	24	30	10	26	16	30	26	30	25
Zone Unk.	1	2	2	1	1	1	1	1	1
Sum	100	100	100	100	100	100	100	100	100
% Abundance									
Aerial	4	7	4	3	3	3	3	5	4
Arboreal	53	43	70	47	60	47	46	45	51
Scansorial	7	8	4	12	9	8	12	7	8
Terrestrial	32	36	16	32	21	37	35	39	32
Zone Unk.	4	6	6	6	7	5	4	4	5
Sum	100	100	100	100	100	100	100	100	100

3.3. Spatial and Temporal Patterns of Owl Territories

3.3.1. Spatial Patterns of Owl Territories

Owl locations for 1990 – 2009 exhibited a significantly dispersed pattern with a minimum average distance of 1.5 km; however there was no pattern for the years 1988-1989 (Table 3.3.1) indicating that owl pair locations during that period were random. In two years (1997 and 2002) the pattern of dispersion occurred at two scales; a smaller scale (0.5-2 km) and a larger scale (2.9-4 km). At a watershed group level, the sample sizes were too small to evaluate the scale of pattern using the G-function (Table 3.3.1).

Table 3.3.1: Scale of significant dispersed point patterns in best owl location sites by year determined using the G-function ($p < 0.05$).

Year	# Nesting	# Locations	All
1988	35	63	No pattern evident
1989	17	73	No pattern evident
1990	58	99	0.9-1.4 km
1991	23	100	0.8-1.8 km
1992	75	99	1.1-1.5 km
1993	3	88	0.8-1.5 km
1994	33	80	1.0-2.1 km
1995	11	78	0.9-1.8km
1996	52	72	0.9-1.8 km
1997	20	85	1.1-1.7 km 2.9-3.1 km
1998	51	107	1.2-3.2 km
1999	16	97	0.8-2.2 km
2000	44	96	0.9-1.8 km
2001	52	101	1.1-2.6 km
2002	45	94	0.9-2km 3-4 km
2003	15	95	1.1-2.5 km
2004	70	99	1.5-2.5 km
2005	20	95	1.0-2 km
2006	15	88	1.2-2 km
2007	40	93	1.7-2.8 km
2008	30	83	1.1-1.5 km
2009	16	86	1.0-2.0 km

The distances between owl locations were measured each year except 1988-1989 because those years were found by the g-function to be no better than randomly located (Table 3.3.2). The mean nearest neighbor distances differed significantly among three watershed groups (Table 3.3.3). Mean nearest neighbor distances in Upper McKenzie were 0.938 km larger than in Blue River (1988-2009) (Welch's two-sample test, 95% confidence interval 0.730 to 1.146 km, p-value <<0.001) and 1.207 km larger than owl territories in Fall Creek (2000-2009) (Welch's two-sample test, 95% confidence interval 0.990 to 1.426 km, p-value<<0.001). The significant differences in mean nearest neighbor distances among Blue River and Upper McKenzie were consistent with the minimum scale of dispersed pattern found at two scales of owl locations for 1997 and 2002 using with the g-function.

Table 3.3.2: The average nearest neighbor distance for three watersheds (Blue River, Fall Creek, and Upper McKenzie River) and two time periods (1990-2009, 2000-2009) within the HJ Andrews owl demography study area. Of the eight watersheds in the study area, only these three had sufficiently low edge effects and adequate sample size for point pattern analysis.

WSHED GROUP	Average 1990-2009	ST DEV	Average 2000-2009	ST DEV
All	2.61 km	0.148	2.58 km	0.066
Blue River	2.10 km	0.217	2.22 km	0.164
Upper McKenzie	3.04 km	0.400	3.33 km	0.267
Fall Creek	-	-	2.13 km	0.186

Table 3.3.3: Significance of the difference in average nearest-neighbor distance between owl locations in three watersheds: Blue River, Fall Creek, and upper McKenzie River, results of the Welch two-sample t-test with 95% confidence interval (CI 95%) and p-value.

Comparisons	Estimated Diff	CI 95%	p-value
BLUE—UMKR	- 0.938 km	- 0.730 to - 1.146 km	<0.001
BLUE—FALL (2000-2009)	not significant		0.583
FALL—UMKR (2000-2009)	-1.207 km	-0.990 to -1.426 km	<0.001

Blue River had the highest mean owl pair density (0.080 owl pairs/km^2) compared to South Fork McKenzie (0.056 owl pairs/km^2) and Upper McKenzie (0.047 owl pairs/km^2) over the period 1990-2009 (Appendix E). For 2000-2009, owl pair density declined in Blue River but remained higher (0.071 owl pairs/km^2) than Fall Creek (0.055 owl pairs/km^2), South Fork McKenzie (0.055 owl pairs/km^2) and Upper McKenzie (0.039 owl pairs/km^2) (Appendix E).

Owl pair densities (natural log transformed) were significantly different among watershed groups (one-way ANOVA; $F_{3,66}$ =23.9, p-value<<0.001) (Table 3.3.4). Mean owl pair densities in Blue River (BLUE) were larger than Fall Creek (FALL), South Fork McKenzie (SFMK) (0.024 owl pairs/km^2), and Upper McKenzie (UMKR) (0.033 owl pairs/km^2) after accounting for pair-wise comparisons using Tukey HSD.

Table 3.3.4: Significance of the difference in mean (untransformed) owl pair density between owl locations in four watersheds: Blue River, Fall Creek, South Fork McKenzie, and Upper McKenzie River. Results of the one-way ANOVA ; $F_{3,66}$ =23.9, with 95% confidence interval (CI 95%) and p-value.

Comparison	Estimated Diff	CI 95%	p-value
FALL-BLUE	-0.024	-0.037 to -0.012	0.0000229
SFMK-BLUE	-0.024	-0.035 to -0.014	0.0000003
UMKR-BLUE	-0.033	-0.043 to -0.023	<<0.0001
SFMK-FALL	0.000	Not significant	0.9999743
UMKR-FALL	-0.009	Not significant	0.2828375
UMKR-SFMK	-0.009	Not significant	0.1195043

3.3.2. Temporal Patterns of Nesting Pairs

The number of nesting owl pairs in any given year was significantly negatively autocorrelated with the number of nesting owl pairs in the previous year; in other words, pairs that nested in the current year, generally did not nest the previous year, but may have nested two years before (Table 3.3.5). This biennial nesting cycle was significant in Blue River, South Fork of the McKenzie River, and Upper McKenzie watersheds, but not in Fall Creek and Lower McKenzie River (Table 3.3.5; Appendix A).

Table 3.3.5: Autocorrelation coefficients (Appendix A), correlation values that exceed +/- 0.426 were considered significant, p-value <0.05).

Watershed Group	Correlation	Years
All (no FALL, NMWI)	-0.573	22
BLUE	-0.465	22
ESMK	-0.237	22
FALL	0.200	10
LMKR	-0.326	22
SFMK	-0.657	22
SSAN	-0.157	22
UMKR	-0.489	22

3.4 Owl Prey and Landscape Characteristics

3.4.1. Owl prey distribution by elevation and fine-scale relief

The occurrence of red tree voles decreased, and the occurrence of pocket gophers increased in owl pellet samples as elevation increased and fine-scale relief decreased (Figure 3.4.1). For every 100m of increase in elevation, when fine-scale relief was held fixed, the odds of encountering red tree vole in owl pellets changed by a factor of 0.73352, ($p < 0.004$) and the odds of encountering pocket gophers in owl pellets changed by a factor of 1.74 ($p < 0.0006$). Similarly, for each increase of 0.01% in fine-scale relief, the odds of encountering red tree vole in owl pellets changes by a factor of 1.12, when elevation is held fixed (p-value <0.0007), and the odds of encountering pocket gophers in owl pellets changes by a factor of 0.93 ($p < 0.061$). The occurrence of bushy-tailed woodrats also was moderately related to elevation and fine-scale relief: for each 100-m increase in elevation the odds of encountering bushy-tailed woodrats in owl pellets changes by a factor of 0.8304, when fine-scale relief is held fixed ($p < 0.0519$) (Figure 3.4.1). For each 0.01% increase in fine-scale relief the odds of encountering woodrats in pellets changes by a factor of 0.95 (p-value<0.088) when elevation is held fixed. The odds of encountering rabbits/hares change with each 0.01% increase in fine-scale relief by a factor of 0.91 (p-value<0.0016) (Figure 3.5.2). Distributions of prey abundances by elevation and fine-scale relief were shown in Appendix C and Appendix D, respectively.

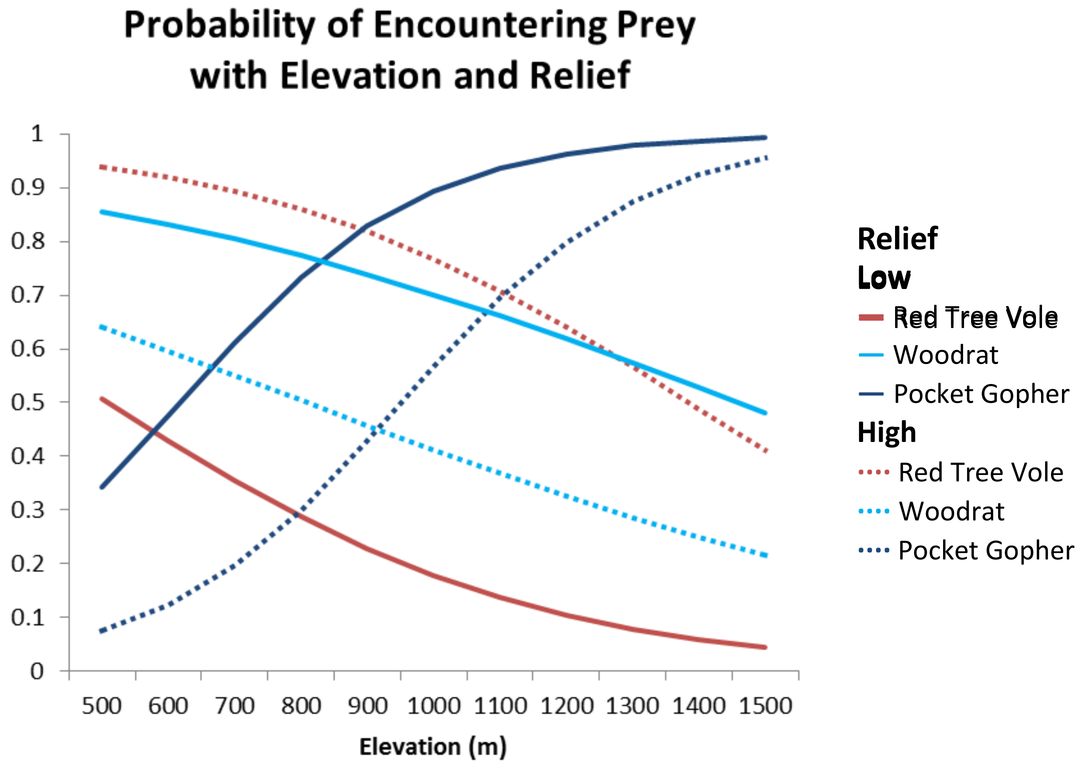


Figure 3.4. 1: Probability of encountering red tree voles, woodrats, and pocket gophers in owl pellets as a function of elevation and fine-scale relief based on logistic regression. Data were pooled for 1988-2009 with n=114.

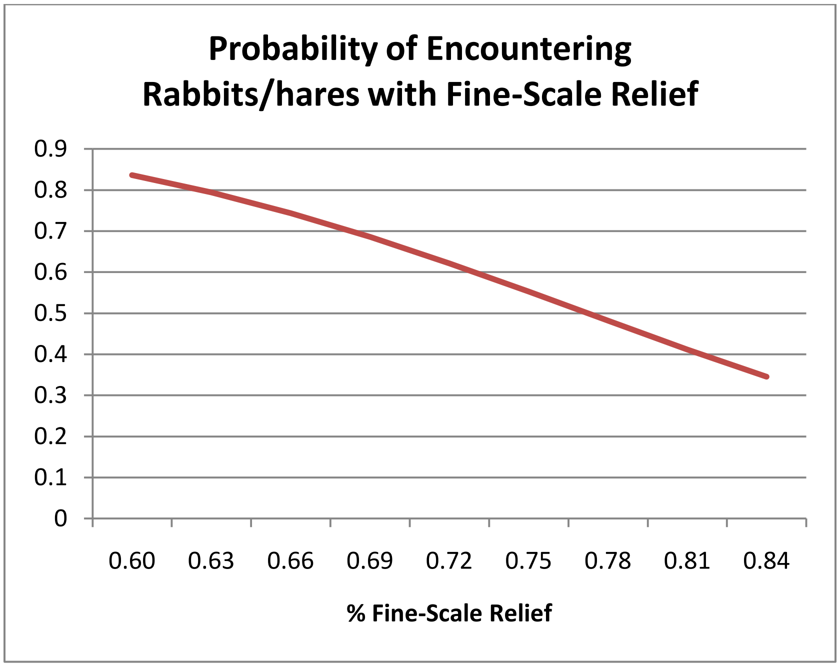


Figure 3.4. 2: Probability of encountering rabbits/hares in owl pellets as a function of fine-scale relief based on logistic regression. Data were pooled for 1988-2009 with n=114.

Owl prey occurrences also were significantly related to easting for red tree voles (p-value < 0.001), great grig (p-value < 0.015), rabbits/hares (p-value < 0.001), pika (p-value < 0.005), creeping vole (p-value < 0.046), and pocket gopher (p-value < 0.001) (Figure B.1-B.4, Appendix B).

3.5. Patterns of Prey Communities

Prey communities differed among watershed groups (A=0.2021, p-value<< 0.0001) with Fall Creek strongly differing from Upper McKenzie (A = 0.3628, p-value << 0.0001), South Fork McKenzie (A = 0.2630, p-value << 0.0001), East South Fork of the McKenzie (A = 0.1987, p-value << 0.0001), and South Santiam (A = 0.2718, p-value << 0.0001) (Appendix G). However, the differences between Fall Creek and South Santiam were potentially artificial. Owl sites with insufficient sample size in the South Santiam such as House Rock and East Gordon Meadows which occurred west and in low elevations had red tree voles present. Fall Creek also differed from its adjacent watershed group, North Middle Fork of the Willamette (A = 0.1320, p-value < 0.0003), but prey communities among Blue River, NM Willamette, SF McKenzie, and Lower McKenzie were no different than expected by chance (Appendix G).

A non-metric multidimensional scaling (NMS) ordination of 13 key prey by 114 owl sites converged on a stable, 3-dimensional solution (final stress=18.29, final instability =0.00000, iterations = 99) (Figure 3.5.1). A Monte Carlo test confirmed a similar final stress would not likely occur by chance (p-value < 0.004). The structure of the ordination was driven by strong associations of pocket gophers (Appendix H: Figure H.1) and rabbits/hares (Appendix H: Figure H.2) with owl sites that were east, low fine-scale relief, and high elevation. The pattern was also driven by strong associations of red tree voles in owl sites that were west, high fine-scale relief, relatively high percent of maple/alder forest, and low elevation (Appendix H: Figure H.3). High percentages of maple/alder forest (0.4 – 4.4% dominant trees within core) explained 23.5 % of the variation in Axis 1, because this forest type was found only in owl sites that were west and at lower elevations. The proportions of mature (r^2= 0.010; Axis 2), and old growth (r^2= 0; all axes), forest did not explain the ordination of owl sites because high proportions occurred in all sites and watershed groups. The average proportion of old growth and mature forest within owl sites ranged from 53 to 64% and 7.5 to 11.7 %, respectively. Similarly, the proportion of Douglas fir as a dominant tree species did not explain the ordination of owl sites (r^2 = 0.048; Axis 1) and average proportions of Douglas fir trees ranged from 87.4 % in Upper McKenzie to 98.6 % in Fall Creek.

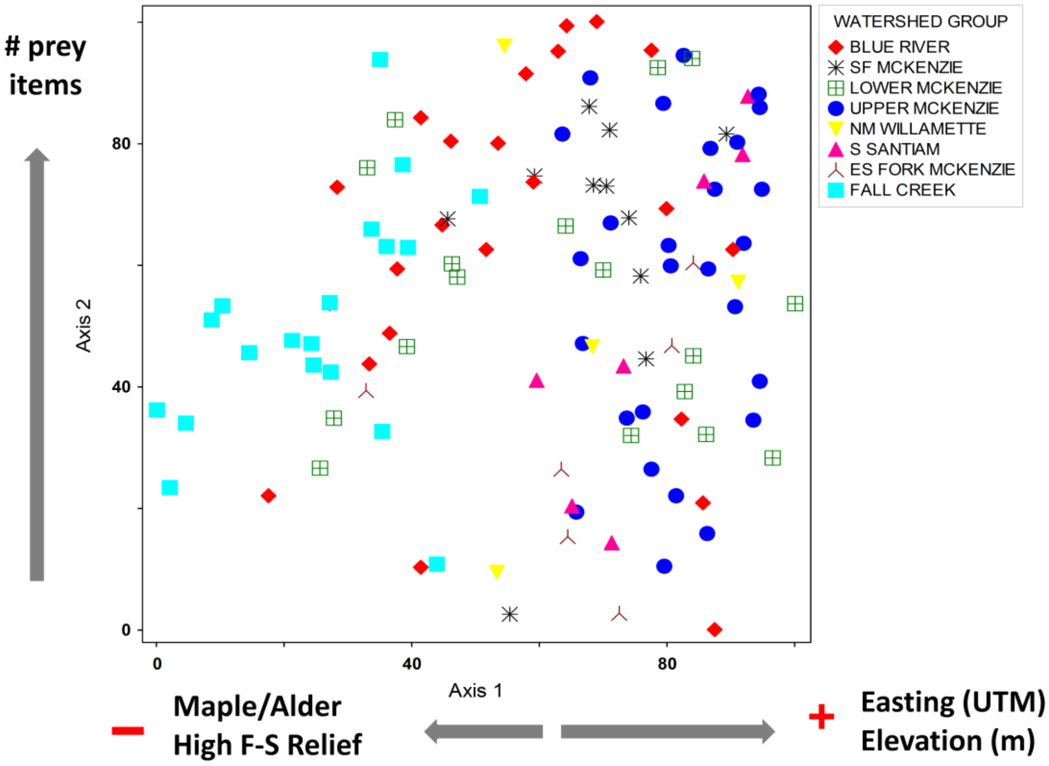


Figure 3.5. 1: Nonmetric multidimensional scaling analysis; each symbol represents an owl site (n=114) in species space. Owl sites close together have similar prey communities than owl sites farther away in species space. Prey communities within sites were positively correlated to easting and elevation and negatively correlated with fine-scale relief and percent maple/red alder forest (Axis 1). Axis 2 was correlated to sample size. Colored symbols were based on eight categorical watershed groups.

Pearson and Kendall correlations were examined for each axis. Axis 1, which accounted for the majority of variation in the NMS (r^2= 0.362), was correlated with easting (r^2 = 0.515) and less so with fine-scale relief (r^2 = 0.254), percent of maple/alder forest (r^2 = 0.235), and elevation (r^2 = 0.226). Axis 2 accounted for less variation (r^2 = 0.197) and was driven by unidentified environmental factors, but upon close inspection of the ordination of owl sites the arrangement appears to be positively related to sample size. Ordination was sensitive to the range of values created by log transformation of counts. Flying squirrels and red-backed voles showed strong associations with the Axis 2 (r^2 = 0.622 and 0.458, respectively). The third axis accounted for less variation (r^2 = 0.158) and was driven by unidentified factors. (Figure: 3.5.1)

Table 3.5. 1: Pearson and Kendall Correlations with ordination axes, n=114 with key prey matrix. Strong correlations are bold.

Axis:	**1**			**2**			**3**		
	R	R^2	τ	R	R^2	τ	R	R^2	τ
Red Tree Vole	**-0.670**	0.449	-0.535	0.414	0.172	0.301	0.137	0.019	0.124
Great Grig	0.267	0.071	0.272	0.243	0.059	0.219	-0.117	0.014	-0.119
Flying Squirrel	0.185	0.034	0.102	**0.789**	0.622	0.631	0.079	0.006	0.061
Rabbits/hares	**0.603**	0.364	0.471	0.457	0.209	0.339	0.074	0.005	0.059
Creeping Vole	0.394	0.155	0.316	0.308	0.095	0.229	-0.114	0.013	-0.084
Moles	0.189	0.036	0.125	0.038	0.001	-0.019	0.122	0.015	0.064
Red-backed Vole	0.345	0.119	0.232	**0.677**	0.458	0.514	-0.104	0.011	-0.083
Woodrat	0.295	0.087	0.186	0.294	0.086	0.205	**0.715**	0.511	0.594
Pika	0.390	0.152	0.321	**0.533**	0.285	0.46	0.136	0.018	0.075
Deer Mice	0.174	0.030	0.114	0.420	0.176	0.313	-0.064	0.004	-0.055
Shrews	0.184	0.034	0.139	0.209	0.044	0.151	0.104	0.011	0.076
Chipmunks	0.141	0.020	0.079	0.325	0.106	0.237	0.116	0.013	0.069
Pocket Gopher	**0.726**	0.527	0.575	0.297	0.088	0.216	-0.339	0.115	-0.256

Table 3.5. 2: Pearson and Kendall Correlations with Ordination axes, n=114 with environmental matrix (second matrix): elevation (ELEVM), easting (UTMX), northing (UTMY), tree size categories (REG, YOUNG, MAT, OLD), dominant tree species categories (Douglas fir (PSME), maple/alder (MAP/AL), western hemlock and red alder (HE-RED), unidentified dominant (REGEN), incense cedar and chinquapin (DRY), high coniferous forest (HICON)), mainstem stream aspect, and fine-scale relief.

Axis:	**1**			**2**			**3**		
	R	R^2	τ	R	R^2	τ	R	R^2	τ
ELEVM	**0.475**	0.226	0.305	-0.024	0.001	-0.003	-0.350	0.123	-0.240
UTMX	**0.718**	0.515	0.498	0.029	0.001	0.024	-0.199	0.040	-0.175
UTMY	**0.477**	0.228	0.321	0.004	0	0.008	-0.022	0	-0.009
REG	0.072	0.005	0.039	-0.081	0.007	-0.046	-0.112	0.013	-0.082
YOUNG	-0.246	0.060	-0.219	0.110	0.012	0.050	0.133	0.018	0.074
MAT	-0.077	0.006	-0.056	0.102	0.010	0.064	-0.094	0.009	-0.008
OLD	0.007	0	0.015	0.018	0	0.021	0.016	0	0.011
PSME	-0.219	0.048	-0.134	0.014	0	-0.004	0.115	0.013	0.078
MAP/AL	**-0.485**	0.235	-0.323	0.065	0.004	0.012	0.283	0.080	0.192
HE-RED	0.011	0	0.014	0.126	0.016	0.097	-0.105	0.011	-0.058
REGEN	0.336	0.113	0.260	-0.120	0.014	-0.012	-0.310	0.096	-0.220
DRY	-0.383	0.147	-0.297	0.023	0.001	0.003	0.252	0.063	0.166
HICON	0.338	0.114	0.296	-0.043	0.002	-0.006	-0.223	0.050	-0.222
ASPECT	-0.192	0.037	-0.253	-0.215	0.046	-0.209	0.064	0.004	0.068
RELIEF	**-0.504**	0.254	-0.334	-0.004	0	-0.010	0.035	0.001	0.011

Owl sites within watershed groups separated out in NMS and were grouped into three similarity categories based on relationship to Axis 1: like Fall Creek, like Upper McKenzie, and between (Figure 3.5.1). Owl sites that were “like Fall Creek” were west, had high fine-scale relief, low elevation, had small amounts of dominant maple/alder forests within the core and had prey communities that included red tree voles. Owl sites that were “like Upper McKenzie” were east, had low fine-scale relief, higher elevation, no dominant maple/alder forests within the core and had prey communities that included pocket gophers and rabbits/hares. Sites that were located between Fall Creek (blue squares) and Upper McKenzie (blue circles) were categorized as “between” and have the highest potential for prey species diversity because those sites have moderate elevation, moderate fine-scale relief, and prey communities include the two disparate prey species (red tree voles and pocket gophers). Owl sites defined by NMS were mapped according to similarity (Figure 3.5.2).

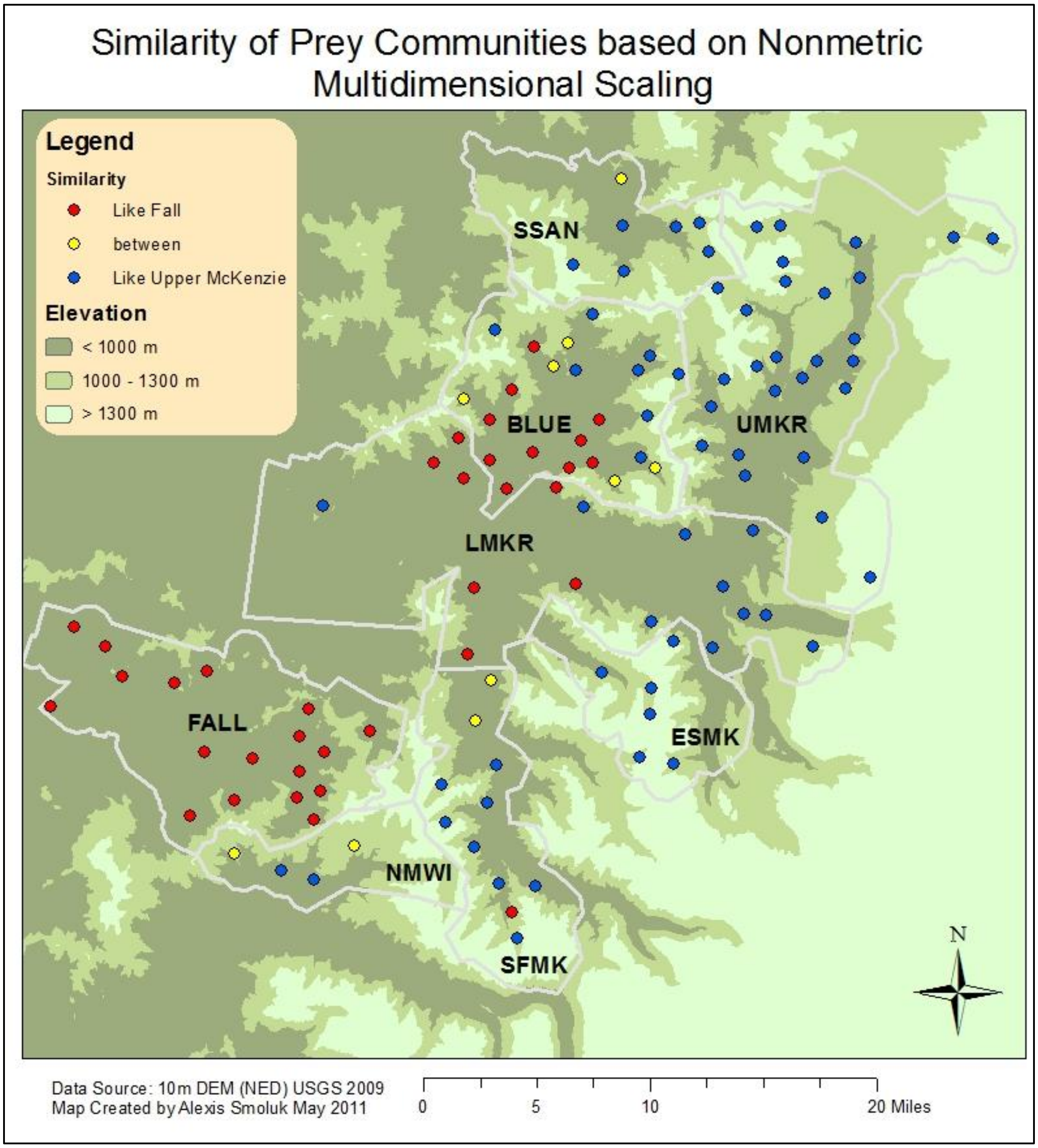


Figure 3.5. 2: From the NMS, three groups were identified: *like FALL, like UMKR,* and *between* the two. All the red dots, which represent *like FALL*, were found in elevations ≤ 1000m. Yellow dots, which represent sites in between, were physically located between red and blue sites. The blue dots, which represent sites like UMKR, were found at higher elevations and east. Two outliers: (1) Chucksney Mountain (red site in SFMK) was like FALL because it had red tree voles and only 1 pocket gopher. (2) Lookout Hagan (blue site, west in LMKR) had no red tree voles or pocket gophers. This site is characterized by single age stands < 100 years old with a small grove of remnant old Douglas fir with complex crowns. This owl pair attempts to nest within this grove, but fail to fledge young.

3.6. Pearson's Correlations with Gradients

Results from Pearson's correlation indicate that owl sites found north and east have low fine-scale relief (r = -0.9986 and -0.548, respectively). Low elevation sites had higher percentages of maple/red alder (r = -0.607) and high fine-scale relief (r = -0.215), while high elevation sites were found east (r = 0.518).

4. DISCUSSION

This study has several limitations. There was no attempt to randomly sample pellets in owl sites and pellet collection effort was decidedly *ad hoc*. Pellets, when collected, were often found under roosts near nest trees. Nesting owl pairs require more site visits to reach protocol (usually > 3 visits), which creates more opportunities for owl pellets to be collected than in non-nesting owl sites that would require 1-3 visits a year. The majority of the prey items (80%) were obtained from nesting pairs; pellets are largely representative of prey that was fed to juveniles by adults. This can further bias the sampling effort toward larger prey and may reflect what owls feed their young, because males are likely to bring larger prey back to nesting females and young (Forsman et al. 2004b). It is likely that small prey were eaten by adults and could be egested anywhere, while large prey were worth the effort to carry back to the young to be egested in the center of activity and found by intrepid surveyors. Considering all the limitations, these data provide valuable insight to what prey species were available to spotted owls given landscape and vegetation characteristics.

Additional factors including land-use practices and survey type could potentially affect differences in nearest neighbor distances and owl pair densities among watersheds. Watersheds included areas occupied by private land (buildings) and other areas of non-habitat such as reservoirs and highways. Density estimates and nearest neighbor distances can be confounded by the HJA's type of survey. The HJA is a territorial study area (TSA) (Anthony et al. 2006), which means that owl territories were surveyed by visiting historic nest locations and expanding search efforts outward in cases where no owls were found. When owls were located near historic nest trees, the survey was stopped. The entire study area was never completely surveyed (under-sampled) each year, which suggests that all territorial owls were not located in a given year. Under-sampling effort of the forest within the HJA was assumed to be the similar between years and among watershed groups. This bias was addressed using the g-function to remove years with obvious random locations (1988-1989).

This study was based on retrospective and observational data. Results were interpreted to evaluate hypotheses about local prey variation in space, and their relationships with spatial distribution of nesting owls.

4.1. **Spatial Gradients in Owl Prey**

Results from the NMS did not find a relationship between the amount of Douglas fir forest, mature and old growth forest, and prey communities.   This was presumably because owl pellets were collected in close proximity to NSO nest trees and not necessarily indicative of the habitat of prey. It has been shown repeatedly that NSO are intimately associated with mature/old growth forest (Forsman et al. 1984, Thomas et al. 1990, Carey et al. 1992, Dugger et al. 2005), therefore all prey collected within the owl's core would also have that association. The amount of mature/old growth forest and percent of Douglas fir as a dominant tree species within owl cores did not change appreciably among owl sites, supporting previous findings that owls in the HJA occupy areas with large amounts of mature/old growth forest (Forsman et al. 1984, Thomas et al. 1990, Carey et al. 1992, Dugger et al. 2005) and Douglas fir as the dominant canopy tree. The dominant tree species group that was correlated with red tree voles was the percentage of maple/red alder forest. Red tree voles are associated with old growth Douglas fir forest as the Douglas fir is their primary food (Forsman et al. 2004a). The correlation between red tree voles and percent of dominant maple/red alder forest can be explained by correlations with landscape gradients. Maple/Red alder as a dominant tree species occurs only in small amounts (0.4 – 4.4 %) within owl cores and was found in owl sites that were west, low in elevation, and high fine-scale relief.   Furthermore, the relationship between old growth forest, pocket gophers, and rabbits/hares is artificial because these prey are associated with open meadows (Wilson and Ruff 1999, Engeman and Witmer 2000).

The abundance of large prey in NSO pellet samples, such as pocket gophers and rabbits/hares was related to landscape characteristics, especially elevation and fine-scale relief. Open meadow mosaics and herb-rich seeps with deep soils that were characteristic of high-elevation vegetation zones and low fine-scale relief may provide ample forage and burrow sites for pocket gophers and rabbits/hares. Pocket gophers have received relatively little attention in studies of spotted owl diet (Thomas et al. 1990, Rosenberg et al. 2003). This study found pocket gophers were an important part of owl diets in sites at relatively high elevation (+900m), and in sites with low fine-scale relief. Pocket gophers contributed 10% of the biomass in owl diets in the Upper McKenzie but 0% in Fall Creek which occurs at lower elevation. Pocket gophers were often found in owl pellets within the same sites as juvenile rabbits/hares. Although rabbits/hares were less abundant in owl pellets, they also tended to occur in sites with low fine-scale relief. Rabbits/hares contributed approximately 13% of the biomass in the spotted owl diet in the study area as a whole, and 16% in Lower McKenzie and South Santiam watersheds. Juvenile brush rabbits and snowshoe hares are available in early spring (Kurta 1995) when owls are nesting. (Appendix I: Figures I.4 and I.8)

Bushy-tailed woodrats were more abundant in owl pellets in sites with low fine-scale relief, but decreased in abundance as elevation increased. While little is known about the density estimates of bushy-tailed woodrats in the HJA (Rosenberg et al. 2003), much is known about their life history. Bushy-tailed woodrats are scansorial (habitually climbing), solitary rodents that prefer old natural forests with wide stream margins (Carey 1995). Areas with wide stream margins and rushing streams occurred in the HJA at lower elevations. Owl sites with bushy-tailed woodrats had wide rivers or streams in portions of the core, which was reflected by relatively low fine-scale relief and moderate to lower elevations. The McKenzie River, White Branch Creek, Lookout Creek, and the South Santiam River had relatively high abundances of woodrats, and these areas provide open riparian habitats, consistent with the habitat preferences of woodrats (Appendix I: Figure I.6). Woodrats contributed approximately 13% of the biomass of owl diet in the study area as a whole, but 22% in Lower McKenzie and South Santiam watersheds. Since information on woodrats in the HJA is lacking (Rosenberg et al. 2003), this information may help biologists gather information on density estimates by using elevation and fine-scale relief to stratify sampling efforts.

Red tree voles were an important part of the spotted owl diet, especially at low elevation sites (Forsman et al. 2004). Results from this study confirmed this finding and suggest that red tree voles were abundant in owl pellets from sites with high fine-scale relief, which were more common at low elevations in the study area. Red tree voles constituted 8% of the biomass of pellets with high fine-scale relief (low-elevation) sites but only 1% at low fine-scale relief (high-elevation) sites. This finding may be explained by the relationship between landform relief, wildfire history, and the abundance of large, old trees that provide owl and red tree vole habitat. Red tree voles are associated with old forests (Corn and Bury 1986, Gomez and Anthony 1998, Manning and Maguire 1999, Martin and McComb 2002, Swingle and Forsman 2009). Old-growth stands with no evidence of fire for > 400 years tended to occur in concave landforms beneath high (~1200 m) ridgetops (Tepley 2010). Owl sites found with high fine-scale relief contain many large old Douglas fir trees. Large old Douglas fir trees are characterized by trunk reiterations, broken tops, and large epicormic branches, which provide suitable nest structure for spotted owls and red tree voles (Forsman et al. 2004). Red tree voles were rare in owl sites above 1000 m; this elevational range was characteristic of sites found in the north and east portions of the study areas, where landforms were relatively flat. The red tree vole may be rare in high elevations of true fir forests because their arboreal nests do not provide adequate insulation from cold winter temperatures, thus making it difficult to forage on ice/snow covered branches (Forsman et al. 2004). However, some high elevation owl sites such as Pothole Creek (1300m) have high-relief landforms. In 2009 the author discovered resin ducts, the nest material of red tree voles, under a large tree located in a deep V-shaped valley in a small tributary to Pothole Creek, at the maximum reported elevational range of red tree voles in the Central Cascades by Huff (Forsman et al. 2004b). However, Manning and Maguire (1999) reported capturing a red tree vole at 1600 m in the Cascades. More study is needed to determine the relationship between deep V-shaped valleys and red tree voles at higher elevations. (Appendix I: Figure I.1)

4.2. Landform and vegetation effects on owl prey

Although spotted owls depend on old growth forest (Forsman et al. 1984, Thomas et al. 1990, Carey et al. 1992, Dugger et al. 2005), this study suggests that differences in owl prey species availability within and adjacent to old forest may also explain differences in spotted owl densities among watershed groups. The spatial variation in large prey in particular, observed in owl pellets at the watershed group scale may explain some of the differences in spotted owl densities we observed. Spotted owls inhabit areas where large prey (>100g) such as flying squirrels and woodrats are abundant (Barrows 1980, Forsman et al. 1984, Ward et al. 1998).

Zabel (1995) observed that spotted owl home range size was inversely related to primary prey density. In areas where Mexican spotted owls consumed fewer woodrats, owls had larger home ranges (Block et al. 2005). This study found that large prey (flying squirrels, bushy-tailed woodrats, rabbits/hares, and pocket gophers) were abundant in owl diets in Blue River, which had the highest owl pair density. However, the Upper McKenzie had the lowest owl pair density and largest territories, yet large prey (excepting woodrats) also were abundant in owl diets. Large prey such as rabbits/hares and pocket gophers may not be available year-round in high elevation areas, as insects, birds, juvenile rabbits/hares, and terrestrial mammals become less active above the snow or hibernate (Forsman et al. 2004), suggesting that owls in the Upper McKenzie would apply more pressure on arboreal mammals (flying squirrels) during the non-nesting season and early in nesting and thus require large expanses of forest to hunt arboreal prey.

Owl prey species availability and owl density may also be related to environmental variables, such as elevation, fine-scale relief, easting and accompanying vegetative responses to gradients. Environmental variables such as elevation, relief, and mean minimum and maximum temperature are shown to influence mammal species density along gradients (Badgley and Fox 2000). Increasing elevation has similar climatic effects as increasing latitude (Stevens 1992), perhaps high elevation owl sites in HJA have comparable prey densities to higher latitude study areas. The HJA study area was found at ~45˚ latitude. While more than half of the area of Blue River was within the elevational range of the Western Hemlock Zone (<1000 m), greater than half of the Upper McKenzie was within the elevational range of the Pacific Silver Fir Zone (1000-1200 m) with only a quarter within the range of the Western Hemlock Zone. The Upper McKenzie also had the lowest owl pair density. Perhaps the low density of spotted owl pairs in the Upper McKenzie was related to the lower proportion of Western Hemlock Zone resulting in lower density of flying squirrels. Owl studies in Washington (47˚ latitude), where the forest is dominated by western hemlock forests, revealed that where flying squirrel biomass was greater than 60% in spotted owl diet home ranges were largest (0.5 squirrels/ha; 1700 ha owl home range)(Carey et al. 1992). Approximately 60% of biomass from owl pellets found in the Upper McKenzie was from flying squirrels; pellets were relatively depauperate of woodrats except in sites found along the main-stem of the McKenzie River. There appears to be no direct flying squirrel density estimates for the Upper McKenzie River Basin. Local flying squirrel density estimates were derived from Blue River and the South Santiam (Rosenberg et al. 2003), both share a boundary with the Upper McKenzie yet, have distinctly different proportions of vegetation zones. Filling the knowledge gap regarding density estimates of flying squirrel along the elevational gradient could be vital to managers evaluating space use by owls in the West Cascades.

Local variation in prey communities seems to be related to forest composition effects on the density of flying squirrels, as suggested by differences in prey composition between Fall Creek and South Fork of the McKenzie River. Despite similar spotted owl densities, biomass contributions from flying squirrels and other large prey were quite different in these two watersheds. In Fall Creek owl pellets were depauperate of other large prey such as rabbits/hares and pocket gophers, but flying squirrels comprised an overwhelming 75% of the biomass. Comparable biomass contribution from flying squirrels has been documented in the North Cascades of Oregon (Forsman et al. 2004), but little spotted owl density information is available for this region (USDI FWS et al. 2008). In the South Fork of the McKenzie River the prey community was different. Although flying squirrels represented the majority of biomass in owl pellets (60%), other large prey such as rabbits/hares, woodrats, and pocket gophers each contributed >5% of owl prey biomass. These differences may be related to forest composition; 85% percent of Fall Creek is within the elevational range of the Western Hemlock Zone (< 1000 m) and perhaps supports greater densities of flying squirrels, while only 40% of South Fork of the McKenzie is within the Western Hemlock Zone (30% in both the Pacific Silver Fir and Mountain Hemlock Zones). The densities of flying squirrels in different watersheds in HJA (except for Blue River and South Santiam, 2 squirrels/ha) are unknown (Rosenberg et al. 2003).

4.3. Implications for Forest Management for Spotted Owls

Nearest neighbor owl territory distance was not uniform within the HJ Andrews spotted owl demography study area possibly in part due to spatial variation in prey, suggesting that single owl territory sizes may be inadequate for planning and management of forests. Spotted owl habitat values from Blue River such as median home range size and amount of old growth and mature forest within home ranges are the basis for management values in the West Cascades Physiographic Province (Thomas et al. 1990, USDI FWS et al. 2008). Blue River, which has the highest owl pair density, highest key prey species diversity, high fine-scale relief and moderate elevation, does not appear to be representative of the HJA, so extrapolating those values to the entire West Cascades Physiographic Province may prove detrimental to the spotted owl. National forest managers employ a methodology, the Incidental Take Statement version 2.0 (ITS), to estimate the number of spotted owl home ranges that occur within areas affected by proposed Federal actions using standard nearest neighbor distances and home ranges based on the best available science (USDI FWS et al. 2008). The ITS assigns a one-size-fits-all nearest neighbor distance and home range to each physiographic province. In the West Cascades where the HJ Andrews spotted owl demography study is located, the mean nearest neighbor distance used by managers is 2080 m (USDI FWS et al. 2008). This value was similar to the mean nearest neighbor value calculated in the study for both Blue River and Fall Creek, but it was 30% smaller than mean nearest neighbor owl territories within the Upper McKenzie River Basin. Applying the one-size-fits-all nearest neighbor distances to estimate potential owl territories in the Upper McKenzie River Basin may over-estimate owl populations by at least 30%. The actual sizes of spotted owl core and home ranges in the High Cascades may be much larger than in the West Cascades, and leaving the minimum required amounts of forest post Federal action may be inadequate to support spotted owl pairs.

Biological Opinions using one-size-fits-all values may arrive at a “no jeopardy” opinion based on low “likelihood of adversely affecting” the inflated virtual owl population. The determination of a no jeopardy opinion could have a negative effect on owls by allowing federal actions to occur within core and home ranges that were potentially too small (~30%). Perhaps owl territories within the Upper McKenzie River Basin were more comparable to the Washington Cascades than to the Oregon Cascades, as increasing elevation has similar climatic effects on vegetation as increasing latitude (Stevens 1992) and by extension prey associated with vegetation. The ITS recognizes the Washington Cascades as having different spatial requirements for owls, notably larger home ranges (2.90 km radius) than the Oregon Cascades (1.93 km radius) (Thomas et al. 1990, USDI FWS et al. 2008). Given a declining owl population (Forsman et al. *In review)*, and the increased importance of high-elevation wilderness areas for maintaining spotted owl populations, managers may consider re-evaluating the one-size-fits- all values in the HJ Andrews spotted owl demography study area when evaluating proposed federal actions.

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APPENDICES

Appendix A: Significant autocorrelation plots for nesting owl pairs overall and within selected watershed groups for the years 1988-2009 using the HJA annual report data. In the case of nesting pairs the first serial correlation coefficient accounts for the most variation. South Santiam and East South Fork of the McKenzie were not included; there was rarely more than 2 nesting pairs in any given year.

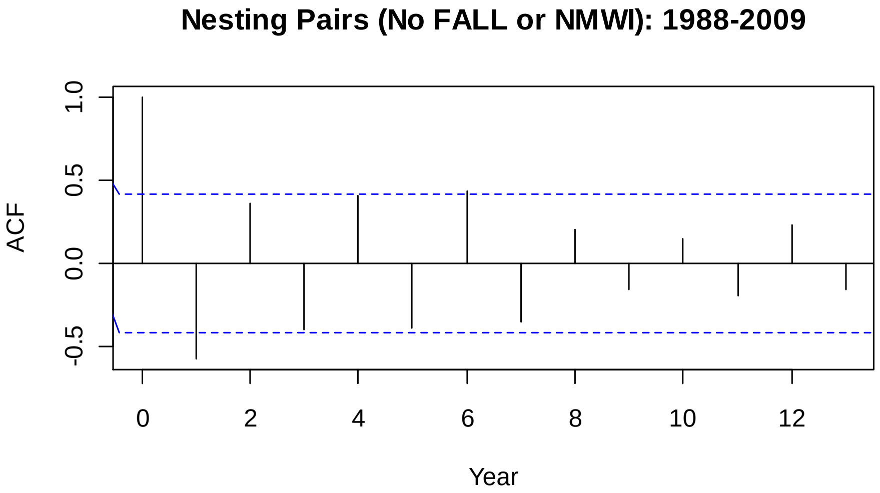


Figure A. 1: Autocorrelation plot (ACF) of nesting pairs through time: 1988-2009. At a lag distance of 1 year the number of nesting pairs is significantly below average (blue dashed line is the 95% confidence levels). All HJA refers to combined watersheds except Fall Creek (FALL) and North Middle Fork of the Willamette (NMWI) because the dataset is truncated. At a lag distance of 1 year nesting owl pairs were negatively autocorrelated (-0.573).

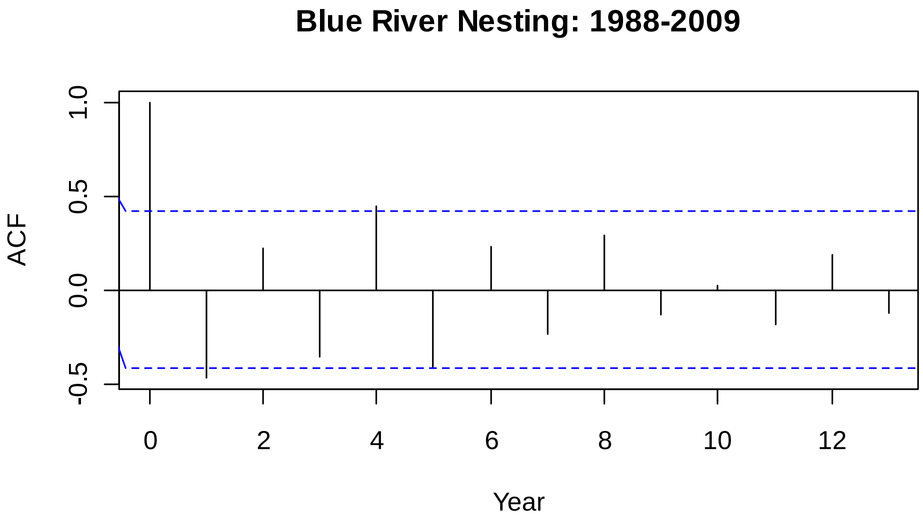


Figure A. 2: Autocorrelation plot (ACF) of nesting pairs in Blue River through time: 1988-2009. At a lag distance of 1 year the number of nesting pairs is significantly below average (-0.465) (blue dashed line is the 95% confidence levels).

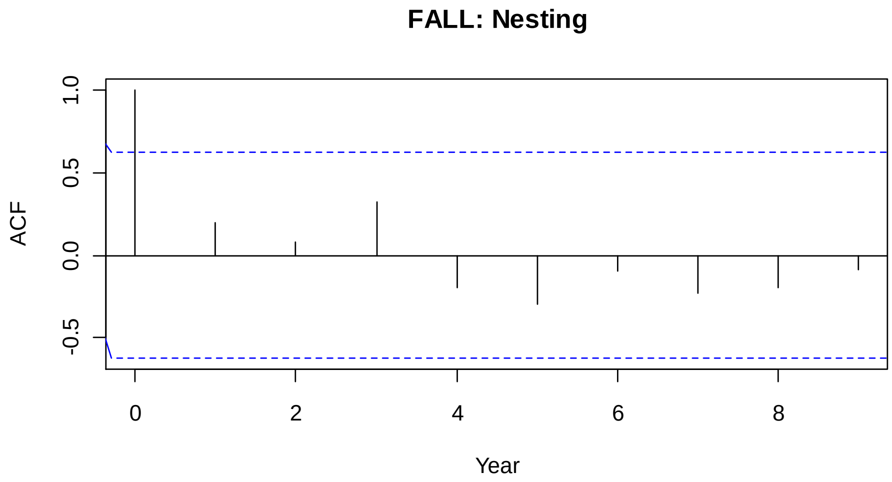


Figure A. 3: Autocorrelation plot (ACF) of nesting pairs in Fall Creek through time: 2000-2009. The blue dashed line is the 95% confidence levels. Nesting pairs do not appear to exhibit the biannual nesting cycle, however this dataset is truncated.

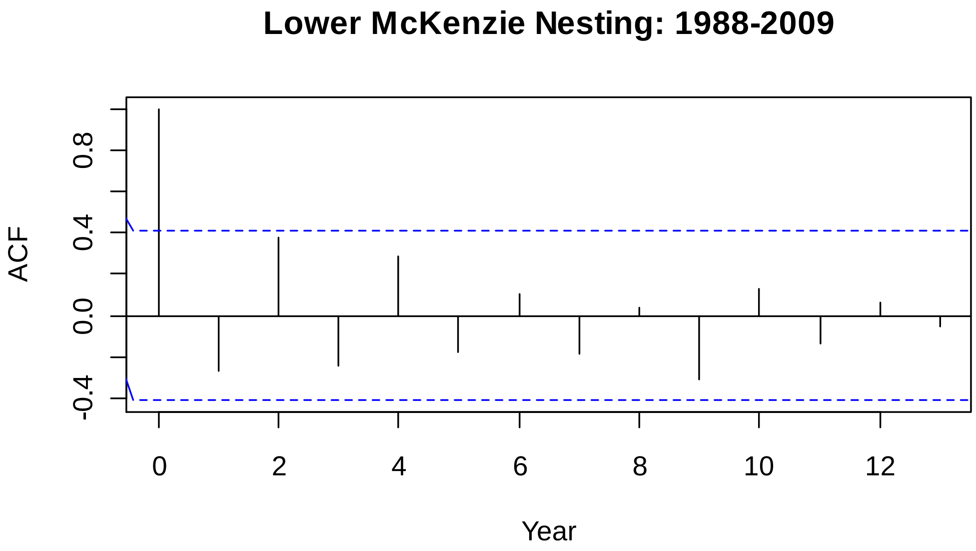


Figure A. 4: Autocorrelation plot (ACF) of nesting pairs in Lower McKenzie through time: 1988-2009. The blue dashed line is the 95% confidence levels. Nesting pairs do not appear to exhibit the biannual nesting cycle.

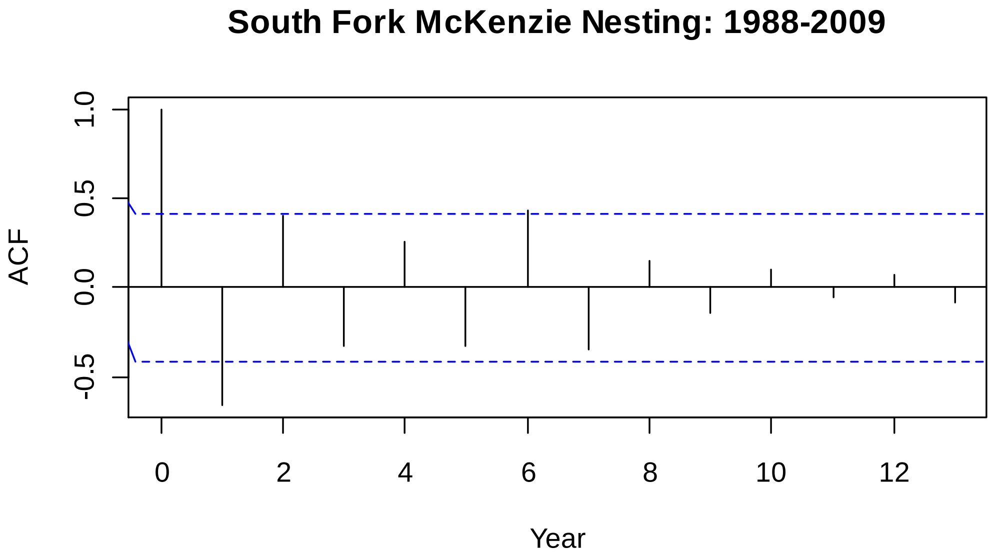


Figure A. 5: Autocorrelation plot (ACF) of nesting pairs in South Fork McKenzie through time: 1988-2009. At a lag distance of 1 year the number of nesting pairs is significantly below average (-0.657) (blue dashed line is the 95% confidence levels).

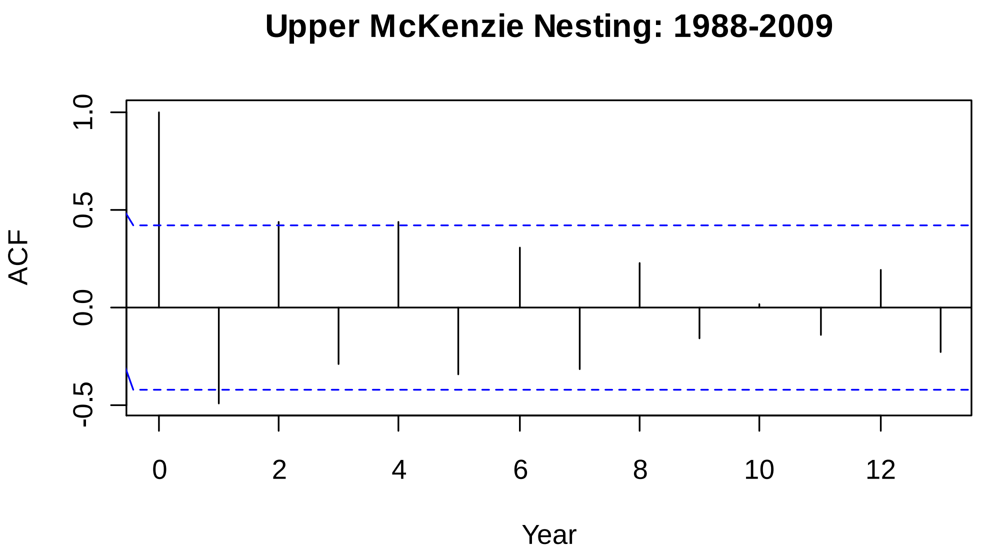


Figure A. 6: Autocorrelation plot (ACF) of nesting pairs in Upper McKenzie through time: 1988-2009. At a lag distance of 1 year the number of nesting pairs is significantly below average (-0.489) (blue dashed line is the 95% confidence levels).

Appendix B: Graphical representation of predicted estimates of the probability of encountering a particular key prey versus important covariates in pellet samples collected during 1988 – 2009. Estimates based on logistic regression models using a binomial response (presence/absence) for each key pre occurring at least once in each owl site.

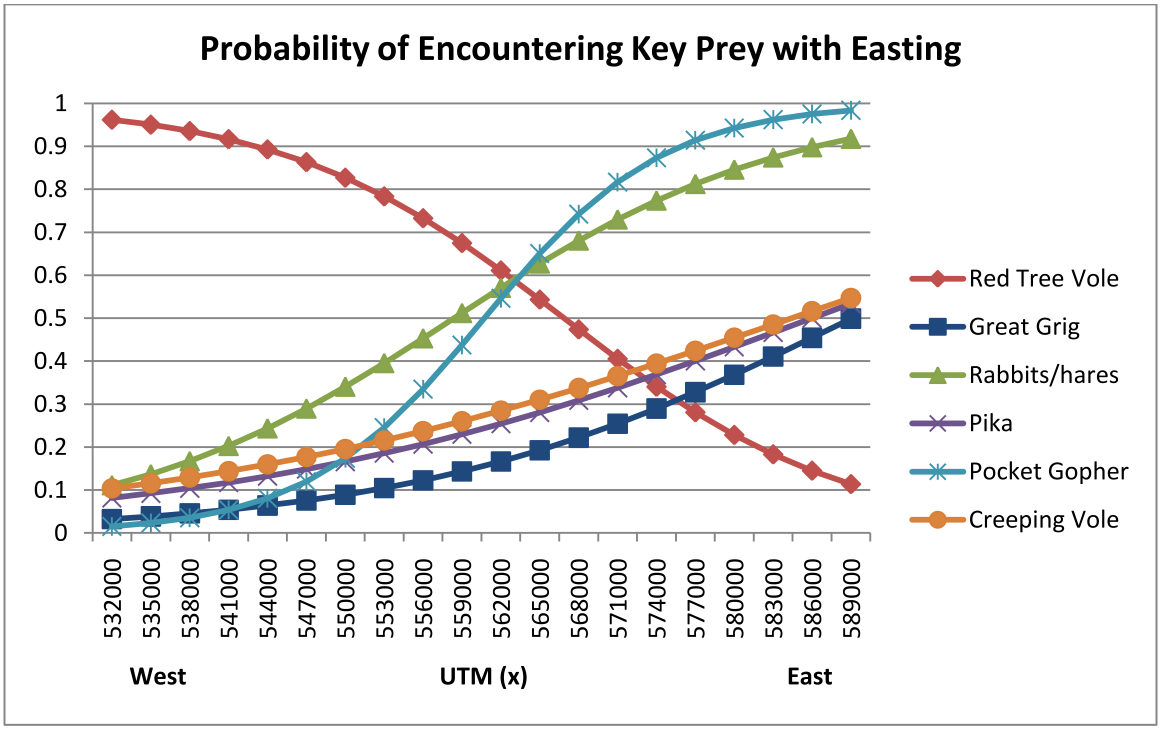


Figure B. 1: Probability of encountering key prey using logistic regressions based on binomial response (presence/absence) in owl pellets spanning 1988-2009 pooled over the study area as a function of easting. Key prey were not represented by the optimal model based on lowest AIC value.

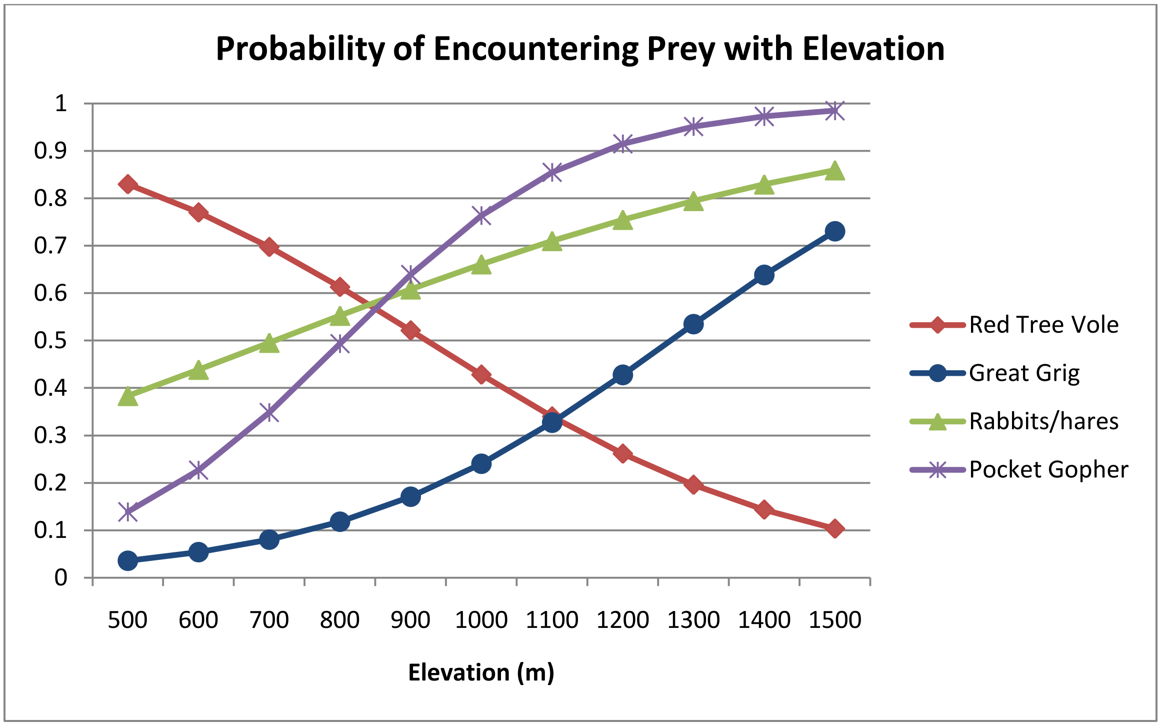


Figure B. 2: Probability of encountering statistically significant key prey as a function of elevation using logistic regressions based on binomial response (presence/absence) in owl pellets spanning 1988-2009. Key prey were not represented by the optimal model based on lowest AIC. At approximately 1000m the Western Hemlock Zone transitions to the Pacific Silver Fir Zone, which transitions to the Mountain Hemlock Zone between 1200-1300 m (Franklin and Dryness 1973).

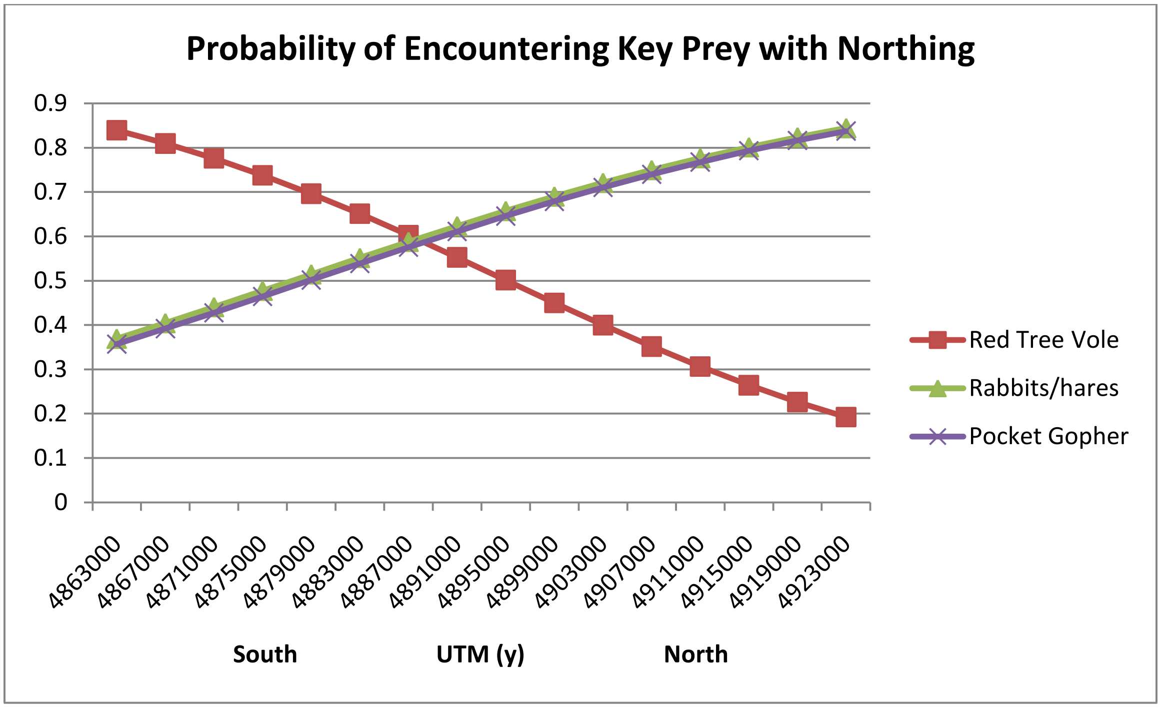


Figure B. 3: Probability of encountering statistically significant key prey as a function of northing using logistic regressions based on binomial response (presence/absence) in owl pellets spanning 1988-2009 pooled over the study area. Key prey were not represented by the optimal model based on drop in deviance model selection criteria (AIC). Note: Northing is correlated with relief (-0.9985).

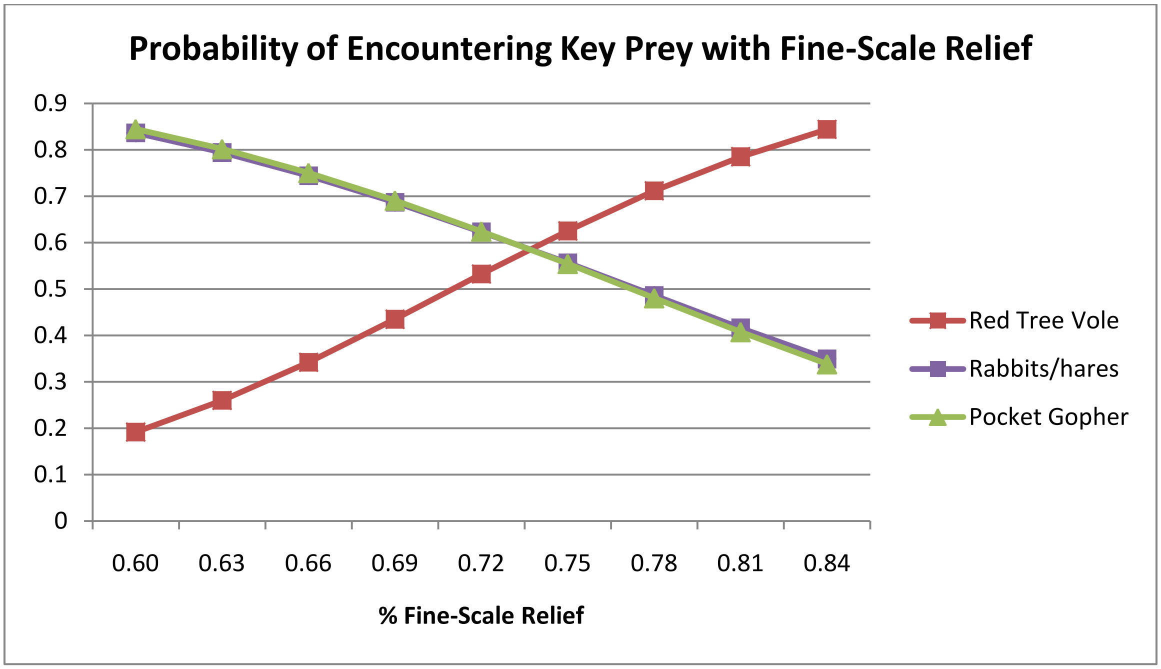


Figure B. 4: Probability of encountering statistically significant key prey as a function of fine-scale relief using logistic regressions based on binomial response (presence/absence) in owl pellets spanning 1988-2009 pooled over the study area. This is the optimal model for rabbits/hares. Red tree voles and pocket gophers were not represented by the optimal model based on lowest AIC: Relief is correlated with northing (-0.9985).

Appendix C: Prey and watershed groups using elevation derived from owl locations where key prey species (n=3739) were found in owl pellets (1988-2009) provided that sites met the ≥10 prey item criteria (n=114).

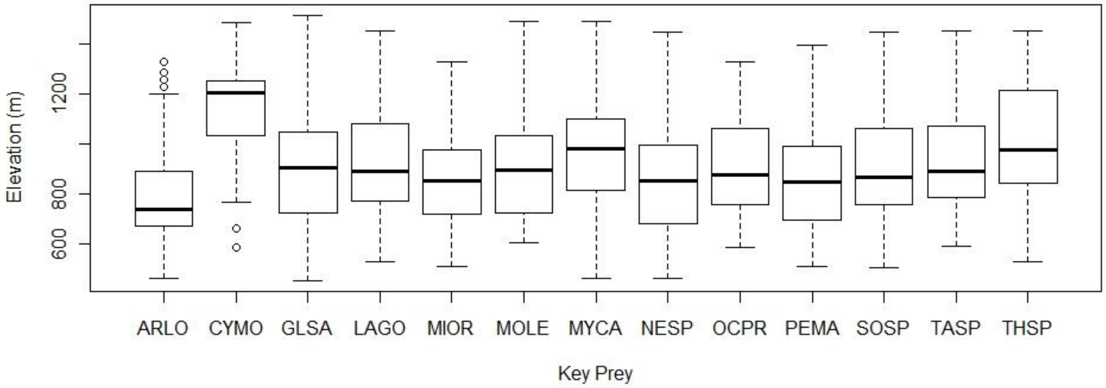


Figure C. 1: Median elevation (boxes show 25th to 75th quartile, whiskers show the range) of owl locations where key prey species (n=3739) were found in owl pellets (1988-2009). See Table 3.1 for species codes. The 13 key: (1) red tree vole (*Arborimus longicaudis*) (ARLO), (2) great grig (*Cyphoderris monstrosa*) (CYMO), (3) northern flying squirrel (*Glaucomys sabrinus*)(GLSA), (4) rabbits/hares (LAGO), (5) creeping vole (*Microtus oregoni*)(MIOR), (6) moles (MOLE), (7) western red-backed vole (*Myodes californicus*)(MYCA), (8) bushytailed woodrat (*Neotoma cinerea*)(NESP), (9) pika (*Ochotona princeps*)(OCPR), (10) deer mouse (*Peromyscus maniculatus*)(PEMA), (11) shrews (SOSP), (12) Townsend's chipmunk (*Tamias townsendii*)(TASP), and (13) pocket gopher (*Thomomys mazama*) (THSP).

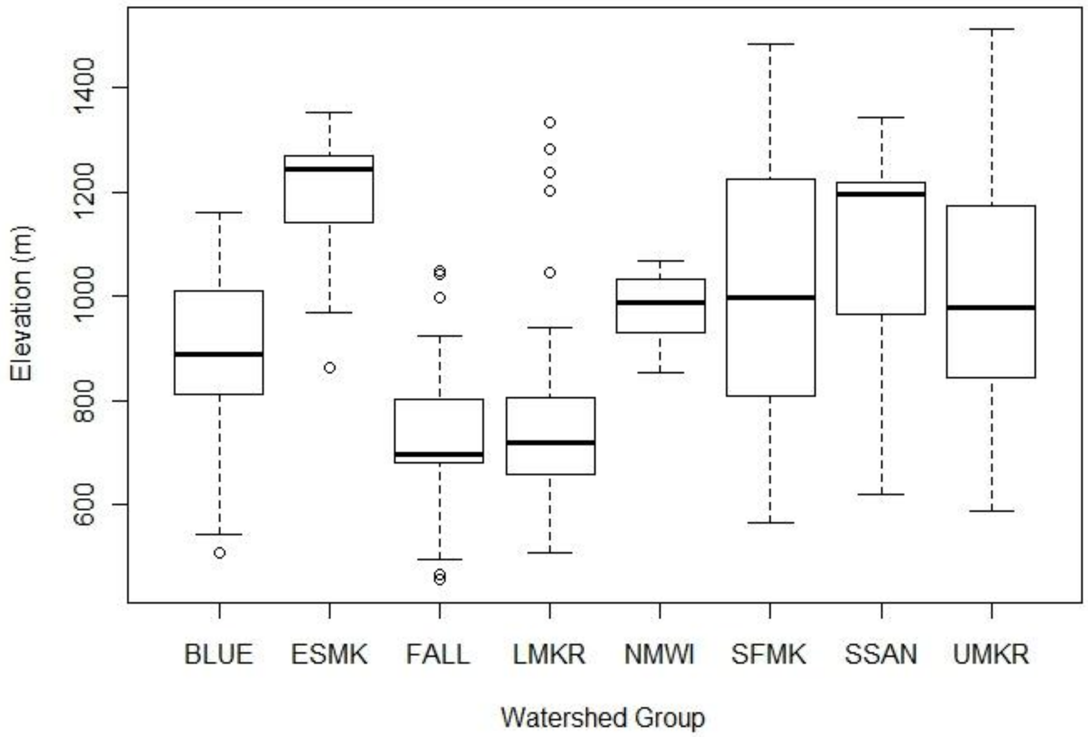


Figure C. 2: Median elevation (boxes show 25th to 75th quartile, whiskers show the range) of owl locations where pooled key prey species (n=3739) were found in owl pellets (1988-2009) for each watershed group. Watershed groups are: Blue River (BLUE), East South Fork McKenzie (ESMK), Fall Creek (FALL), Lower McKenzie (LMKR), North Middle Fork of the Willamette (NMWI), South Fork McKenzie (SFMK), South Santiam (SSAN), and Upper McKenzie (UMKR).

Appendix D: Fine-scale relief by key prey (n=3733) and watershed group (n=114). Fine-scale relief is percent difference between surface area and planar area of the 800m radius owl core derived from owl locations in sites where pellets were found.

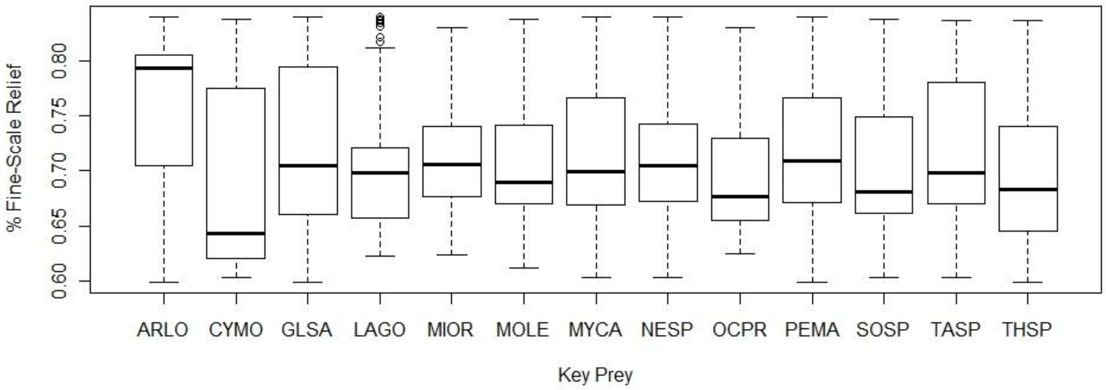


Figure D. 1: Key prey and fine-scale relief (boxes show 25th to 75th quartile, whiskers show the range) based on best annual owl location. The 13 key: (1) red tree vole (*Arborimus longicaudis*) (ARLO), (2) great grig (*Cyphoderris monstrosa*) (CYMO), (3) northern flying squirrel (*Glaucomys sabrinus*)(GLSA), (4) rabbits/hares (LAGO), (5) creeping vole (*Microtus oregoni*)(MIOR), (6) moles (MOLE), (7) western red-backed vole (*Myodes californicus*)(MYCA), (8) bushytailed woodrat (*Neotoma cinerea*)(NESP), (9) pika (*Ochotona princeps*)(OCPR), (10) deer mouse (*Peromyscus maniculatus*)(PEMA), (11) shrews (SOSP), (12) Townsend's chipmunk (*Tamias townsendii*)(TASP), and (13) pocket gopher (*Thomomys mazama*) (THSP).

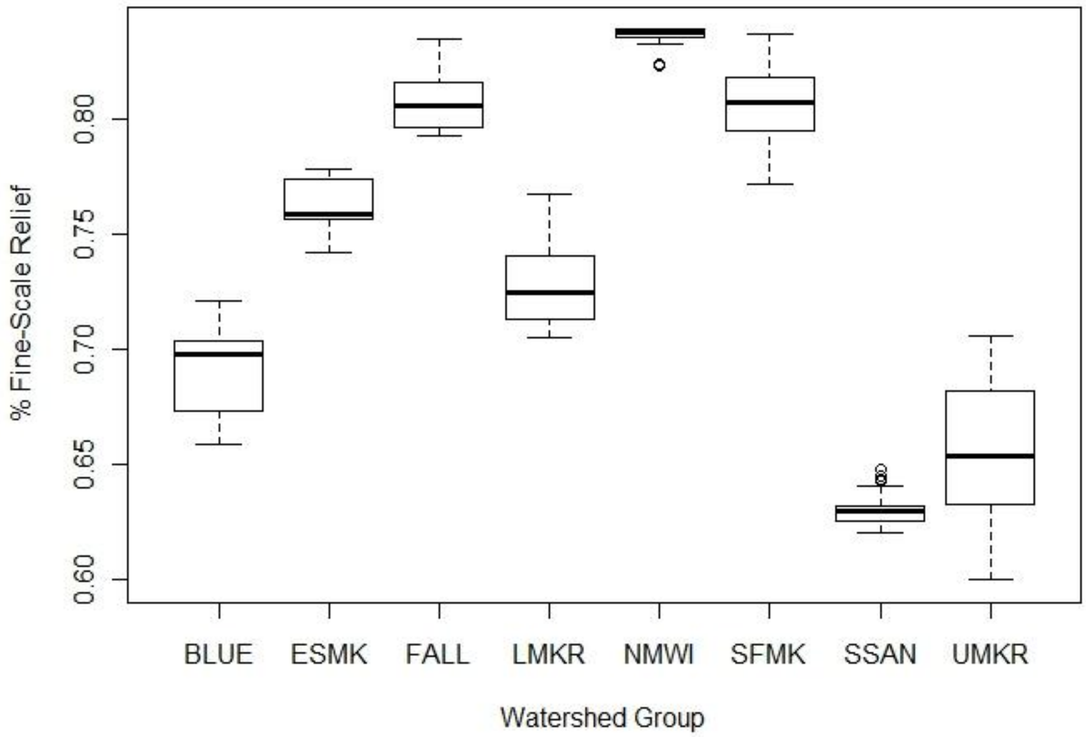


Figure D. 2: Fine-scale relief (boxes show 25th to 75th quartile, whiskers show the range) and watershed groups based on owl locations. Watershed groups are: Blue River (BLUE), East South Fork McKenzie (ESMK), Fall Creek (FALL), Lower McKenzie (LMKR), North Middle Fork of the Willamette (NMWI), South Fork McKenzie (SFMK), South Santiam (SSAN), and Upper McKenzie (UMKR).

Appendix E: Annual Spotted Owl Pair Densities

Table E. 1: Owl pair densities (owl pairs per square kilometer) for four watershed groups. Groups were selected based on minimum mean number of active owl pairs >8. Mean owl pair densities were listed for two time periods: 1990-2009 (90-09) and 2000-2009 (00-09). Fall Creek has no density estimates until 2000, when the area was officially annexed by the HJ Andrews demography study.

	Blue River		**Upper McKenzie**		**South Fork McKenzie**		**Fall Creek**	
Year	Pairs	Density	Pairs	Density	Pairs	Density	Pairs	Density
1990	20	0.095	24	0.062	13	0.082	-	-
1991	17	0.081	25	0.065	11	0.069	-	-
1992	25	0.119	28	0.072	10	0.063	-	-
1993	14	0.066	15	0.039	6	0.038	-	-
1994	20	0.095	24	0.062	9	0.057	-	-
1995	20	0.095	23	0.059	7	0.044	-	-
1996	19	0.090	20	0.052	10	0.063	-	-
1997	19	0.090	20	0.052	7	0.044	-	-
1998	20	0.095	19	0.049	9	0.057	-	-
1999	15	0.071	17	0.044	9	0.057	-	-
2000	15	0.071	17	0.044	8	0.050	15	0.055
2001	18	0.085	19	0.049	8	0.050	21	0.077
2002	15	0.071	14	0.036	9	0.057	19	0.070
2003	15	0.071	18	0.047	8	0.050	15	0.055
2004	17	0.081	16	0.041	10	0.063	16	0.059
2005	13	0.062	13	0.034	8	0.050	16	0.059
2006	14	0.066	13	0.034	8	0.050	11	0.040
2007	14	0.066	15	0.039	10	0.063	16	0.059
2008	15	0.071	12	0.031	10	0.063	12	0.044
2009	13	0.062	12	0.031	8	0.050	11	0.040
90-09	**16.9**	**0.080**	**18.2**	**0.047**	**8.9**	**0.056**	**-**	**-**
00-09	**14.9**	**0.071**	**14.9**	**0.039**	**8.7**	**0.055**	**15.2**	**0.056**

Appendix F: GIS analysis of landscape characteristics to be used in Community Analysis

Landscape characteristics were hypothesized to influence small mammal communities by creating habitat and influencing vegetation. Characteristics include tree size category, tree species community, elevation, fine-scale relief, and aspect, all of which vary with location. The landscape characteristics were derived from remotely sensed data, GIS, and field data.

The first step in this analysis was to assign a best annual owl location for each owl territory with the qualifying minimum number of prey items (≥10) over 22 years of sampling. The "ideal" location for each site (n=114) was chosen to represent the landscape character at the time period where the most prey items were collected. This ideal location was used to define placement of the 800m radius buffer (core) in space and time. The 800m radius buffer is the standard owl core size for spotted owl territories within Oregon (USDI FWS et al. 2008). The core size was derived from telemetry studies and landscape occupancy models (CAREY et al. 1992, Zabel et al. 1995, Swindle et al. 1999, Olson et al. 2005b, Dugger et al. 2005).

The general azimuth of the main-stem stream was determined for each watershed group in degrees by applying a compass to the 10 m DEM and deriving the general direction of flow of the main-stem stream within each watershed group.

All 114 selected ideal locations with the qualifying minimum number of prey items (≥10) for 1988-2009 were buffered at a radius of 800m. This 800m core will be used to spatially intersect with the GNN layers to calculate the percent of stand age categories, percent of dominant tree species categories, and relief.

In order to determine a representative snapshot of tree size class for each (n=114) owl core area 2 Landsat images (GLOVIS 2010) and the Gradient Nearest Neighbor (GNN) 2000 layer (LEMMA, IMAP 2010) were analyzed. The time series 1988-2009 was broken into three time periods based on disturbance regimes such as forest practices and wildfire events; they are: 1988-1995, 1996-2003, and 2004-2009. Landsat images from September 1985 and September 2010 were processed using ENVI 4.7. Landsat September 1985 was the closest to 1988 without clouds obscuring the image. Bands 5-4-3 were layer stacked to get partial false color images that detects a wavelength that our eyes cannot but is sensitive to disturbed or dry, turning areas a hot pink (influence of Band 3). Landsat images were chosen instead of the time-step disturbance map (LARSE 2005) to tease out small changes such as landslides, roads, and sites that were altered by wildfire. For instance, the time-step disturbance map blots out entire parcels affected by wildfire when in fact old growth characteristics were still present in the stand. The spectral reflectance of the live trees left behind by fire is detected with ENVI. Files were exported as a .tiff and brought into ArcGIS 10.

The two new tiffs were changed from 3-band images to single layers with integers. Both layers were clipped to the study area extent and reclassified to pick out recently harvested forest (<15 years). Threshold values for reclassification were determined by visually checking layers with georeferenced sites (known dates of clear-cuts and nest trees (old growth) for 1985 and 2010). The threshold value for 2010 was 100. The threshold value for 1985 was 95. Binary layers were created through reclassification of the integer layer based on threshold values. The reclassified binary layers, separately, were spatially analyzed with the Gradient Nearest Neighbor (GNN) 2000 layer to determine percent of five stand age categories within owl core areas.

Tree size class by time period

To determine five stand age categories for the time period 1996-2003, the GNN layer from 2000, specifically the quadratic mean diameter of dominant canopy (QMDA_DOM) field with pre-defined tree size classes was used to determine % of dominant stand age categories. The QMDA_DOM field was classified to display five categories; categories were: non-forest (reservoirs and highways, but not lava flows), regenerating stand (2.5-25 cm), young (25-37.5 cm), mature (37.5-50), and old (>50 cm). Defining more than four broad classes would degrade map accuracies (Cohen et al. 1995), discounting non-forest. The dominant tree age category layer created will be used for defining the layers in the two remaining time periods.

In order to create a representative layer of stand age classification for owl territories within the time period 1988-1995, raster math was applied to the binary layer created from Landsat image and the 2000 GNN layer to add stand age structure, such as old forest, to that time period.

In order to capture a representative snapshot of stand age class for the time period 2004-2009 I applied raster math to the binary layer created from Landsat image and the 2000 GNN layer to subtract stand structure caused by disturbance such as wildfire.

The resulting three time period layers of general stand age categories, which were now comparable, were changed from a raster to a vector, spatially intersected with 800m buffered ideal owl locations, and the areas of stand age category was calculated using the Calculate Areas script. After exporting the resulting database file to Excel the percent stand age categories was calculated for each ideal location. Stand age percentages were then arc-sine square-root transformed for use in the environmental (second) matrix and NMS. Of the 5 categories, only four were considered in NMS: regenerating stand, young, mature, and old.

Dominant Tree Species

In order to determine the percent tree species category the GNN layer and the dominant tree species field was applied to the HJA through the time period 1988-2009, because dominant tree species were assumed to not appreciably change in 11 years (+/- 2000). The GNN raster image was changed to a vector and spatially intersected with 114 800m buffered ideal locations. The areas within the core were calculated using Calculate Areas script. The resulting database file was exported into Excel and the total area for 28 tree species at each best location (n=114) was summed. Five tree species categories were considered: (1) PSME, Douglas fir (*Pseudotsuga menziesii*), (2) HE-RED, western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and pacific yew (*Taxus brevifolia*), (3) HICON, mountain hemlock (*Tsuga mertensiana*), Pacific silver fir (*Abies amabilis*), white fir (*Abies concolor*), grand fir (*Abies grandis*), noble fir (*Abies procera*), Shasta red fir (*Abies x shastensis*), lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), and Engelmann spruce (*Picea engelmannii*) (4) Maple/alder, big leaf maple (*Acer macrophyllum*) and red alder (*Alnus rubra*), (5) DRY, Incense cedar (*Calocedrus decurrens*), giant chinquapin (*Chrysolepis chrysophylla*), and Pacific madrone (*Arbutus menziesii*). The percent of each tree species category was determined for 114 owl locations. Tree species categories were then arc-sine square-root transformed for use in the environmental (second) matrix and NMS.

Appendix G: MRPP Pair-wise Comparisons of Watershed Groups

Table G. 1: MRPP pair-wise comparisons of eight watershed groups, T-statistic, A-statistic, and associated p-value listed from most different to most similar. The T-statistic (T) is the difference between the observed and the expected weighted within group mean distance divided by the standard deviation of the expected distance. The A-statistic (A) is the chance-corrected within group agreement and describes within group homogeneity (A-statistics were commonly <0.1, while values >0.3 were considered very high, McCune and Grace 2002). Use caution when evaluating A-statistics with larger p-values because data were not tested for multiple pair-wise comparisons.

Groups Compared			T	A	p-value
Fall Creek	vs.	Upper McKenzie	-21.8473	0.362775	0
Fall Creek	vs.	S Santiam	-10.3326	0.2718	0.00000038
Fall Creek	vs.	SF McKenzie	-10.7935	0.263025	0.00000074
Fall Creek	vs.	ES Fork McKenzie	-7.76874	0.198715	0.00000324
Fall Creek	vs.	Lower McKenzie	-8.01328	0.145036	0.00001311
ES Fork McKenzie	vs.	NM Willamette	-2.06437	0.139152	0.03467997
Fall Creek	vs.	NM Willamette	-4.7343	0.132045	0.00032188
S Santiam	vs.	ES Fork McKenzie	-2.56518	0.126064	0.01526738
Fall Creek	vs.	Blue River	-7.1987	0.110035	0.0000307
Upper McKenzie	vs.	Blue River	-7.68852	0.102803	0.00000259
Blue River	vs.	ES Fork McKenzie	-3.24853	0.081218	0.00662746
ES Fork McKenzie	vs.	SF McKenzie	-2.48245	0.080969	0.0185706
S Santiam	vs.	SF McKenzie	-2.02071	0.069526	0.04069642
S Santiam	vs.	Blue River	-2.92876	0.067866	0.01062373
Upper McKenzie	vs.	Lower McKenzie	-4.30801	0.064588	0.00091009
S Santiam	vs.	Upper McKenzie	-2.16859	0.045226	0.03227804
SF McKenzie	vs.	NM Willamette	-1.06734	0.039111	0.14282083
ES Fork McKenzie	vs.	Lower McKenzie	-1.14369	0.03327	0.12875001
S Santiam	vs.	Lower McKenzie	-0.99876	0.028657	0.15386595
Blue River	vs.	SF McKenzie	-1.55901	0.027625	0.07523884
Upper McKenzie	vs.	ES Fork McKenzie	-1.06629	0.022742	0.14110468
Upper McKenzie	vs.	NM Willamette	-0.77762	0.01855	0.20162909
Lower McKenzie	vs.	SF McKenzie	-0.72826	0.015612	0.21331025
Upper McKenzie	vs.	SF McKenzie	-0.49958	0.008343	0.27359306
Lower McKenzie	vs.	NM Willamette	-0.21294	0.007017	0.37911151
Blue River	vs.	NM Willamette	-0.25165	0.00658	0.35016739
Blue River	vs.	Lower McKenzie	0.501455	-0.00838	0.64649932
S Santiam	vs.	NM Willamette	0.983137	-0.05969	0.84814003

Appendix H: Three key prey that drive the structure of the ordination of Nonmetric Multidimensional Scaling.

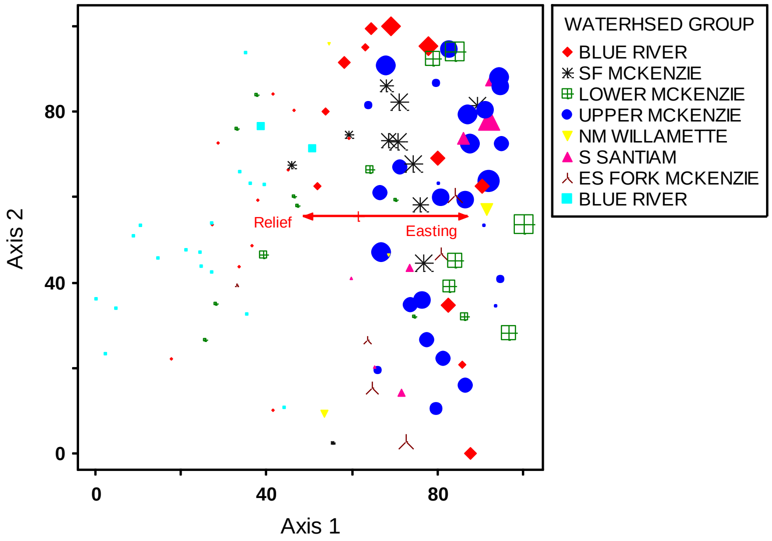


Figure H. 1: Ordination of owl sites (n=114) overlaid with watershed groups. The sizes of the symbols are proportional to the quantitative density measurement of pocket gophers. The arrows in the overlay illustrate the relationship of owl sites to the dominant variables in Axis 1: easting and fine-scale relief.

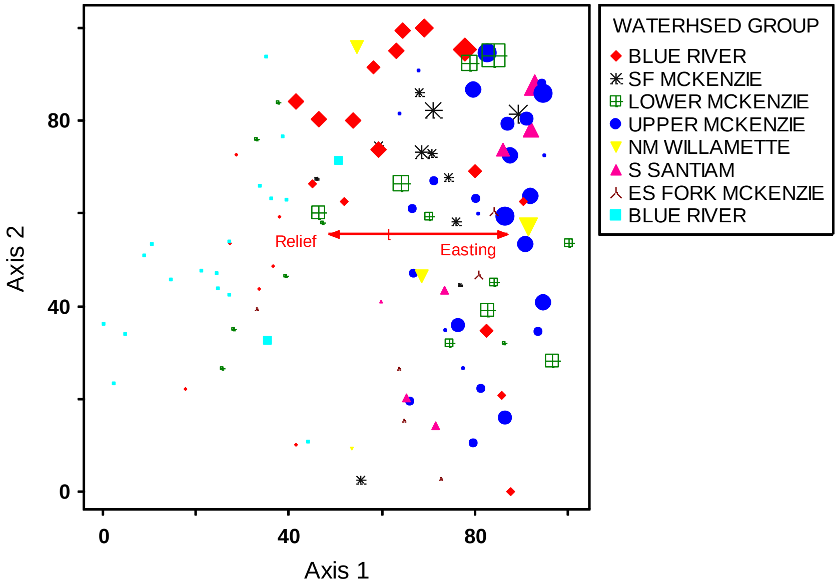


Figure H. 2: Ordination of owl sites (n=114) overlaid with watershed groups. The sizes of the symbols are proportional to the quantitative density measurement of rabbits/hares. The arrows in the overlay illustrate the relationship of owl sites to the dominant variables in Axis 1: easting and fine-scale relief.

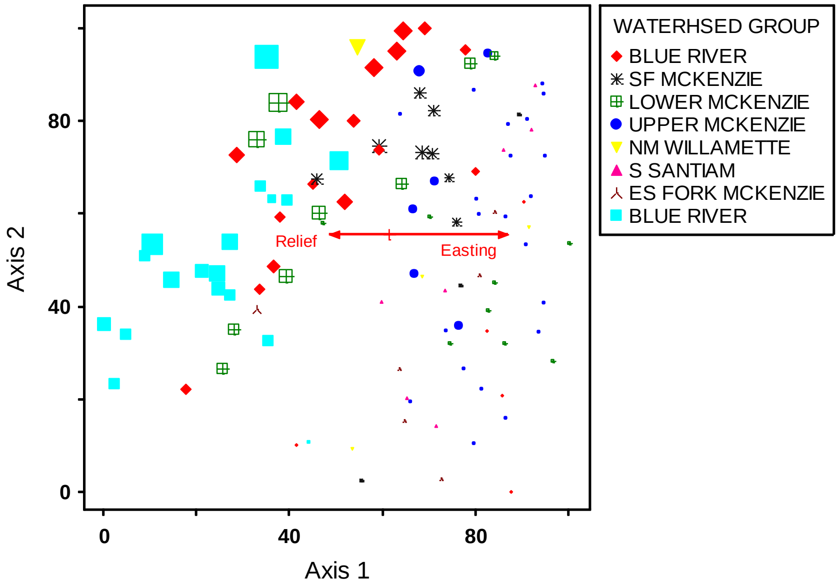
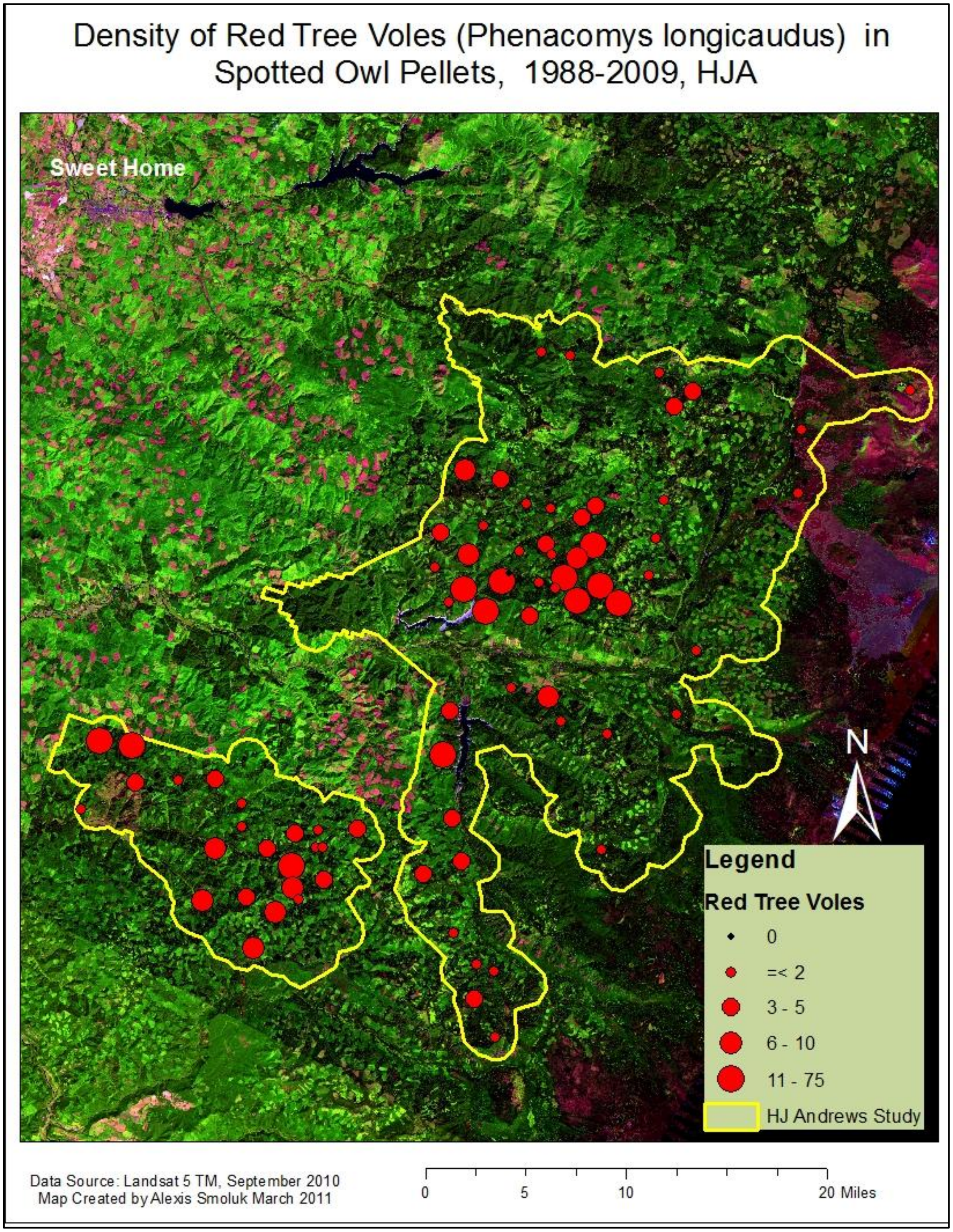


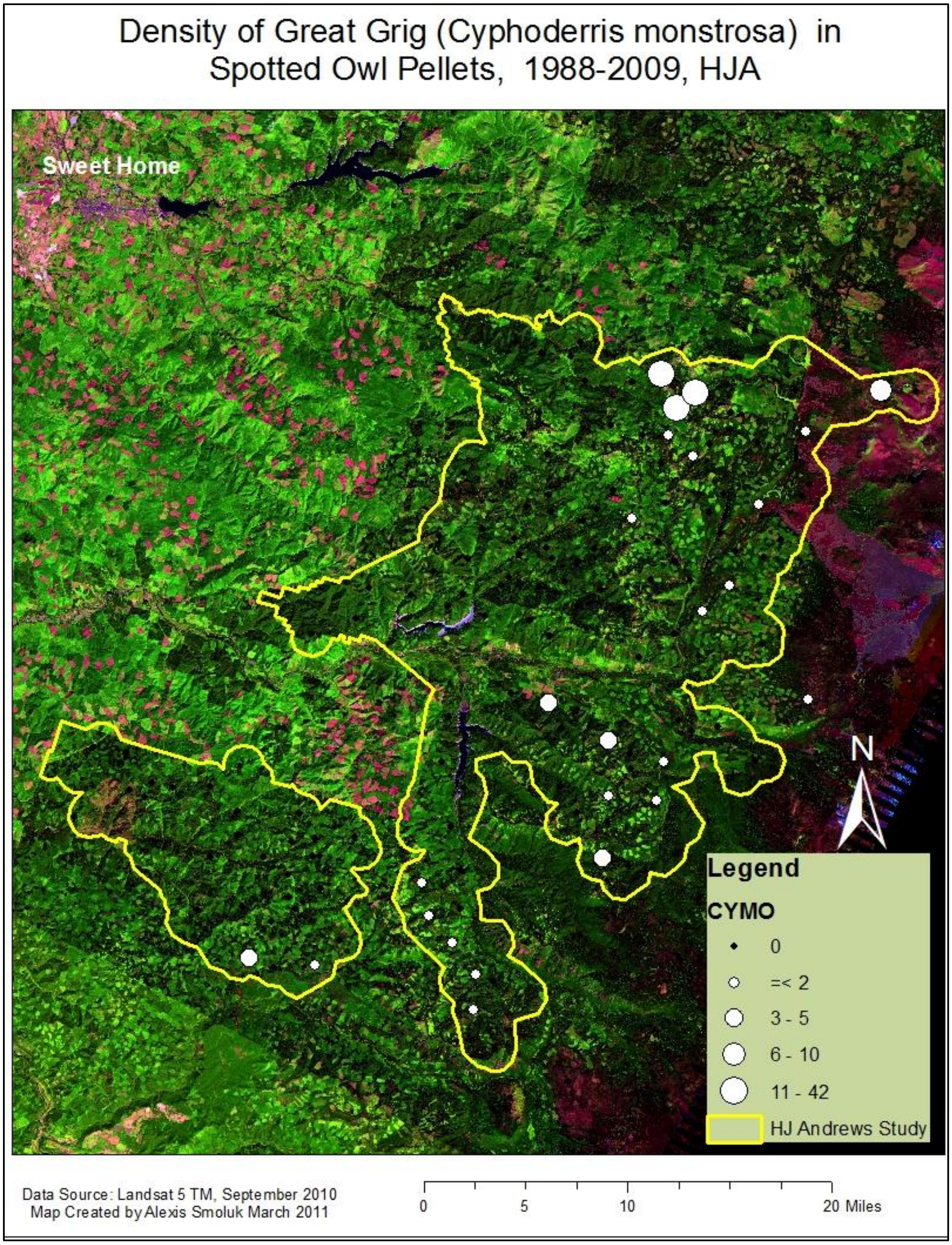
Figure H. 3: Ordination of owl sites (n=114) overlaid with watershed groups. The sizes of the symbols are proportional to the quantitative density measurement of red tree voles. The arrows in the overlay illustrate the relationship of owl sites to the dominant variables in Axis 1: easting and fine-scale relief.

Appendix I: Density Maps are count of select key prey per owl site (n=114), 1988-2009.



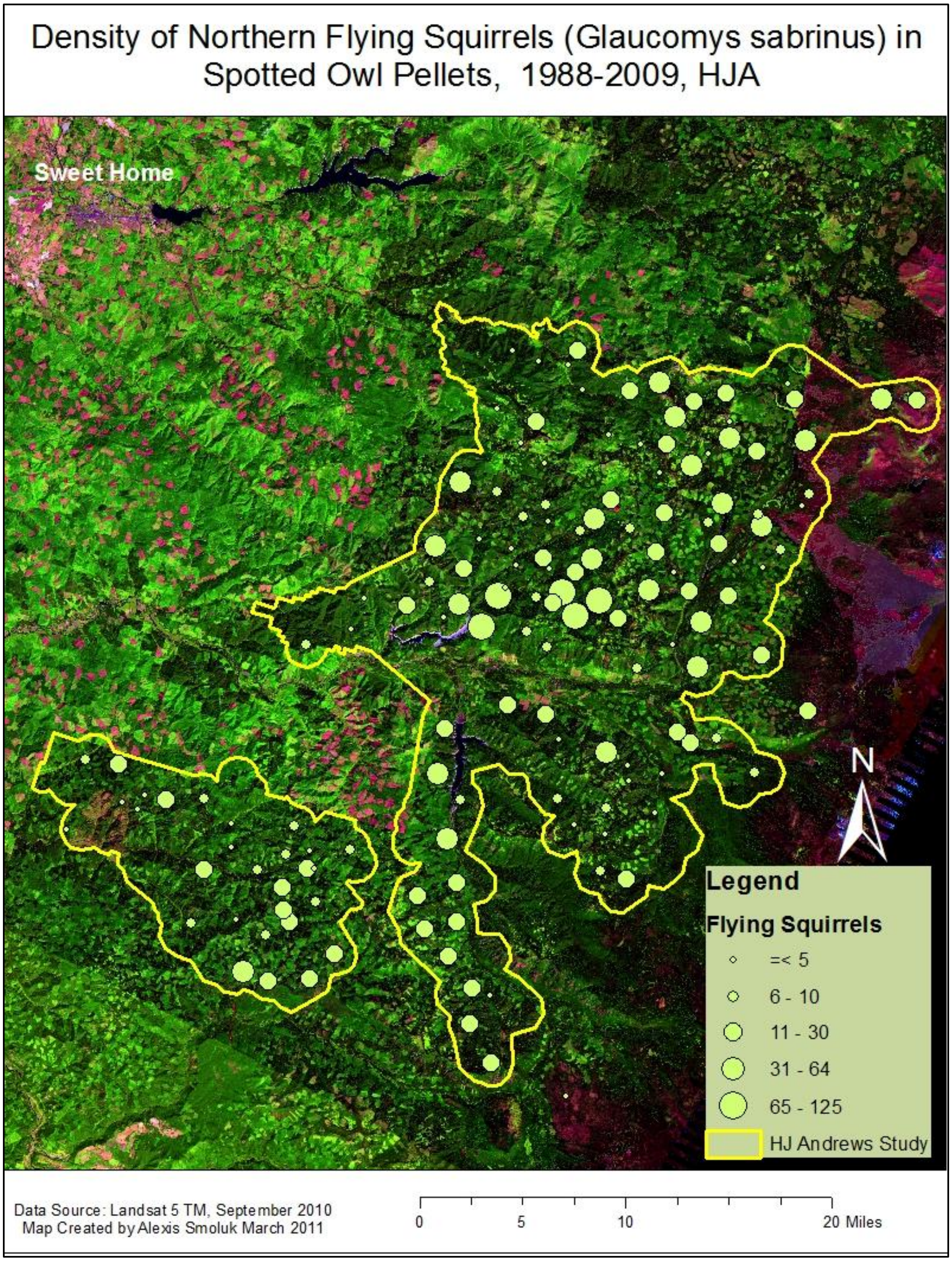
Data Source: Landsat 5 TM, September 2010
Map Created by Alexis Smoluk March 2011

Figure I. 1: Counts of red tree voles in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.



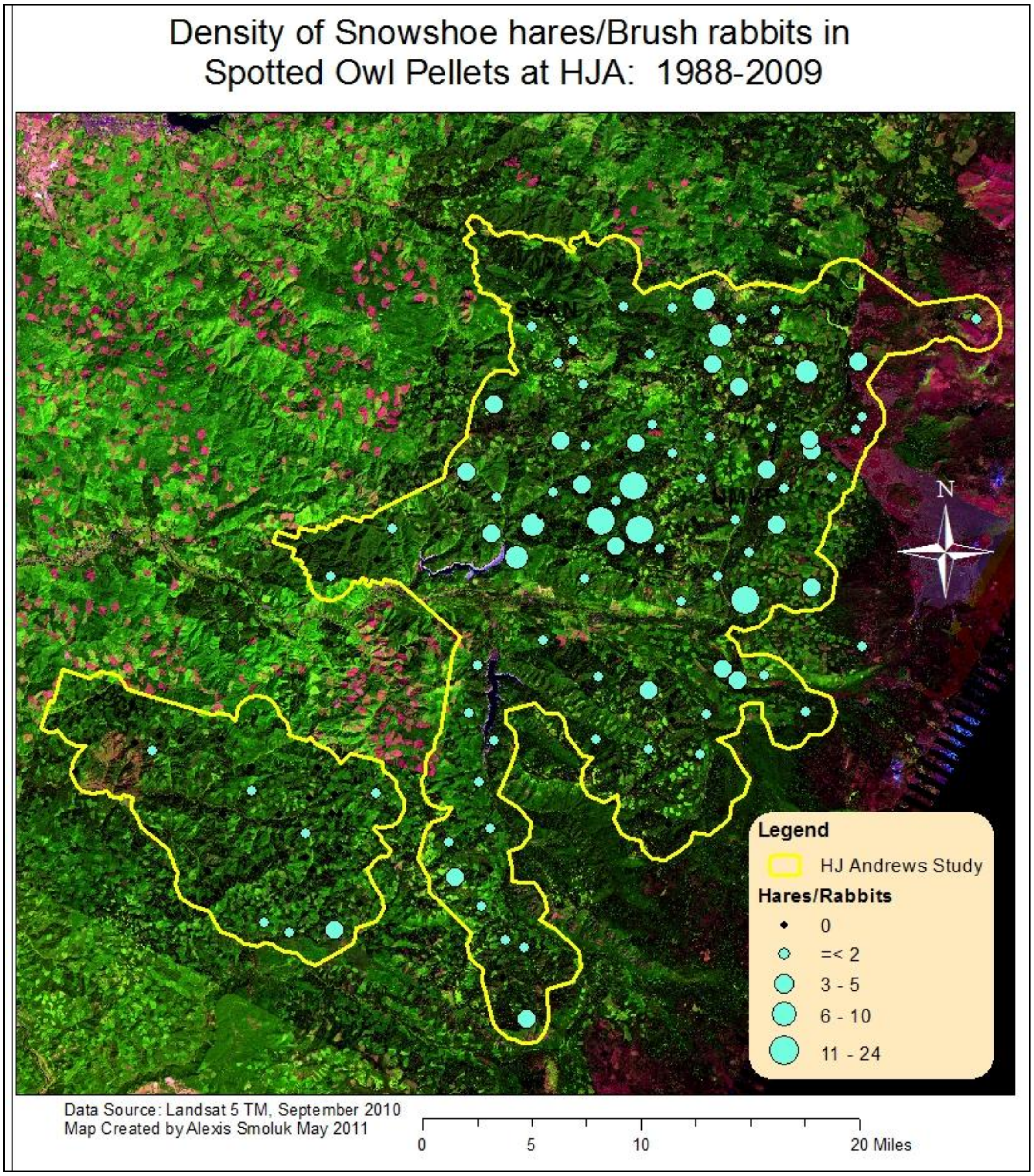
Data Source: Landsat 5 TM, September 2010
Map Created by Alexis Smoluk March 2011

Figure I. 2: Counts of great grig (*Cyphoderris monstrosa*) in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.



Data Source: Landsat 5 TM, September 2010
Map Created by Alexis Smoluk March 2011

Figure I. 3: Counts of flying squirrels in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.



Density of Snowshoe hares/Brush rabbits in Spotted Owl Pellets at HJA: 1988-2009

Data Source: Landsat 5 TM, September 2010
Map Created by Alexis Smoluk May 2011

Figure I. 4: Counts of snowshoe hares and brush rabbits in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.

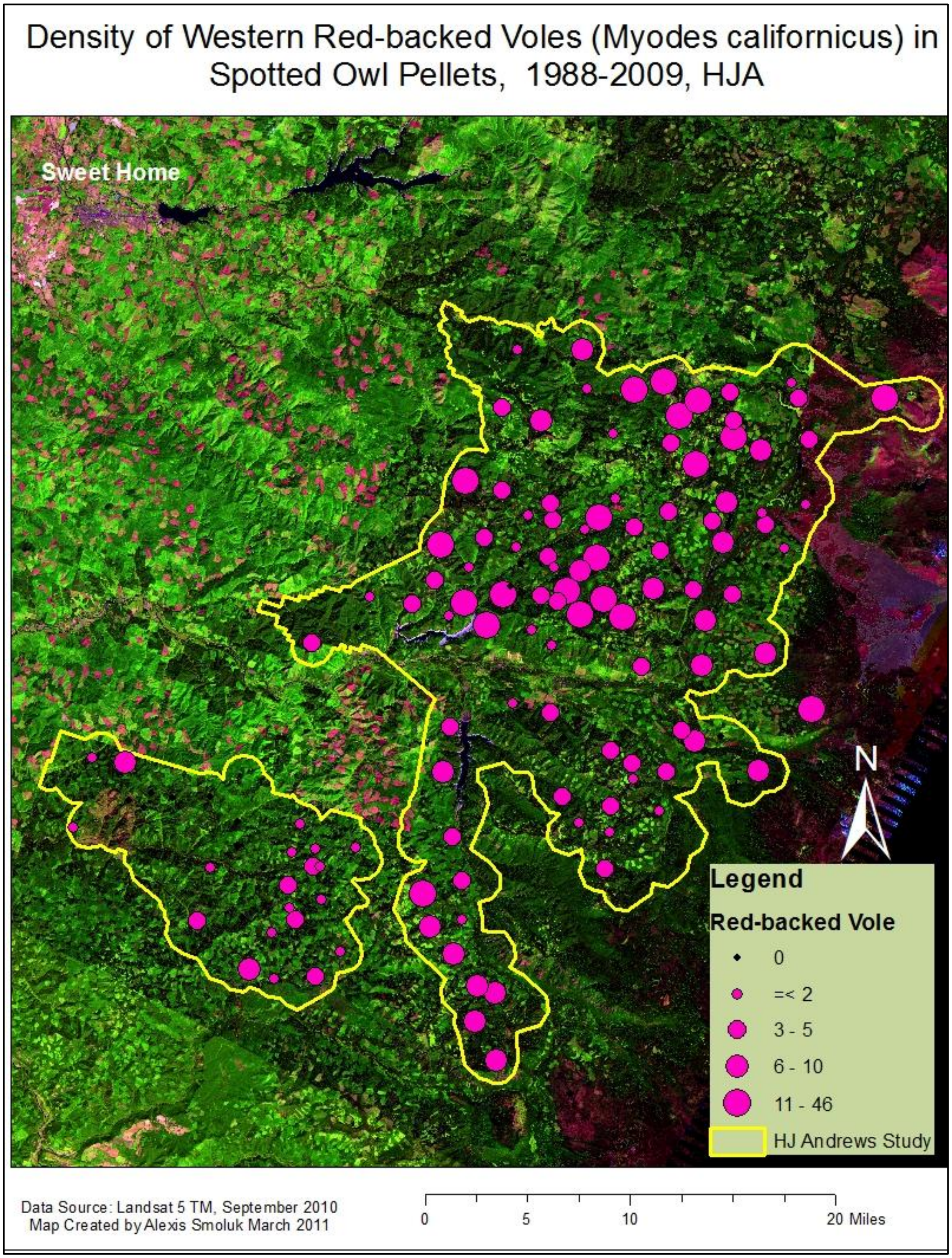


Figure I. 5: Counts of red-backed vole in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.

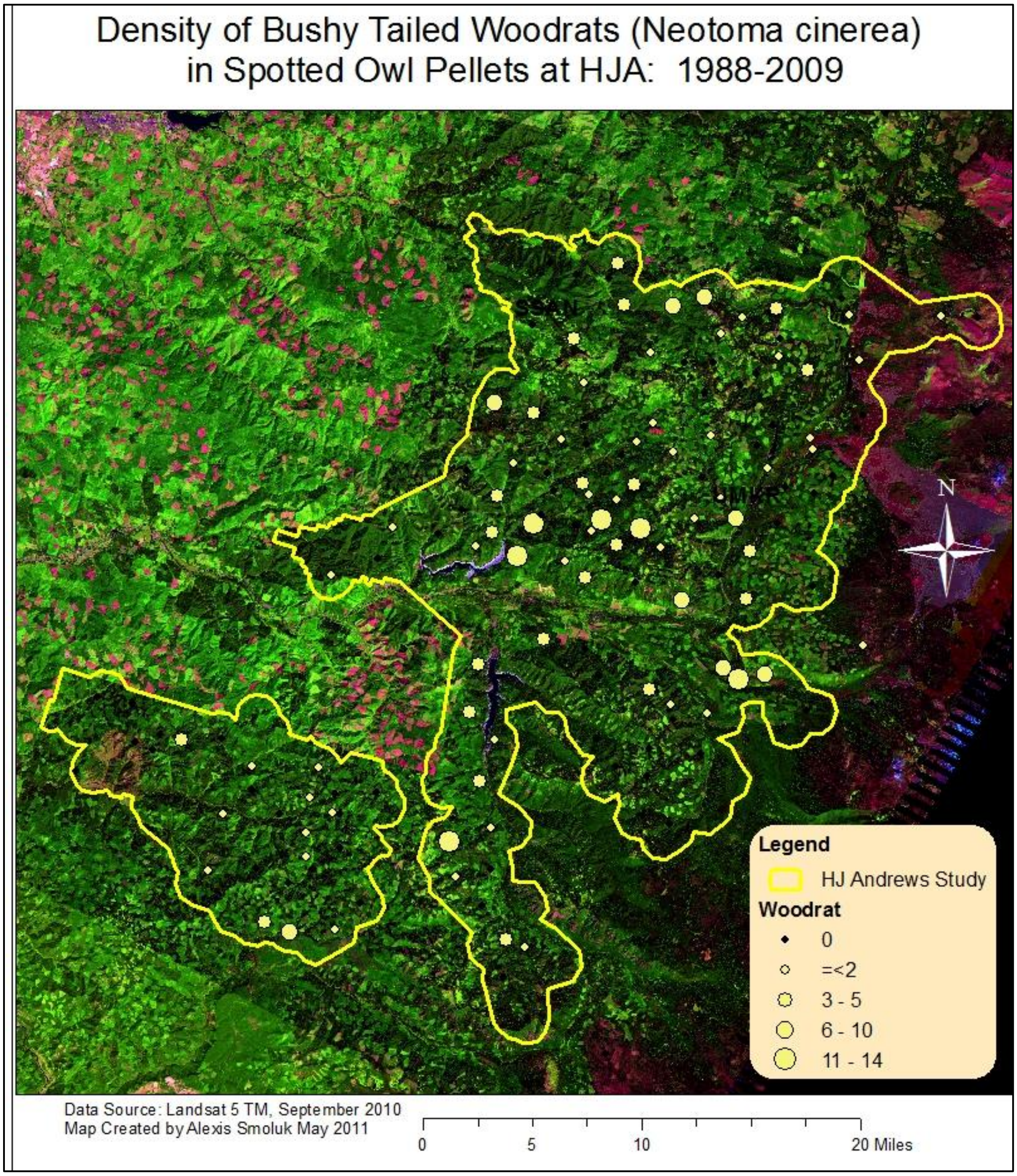


Figure I. 6: Counts of bushy-tailed woodrats in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.

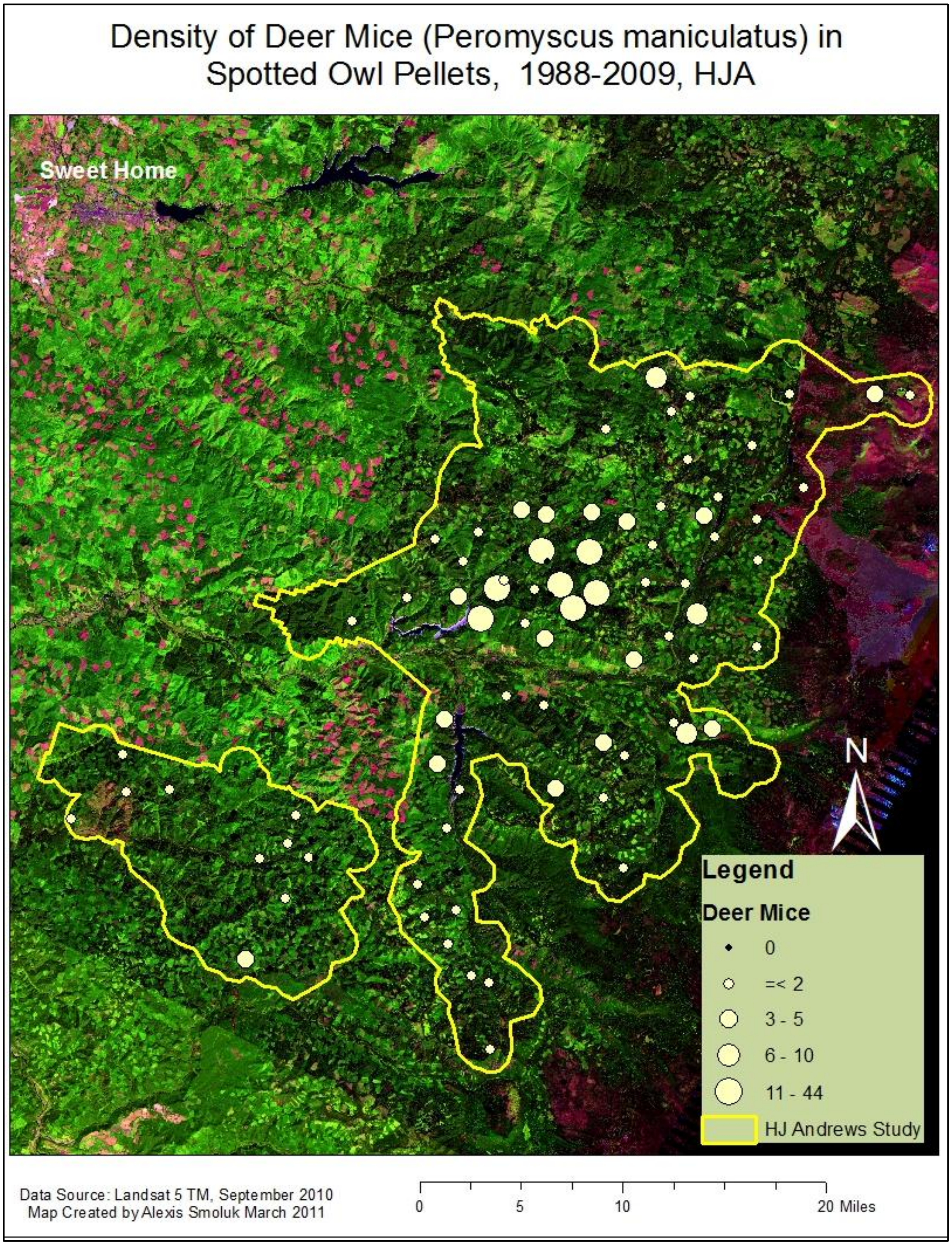


Figure I. 7: Counts of deer mice in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.

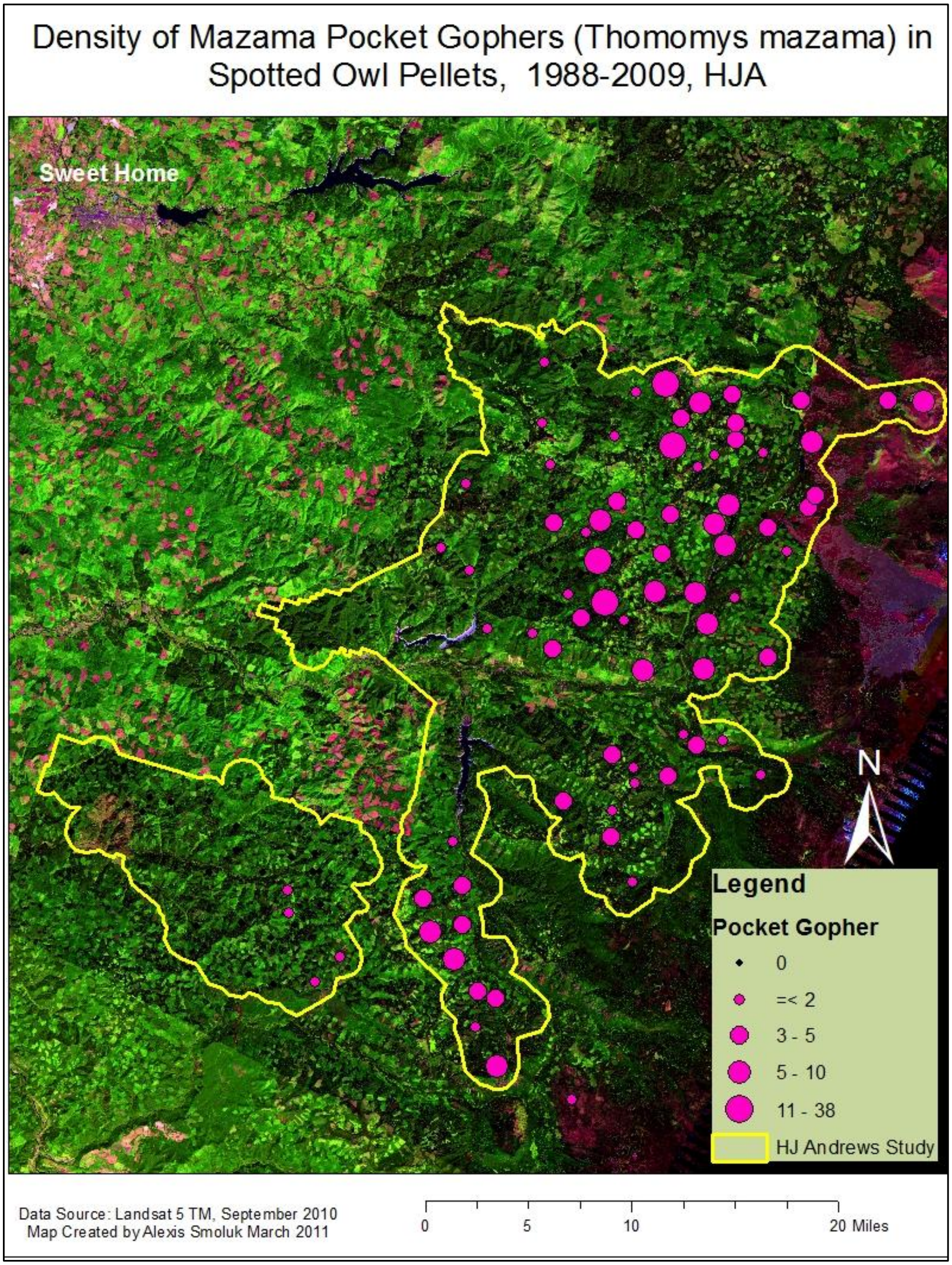


Figure I. 8: Counts of pocket gophers in owl pellets for each owl site (n=114) within HJ Andrews NSO demography study, 1988-2009 over Landsat composite image.