Spring 2014

GIS Modeling of Elk Habitat Suitability in the North Cascades of Washington State

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GIS MODELING OF ELK HABITAT SUITABILITY IN THE NORTH CASCADES OF WASHINGTON STATE

A Thesis

Presented to

The Graduate Faculty

Central Washington University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

Resource Management

by

Anna Quistorff Yost

May 2014
We hereby approve the thesis of

Anna Quistorff Yost

Candidate for the degree of Master of Science

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Chris Danilson, Washington State Department of Fish and Wildlife

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Dr. Kevin Archer, Dean of Graduate Studies
ABSTRACT

GIS MODELING OF ELK HABITAT SUITABILITY IN THE
NORTH CASCADES OF WASHINGTON STATE

by

Anna Quistorff Yost

May 2014

The Washington State Department of Fish and Wildlife (WDFW) elk management goals are to adjust the distribution of elk on the landscape in the North Cascades to reduce negative impacts to private property while maintaining a healthy population of elk in the area. The goal of this study was to use custom Geographic Information System (GIS) elk habitat suitability models to model baseline elk habitat suitability in the 8,600 km² North Cascades elk management area, and then evaluate how theoretical forage enhancement sites would affect habitat suitability. Prior to creating the baseline and proposed habitat suitability maps for the study area, the GIS data inputs were verified and updated as needed, and then model outputs were calibrated using known elk locations in a subset of the study area. Using the baseline predicted habitat suitability, 55 potential forage enhancement sites, covering 726 acres, were outlined within the core elk range. The models predict that these forage enhancement sites would improve the suitability ranking for 2,589 acres. The models indicate that forage enhancement sites have a stronger impact in areas with flatter slopes. The results from this modeling process will be used by WDFW to inform elk forage enhancement planning in the North Cascades.
ACKNOWLEDGMENTS

I am thankful for a fun and rewarding graduate school experience at Central Washington University (CWU), and I attribute this very positive experience to the support of the school, faculty, friends, and family. I want to thank my advisor, Dr. Bob Hickey, for guiding me through the graduate school process and helping me stay focused. I want to thank Chris Danilson at the Washington State Department of Fish and Wildlife (WDFW) for inviting me to work with him on this elk research, supporting the development of my thesis work, and serving on my committee. I also want to thank Dr. Tom Cottrell who provided crucial vegetation insight, research feedback, and was a valuable member of my committee. I am also thankful for all the people who provided technical feedback (Mary Rowland at U.S. Forest Service and Andy Duff at WDFW), access to field locations (Doug Sands at Sierra Pacific Industries), field work support (Mike Yost and Josie Lykken), and all those who were willing to share their valuable insight on elk management issues (William Moore at WDFW and all members of the Elk Forage Enhancement Working Group).

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CHAPTER I
INTRODUCTION

Statement of Problem

Efforts to recover the North Cascades elk (Cervus elaphus) herd appear to have been effective, with the population rebounding from a low of 425 in 2002 (Washington State Department of Fish and Wildlife (hereafter referred to as WDFW) 2002) to a current population of 1,200-1,450 elk (WDFW 2012). However, the current distribution is not entirely desirable because elk in certain areas (e.g. Skagit River floodplain and farmed areas near Acme) are an increasing source of damage to agricultural enterprises and small forest landowners. In addition to impacting crops, orchards, and forest plantations, elk frequently damage fences intended to confine livestock, causing potential livestock losses and liability to the farmer. An additional human safety concern is that the number of elk-vehicle collisions along the State Route 20 corridor in Skagit Valley is on the rise. As the elk population continues to recover, these issues are expected to only worsen. Therefore, there is interest in evaluating a variety of potential strategies that could improve the current distribution of elk as WDFW works to update the North Cascades elk herd management plan (WDFW 2012, C. Danilson, Washington State Department of Fish and Wildlife, personal communication). Among these strategies is trying to improve forage quality in areas where elk-related conflicts are minimized.
Goals and Objectives

Elk are an important component of the North Cascade ecosystem and a valuable resource for the community, therefore WDFW wants to shift elk to other locations where they will be less likely to damage agricultural land (WDFW 2012, C. Danilson, personal communication). To achieve the current population objectives, it is critical that WDFW and other project partners take steps that, over the long-term, will ultimately lead to an elk distribution that minimizes impacts to agriculture. This may involve landscape management treatments (e.g. food plots, forage enhancement, forest manipulations), addressing vehicle access, and/or implementing hunts where elk are not desired. Evaluation of different management scenarios will involve communication with state and federal agencies, Native American tribes, project partners, conservation groups, and other landowners. This modeling process is the first step in developing scenarios that will promote these discussions.

Modeling elk habitat is useful for evaluating elk management options (Bettinger et al. 1999, Benkobi et al. 2004). Donovan et al. (1987) found that GIS models can successfully predict habitat suitability, especially for generalist species whose key habitat requirements are easily identified and captured by GIS data. Boyd et al. (2011) determined that the North Cascades elk are highly correlated with generalized habitat types (i.e., mountain hemlock (*Tsuga mertensiana*) and western hemlock forests (*T. heterophylla*)), shallower slopes, distance from public roads, and distance from cover/forage edge. All of these variables are contained in, or easily derived from, readily
available GIS datasets. Therefore elk in western Washington are a good candidate for GIS habitat suitability modeling.

Researchers at the Pacific Northwest Research Station (PNWRS) in La Grande, Oregon developed the Westside Elk Nutrition and Habitat Use GIS Model Toolbox (referred to as the Westside Models hereafter) specifically to evaluate predicted elk habitat suitability in western Washington and Oregon (Rowland et al. 2013). The initial GIS data inputs for the Westside Models are vegetation coverage, public roads, and elevation, while the model output is a landscape coverage that is ranked according to elk habitat suitability. By adjusting the input vegetation and road datasets, it is possible to simulate habitat management scenarios. These model outputs can potentially be used by WDFW to work with stakeholders to determine the most suitable and feasible landscape management plan to achieve a more optimal elk distribution for this population that minimizes the potential for agricultural damage and highway collisions.

A variety of spatial data analysis methods were used in order to determine how landscape management scenarios will affect predicted elk distribution in the North Cascades. ArcGIS 10 (Environmental Systems Research Institute, Inc, Redlands, CA) was used for all spatial data manipulation and analysis unless otherwise noted. The methods are presented in a chronological format to reflect the research process. Due to the cumulative nature of the results and their importance for shaping the next step of research, the methods and results are presented together for each component of the research. The six major components of the research methods and results are as follows:
1. Synthesis of Elk Location Data

Elk location data from summer 2009 was provided by WDFW and was used to calibrate the outputs from the Westside Model. This location data was provided as a GIS point shapefile of Global Positioning System (GPS) locations collected from GPS collars worn by eleven elk in the North Cascades between 2008 and 2010. Individual elk summer 2009 home ranges were synthesized from this GPS data.

2. Vegetation Verification

The base vegetation data provided with the Westside models is an information-rich raster based on 2006 data most applicable for use on a landscape scale. This vegetation data is the basis for two of the four inputs into the Westside Models, so it was important to verify that this landscape level vegetation data accurately captures actual vegetation conditions. The vegetation verification step was performed on a subset of the study area, the Vegetation Verification Study Area, to facilitate data processing.

3. Model Calibration

The goals of the calibration component were to test the function of all the tools in the Westside models, test the process for updating vegetation, and compare the model output to known elk locations. The calibration step was performed on a subset of the study area, the Model Calibration Study Area, to facilitate data processing.
4. Update Elk Habitat Suitability to 2013 Conditions

It was important to update the vegetation and roads data for the whole study area to reflect current conditions for summer of 2013 (baseline conditions) prior to developing management scenarios.

5. Synthesis of Elk Habitat Management Landscape

Results of the baseline habitat suitability modeling were overlaid with known constraints of agriculture parcels and elevation and then presented to staff at WDFW and the Forage Enhancement Committee of the North Cascades Elk Management Work Group (FEC) to support discussions aimed at identifying sites for potential forage enhancement and elicit potential management scenarios.

6. Potential Forage Enhancement Scenarios

Through discussions with WDFW and the FEC initial potential locations for elk forage enhancement were identified, and these scenarios were modeled using the Westside Models. The resulting potential elk habitat suitability based on these initial scenarios is summarized.

Significance

This research is significant for several reasons. First, results from this project will be considered by WDFW to aid in their evaluation of which landscape management treatments would be most appropriate for achieving their elk distribution goals. This project is also significant because it will provide feedback to the PNWRS on the utility of the Westside Models for modeling landscape management scenarios in the North Cascades. The PNWRS spent several years developing the Westside Models so that
wildlife and habitat managers could use them to evaluate how habitat manipulation scenarios affect predicted elk habitat suitability. By applying these Westside Models in a real management situation, the PNWRS will receive feedback on the utility and functionality of the Westside Models. Finally, publishing results from this project will provide a useful contribution to the evolving dialogue on habitat suitability modeling and management applications.
CHAPTER II

THE STUDY ENVIRONMENT

Geographic Location

The total study area is approximately 8,600 km\(^2\) within the North Cascades physiographic region in northwestern Washington State (Fig. 1). The study area is located between approximately 47° 40’ and 49° 0’ north latitude, and 120° 50’ and 122° 30’ west longitude, and contained within Townships 26N through 41N, and Ranges 4E through 16E. The boundary for the total study area is based on the boundaries of the WDFW’s Game Management Units (GMUs) which is composed of the Nooksack, Sauk, Stillaguamish, and Cascade GMUs (Fig. 2). WDFW uses these GMU area designations to manage the North Cascade elk. The general landscape features that bound the study area are the Puget Sound lowlands and U.S. Interstate 5 to the west, and the north-south ridgeline of the Cascade Mountain Range to the east. The northern boundary coincides with the border between Washington State and Canada, and the southern boundary coincides with Washington Highway 2.

Within the study area is the model calibration area which was used to calibrate the output from the Westside Models with known elk location data (Chapter V). The vegetation verification site nests within the model calibration area and this is where field data was collected in order to verify the digital vegetation data used by the Westside Models (Chapter VI).
Figure 1: Location of study area. Data sources: basemap (US National Park Service), study area (WDFW 2013).
Figure 2: Game Management Units (GMU) define the study area boundary. Data Sources: basemap (US National Park Service), GMUs and study area (WDFW 2013), roads (WSDOT 2011).
Topography and Climate

The North Cascades are a part of a major mountain system, the American Cordillera, which extends from Alaska to South America (Tabor and Haugerud 1999). The mountains in the North Cascades are composed mostly of sedimentary rock that were folded and metamorphosed, then infused with molten rock from volcanic activity (Franklin and Dyrness 1975, Tabor and Haugerud 1999). Alternating sections of softer substrate and harder substrate of the folded sedimentary rock resulted in differential erosion, producing drainage patterns that etch river valleys out of the mountainous landscape (Tabor and Haugerud 1999). Glacial movement over the last two million years has further defined mountain ridges and widened river valleys. There are still active glaciers around the Mount Baker volcano, which is 3,200 meters at the summit (Franklin and Dyrness 1975). Rivers fed from these glaciers generally drain along an east-west gradient from the western flanks of the Cascades Mountains to low elevation river valleys and finally into Puget Sound (Mathews 1999).

The major peaks of the Cascade Mountain Range form a spine along a north-south axis, and the area is characterized by a pattern of ridgelines with similar elevations (1,800 to 2,600 meters) that transition from steep slopes in upper elevations to shallow-gradient slopes in low elevation river valleys (Franklin and Dyrness 1975). The Cascade Mountain Range creates an orographic effect, which means the moisture-laden air brought in on the prevailing westerly winds is forced to rise above the mountains causing heavy precipitation on the western slopes of the Cascade Range and a drier climate on the eastern slopes.
The temperate climate of the region is moderated by the close proximity of the Puget Sound and the Pacific Ocean. Average temperatures in Concrete, WA, near the middle of the study area, at the WRCC station (elevation 60 meters), range between 0°C and 5°C in the winter and between 11°C and 25°C in the summer (Fig. 3). There is a wet season from October through April, when the average monthly precipitation is above 100 mm, and a drier season from May through September (Western Regional Climat 2012). During the colder months, there can be snow on the ground from November through April, which encourages elk to move to lower elevations.

Figure 3: Climograph of average monthly climate in Concrete, Washington (COOP ID: 451679, the period of record for temperature and precipitation is 1981 to 2010) (Western Regional Climate Center 2012).
Vegetation

The mild and wet climate of the study area is conducive to abundant vegetation. The study area is part of the North Cascades Level III Ecoregion, and it is further classified into the Level IV Ecoregion, which classifies the majority of the study areas as either lowland forest, highland forest, or subalpine/alpine forest (USEPA 2011). The Level IV Ecoregion forest classifications use the same general forest types, indicated by their dominant tree species, as the forest zone classifications used by WDFW and USFS to classify forest habitat for elk. These forest zones occur as a result of the elevation and moisture gradients on the western slopes of the Cascade Mountains and are named for their dominant conifer species; the western hemlock (*T. heterophylla*), Pacific silver fir (*Abies amabilis*), and the mountain hemlock (*T. mertensiana*) zones (Franklin and Dyrness 1973). The western hemlock and mountain hemlock zones of the North Cascades provide habitat for the elk population in the region (WDFW 2012).

The Western Hemlock Zone extends from sea level up to 600 meters in elevation and is dominated by western hemlock (*T. heterophylla*) and also includes Douglas-fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*) (Franklin and Dyrness 1973). The Western Hemlock Zone is the most common forest zone in western Washington (Franklin and Dyrness 1973) and is both the most important timber production zone and the zone elk predominately use for their winter range (WDFW 2002). The Pacific Silver Fir Zone occurs from 600 to 1,300 meters and includes shrubs like huckleberry (*Vaccinium spp.*) and mock azalia (*Menziesia spp.*) (WDFW 2012). The Mountain Hemlock Zone is dominated by mountain hemlock (*T. mertensiana*) and
extends from 1,300 to 1,700 meters, has snow pack for over half the year, and is characterized by open alpine meadows at the upper elevations (WDFW 2012). These forest zones are effectively represented in Potential Natural Vegetation (PNV) data produced by the US Forest Service (Fig. 4). The PNV data is a the result of a spatial model which uses elevation, slope, aspect, rainfall, soils, and solar radiation to determine the upper and lower elevations for forest zones (USDA Forest Service 2009).

Researchers at the Pacific Northwest Research station have found that there is a relationship between western hemlock stands, pacific silver fir, and mountain hemlock, and elk presence, and this documented association can aid in predicting where elk are located (Boyd et al. 2011). While the vegetation communities are identified by their dominant, often tallest species, it is important to note that the understory vegetation often provides the majority of the nutritional value for elk diet (Jenkins and Starkey 1991).

Land Management in the North Cascades

The 8,600 km² study area is approximately 90% forested and the remaining 10% is a mixture of agriculture, commercial, residential, transportation, utilities, and other (Table 1 and Fig. 5) (WSDOE 2010). The forested land is managed for a variety of objectives: timber production goals (commercial, state, or federal), wildlife and habitat goals, and public recreation. The variety of forest use designations dictates the forest management practices, and these land-ownerships and regulations will be considered by WDFW when they evaluate areas to increase elk forage.
Figure 4: Potential Natural Vegetation (PNV) zone classifications in the study area. Data sources: basemap (ESRI, USGS, NOAA), study area (WDFW 2013), PNV (USDA Forest Service 2009).
Table 1: General landuse in the study area. Data source: Washington State Department of Ecology (WSDOE) 2010.

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Area (km²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>124.01</td>
<td>1.44</td>
</tr>
<tr>
<td>Commercial</td>
<td>26.93</td>
<td>0.31</td>
</tr>
<tr>
<td>Residential</td>
<td>192.45</td>
<td>2.24</td>
</tr>
<tr>
<td>Open space land classified under chapter 84.34 RCW</td>
<td>310.15</td>
<td>3.61</td>
</tr>
<tr>
<td>Public Areas</td>
<td>26.67</td>
<td>0.31</td>
</tr>
<tr>
<td>Transportation/Utilities</td>
<td>29.11</td>
<td>0.34</td>
</tr>
<tr>
<td>Undeveloped land</td>
<td>149.08</td>
<td>1.73</td>
</tr>
<tr>
<td>Unknown or water</td>
<td>52.40</td>
<td>0.61</td>
</tr>
<tr>
<td><strong>Total Non-Forest Area</strong></td>
<td><strong>910.80</strong></td>
<td><strong>10.60</strong></td>
</tr>
<tr>
<td>Designated forest land under chapter 84.33 RCW</td>
<td>1,373.00</td>
<td>15.98</td>
</tr>
<tr>
<td>Noncommercial forest</td>
<td>76.19</td>
<td>0.89</td>
</tr>
<tr>
<td>Public timberland/non-designated forest</td>
<td>6,213.76</td>
<td>72.30</td>
</tr>
<tr>
<td>Timberland classified under chapter 84.34 RCW</td>
<td>20.08</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>Total Forest Area</strong></td>
<td><strong>7,683.04</strong></td>
<td><strong>89.40</strong></td>
</tr>
<tr>
<td>Total</td>
<td>8,593.83</td>
<td>100.00</td>
</tr>
</tbody>
</table>

As a result of the early emphasis on timber harvesting in the Pacific Northwest, much of the forest is a patchy landscape of relatively even aged classes of trees (Franklin and Forman 1987). Logging activity has decreased since the early 1990s when increased timber harvest protections were enacted in response to concerns about protecting mature and old-growth forest habitat for the Northern Spotted Owl (*Strix occidentalis caurina*) and the marbled murrelet (*Brachyramphus marmoratus*) (Carey and Curtis 1996). As a result of increased concerns about managing forests for a mixture of wildlife, habitat, and public use, there has been less logging activity on public forest land than on private commercial forest land (Alig et al. 2000).
Figure 5: Landuse in the study area. Data sources: basemap (ESRI, USGS, NOAA), landuse (WSDOE 2010), roads (WSDOT 2011).
Timber harvesting has both positive and negative effects on elk. The harvesting activity and road construction that accompanies timber harvests are deterrents to elk and often temporarily drive elk away from an area in (Edge and Marcum 1985). Once logging activity has finished, elk may return to the area because the early seral stages of vegetation are highly nutritious and provide quality forage for elk (Thomas et al. 1976). However, logging roads and open habitats can increase vulnerability to predation and hunter harvest (McCorquodale et al. 2003). After 10 years, young trees can be large enough to shade out most of the grasses and forbs and the harvested area no longer provides high quality forage (Cook et al. 2014 in press, Thomas et al. 1976).

Although agriculture land only comprises 1.4% of the land area in the study area, agriculture is a significant component of the economy in the region (Econorthwest 2010). Agricultural activity is located in low elevations and concentrated along State Route 20 and the western boundary of the study area, and to a lesser extent, along State Route 530. Agricultural fields provide highly nutritious forage for elk and their consumption of crops and damage to property are among the main reasons for this project.

Overview of Elk in the North Cascades

The North Cascades was part of the historic home range for Roosevelt elk (*Cervus elaphus roosevelti*) (WDFW 2012), but hunting in the early 1900s significantly reduced the elk population (Couch 1935, Lyon and Christensen 2002). In an effort to boost elk populations for hunting in the North Cascades, game managers augmented the elk herd through reintroductions three times in the early to mid-1900s and again between 2003 and 2005 (WDFW 2012). The majority of the introductions were the Rocky
Mountain sub-species (*C. e. nelsoni*) and, due to interbreeding, the current elk population in the North Cascades is now predominantly the Rocky Mountain sub-species (WDFW 2012).

The population estimate for the North Cascade elk in 1984 was at a record high of 1,700 elk, but dramatically declined to an estimated low of 300 elk by the late 1990s (WDFW 2012). The decrease in the elk populations is thought to have resulted from a combination of factors including intensive logging, increase in road densities, loss of thermal cover, increase in human disturbances, and loss of travel corridors between low and high elevation habitats (WDFW 2002). The estimated population is at least 1,450 elk (C. Danilson, personal communication), and the desired population objective for this population, established in 2002, remains at 1,950 elk (WDFW 2012). The bull:cow ratio estimate between 2006 and 2011 ranged from 24:100 to 37:100, which is well above the statewide target ratio of 12-20 bulls:100 cows (WDFW 2012). The calf:cow ratio ranged from 26:100 to 47:100 between 2006 and 2011, fluctuating around the target ratio of 35-47 calves:100 cows (WDFW 2012). These population ratios are indicative of a stable or growing population with little to no hunting pressure.

The highest densities of elk in this population occupy a core area along the south fork of the Nooksack River and along the Skagit River between Sedro-Wooley and Concrete (WDFW 2012) (Fig. 6). This core area has been determined through aerial surveys and GPS collar data from a sample of the population. This elk population is deemed non-migratory because individuals have relatively small home ranges, but they
do move to lower elevations (below 600 meters) in the winter to avoid heavy snowpack (WDFW 2012).

According to Yocom and Brown (1971), the North Cascade region supports a wide variety of animals that share the landscape with elk. The other ungulates in the region are black-tailed deer (*Odocoileus hemionus columbianus*) (WDFW 2012). Observational data during elk surveys in the North Cascades indicate that the black-tailed deer population is low in the areas occupied by elk, and are therefore not likely significant resource competitors (WDFW 2012). Overall, elk in the North Cascades do not appear to have significant competition for resources from other ungulates.

Elk calves are preyed upon by bears (*Ursus americanus*), bobcats (*Lynx rufus*), dogs (*Canis lupus familiaris*), coyotes (*Canis latrans*), and wolves (*Canis lupus*), while adult elk are hunted by cougars (*Puma concolor*) (Geist 2002). Bobcats and bears are common in the North Cascades, but wolves are not known to occur in the area occupied by elk (WDFW 2012). Cougars are the only large carnivore documented to prey on elk in the North Cascades (WDFW 2012). While this study will not explicitly look at relationship between elk and other wildlife on the landscape, these relationships may help explain any potential anomalies that do not correlate with environmental or human data.

Elk are an important ecological, economic, and aesthetic resource in the Pacific Northwest. Elk is a traditional food and material source for Native Americans (McCabe 2002). Since European settlement in the Pacific Northwest in the 1800s, elk were hunted by Europeans for food and increasingly for recreation starting in the 1900s (O’Gara and
Figure 6: Core area of North Cascade elk. Data sources: basemap (ESRI, USGS, NOAA), core area (WDFW 2002), elk GPS locations (WDFW 2013), study area (WDFW 2013).
Elk are also valued for passive uses such as wildlife watching and photography. Elk can be pests on agricultural lands, which comprise 1.4% of the study area, but these lands are economically important and are part of a mosaic of higher human density in the region.

Hunting permits are a substantial source of revenue for wildlife management. In 2014, a single elk license cost $50.40 for a Washington State resident ($497 for a non-resident) (WDFW 2014). Over the last 30 years there has been an average of 675 permits sold annually, which could have equaled between $30,000 to $300,000 of annual permit revenue depending on the number of resident and non-resident permits (WDFW 2012). In addition to permit revenue, there are benefits to the local economy from hunting activity. Cooper et al. (2002) estimated that elk hunters in Idaho averaged $65 (residents) to $165 (non-residents) in daily expenditures during a hunting trip, with the average hunting trip lasting 4 days (residents) to 6 days (non-residents). Over the last 30 years there has been an annual average of 2,730 hunter days in the North Cascades (WDFW 2012), and using the expenditures estimated by Cooper et al. (2002) these hunter days could have resulted in $177,450 (all resident) to $450,450 (all non-resident) spent by hunters during their hunting trips. However, due to sub-optimal elk population size, starting in 1997, elk hunting in most areas of the North Cascades has been limited to controlling damage on private property (WDFW 2012). Unfortunately, poaching occurs in the North Cascades and is estimated to result in a loss of 5% to 15% of the elk population each year (WDFW 2012).
CHAPTER III

LITERATURE REVIEW

Elk Biology

Elk are large ungulates (hoofed-mammals) that reach an average size of 270 kg to 400 kg (600 lbs to 900 lbs) and live off a diet of foraged vegetation (Hudson et al. 2002). The females (cows) are smaller than the males (bulls) and often live longer (Raedeke et al. 2002). A 1961 study of 254 elk harvested in Montana found the maximum age in the sample was 18.5 years for cows and 12.5 years for bulls (Raedeke et al. 2002). Cows, calves, and yearlings live in herds; whereas bull elk are either solitary or live in bachelor groups for much of the year (Geist 2002). Mating season, or rut, is in the fall, and calves are born May through June (Hudson et al. 2002). Individual elk home ranges vary between 15 km² to 400 km² but tend to be on the smaller end of the range if forage is abundant (Anderson et al. 2005).

Elk are ruminants, meaning they have specialized stomachs with a rumen chamber that temporarily holds their initially ingested food and then allows them to regurgitate and fully chew it later when they are in a safe location (Cook 2002). This behavior of delayed digestion in a safer location likely contributes to elk preferences for habitat areas where forage vegetation (food) is located near cover habitat, which provides protection from predators; this habitat is known as the cover/forage edge (Thomas et al. 1979, Lyon and Jensen 1980). Elk prefer to eat nutritionally-rich forage when available, which is usually grasses (Cook 2002). Due to seasonal variations, moisture-rich grass is
generally only available in the spring and fall, leaving elk to forage more on twigs, leaves, and forbs in the summer, and woody plants and lichens in the winter (Jenkins and Starkey 1991, Cook 2002). The summer months, June through August, are a critical time for elk nutrition because access to adequate forage during the summer enables the rapid growth of calves and fat accumulation in adults which can result in higher rates of winter survival (Cook et al. 2004).

Elk movements across the landscape are guided by a combination of nutritional requirements, temperature regulation, and avoidance behaviors (Ager et al. 2003, Friar et al 2004). According to Hudson et al. (2002), elk nutritional requirements vary depending on season, age, and gender. Elk move to lower elevations in the winter for forage not covered by snow (Sweeney and Sweeney 1984, Christensen et al. 1993) and move to higher elevations in the summer to keep cool (Thomas et al. 1979, Ager et al. 2003). Elk will avoid locations that have high-quality nutritional forage if predators frequent the area (Geist 2002, Friar et al. 2004). In general, elk are known to avoid areas of human activity, such as public roads and active logging areas (Lyon 1979, Christensen et al. 1993). However, there is recent evidence they can become habituated to human activity along the urban-wildlife fringe (Thompson and Henderson 1998). Overall, the daily and seasonal elk movement patterns appear to be driven predominately by forage choices (Jenkins and Starkey 1984, Ager et al. 2003).
Elk Management

Elk are generalists and are able to thrive in a wide range of habitats and move freely across the landscape, however, their adaptability can be a challenge for wildlife managers when elk become habituated to lands where they are not wanted (Walter et al. 2010). The North Cascade elk herd utilizes a combination of public and private lands, much of which is managed specifically for other purposes including timber production, agriculture, and public recreation (Lyon and Christensen 2002). According to Lyon and Christensen (2002), the major land management factors that affect elk are how vegetation in elk habitat is managed, how human access is managed, and how livestock are managed. West of the Cascade crest free range grazing of livestock is not commonly practiced, therefore, the main components that influence elk distribution and abundance here are how vegetation and human activity are managed.

Within the 2012 Draft North Cascade Elk Management Plan, WDFW recognizes that multiple actions are required to achieve the desired elk distribution goals; actions that discourage elk in high conflict areas and other actions that encourage elk in low conflict areas (WDFW 2012). Strategies that encourage elk use of the landscape include vegetation management techniques such as prescribed burning, selective logging, and seeding and fertilizing of forage plants (Myers 1999, WDFW 2012). These practices increase the availability of high-quality nutritional forage. Concurrently, managers can discourage elk from occupying other areas by using fencing, herding, hazing, or strategic hunting (Myers 1999, Walter et al. 2010, WDFW 2012). In the North Cascades, WDFW
has been responding to elk induced damage with corrective measures such as fencing and strategic hunting, while at the same time encouraging forage enhancement. This project is an effort to evaluate landscape-level habitat improvement as a means of developing a more desirable distribution of elk for this population (Myers 1999, WDFW 2012).

It is also important to recognize the spatial and temporal parameters for elk management activities. Elk forage enhancement can be temporary and unintentional, for example the naturally occurring vegetation that grows following a timber clear-cut is high quality forage for elk, but will be shaded out over time as new trees grow decreasing the forage value of the area for elk (Cook et al. 2014 in press, Thomas et al. 1979). In contrast, permanent areas could be designated for forage enhancement which would be maintained with early seral stage forage vegetation. The size, location, distribution, and permanence of forage enhancement areas, and the potential effects of these choices on the elk population, are considered in this project.

This habitat modeling project is focused on identifying areas to enhance forage in order to provide elk with a highly nutritious forage option that minimizes potential for agricultural conflicts with elk. This project is being conducted as part of a larger WDFW management effort to discourage elk presence in areas with high potential for conflict. As the agency advising this project, WDFW is ensuring that management efforts for elk enhancement and discouragement will be compatible and not counterproductive.
Habitat Suitability Modeling with Geospatial Data

Spatial information models are increasingly used by wildlife managers to analyze landscape dynamics that influence species presence and distribution (Behan 1990, Turner et al. 1995). Ecological modeling of species presence is based on the concept of ecological niches, whereby a species’ location is defined by a set of specific ecological parameters (Hirzel and LeLay 2008). The ability to use models to predict a species’ location is useful for wildlife managers because it enables managers to evaluate the implications of various management scenarios (Turner et al. 1995). Various types of models have been developed to predict the occurrence of a species (Ruston et al. 2004) and the success of the models is dependent on the quality of the species ecological knowledge, validity of underlying concepts, testing rigor, and model usability (Garshelis 2000). The Westside Models were developed specifically for use by wildlife managers to evaluate the effects of landscape management scenarios on elk in Western Washington and Oregon (Boyd et al. 2011).

The Westside Models are GIS models that produce a predicted habitat suitability for elk (Rowland et al. 2013). Habitat suitability models rank habitat units according to a researcher-defined scale (Donovan et al. 1987), and with the Westside Models this continuous rank data is represented categorically as a range of predicted use which includes five categories: low, medium-low, medium, medium-high, and high (Rowland et al. 2013). Habitat suitability models are also referred to as habitat capability models (Benkobi et al. 2004), habitat effectiveness models (Holthausen et al. 1994, Lyon and
Christensen 2002), or resource-selection function models (Anderson et al. 2005). The differences in terminology are reflective of the plethora of ecological perspectives which are informing the development of predictive habitat modeling.

The goal in developing a useful habitat suitability model is to identify the fewest number of variables which reasonably explain a species’ presence (Hirzel et al. 2008). The original developers of the Westside Models, Boyd et al. (2011), started with 50 habitat variables known to influence elk distribution and then tested these variables against known elk locations across Western Washington and Oregon to determine which variables were the best predictors of elk presence. From this original set of 50 variables, Boyd et al. (2011) identified 4 variables that “consistently provided the most support for observed selection patterns of elk”: dietary digestible energy (DDE) (higher DDE equals higher elk use), distance from roads open to public access (further from roads equals higher elk use), slope (flatter slopes equals higher elk use), and distance to cover-forage edge (closer to edge equals higher elk use). These four variables are routinely captured in, or can be derived from, freely available geospatial datasets such as vegetation coverage, road networks, and digital elevation models (DEM)s.

It is important to note that habitat suitability modeling describes one perspective on predicting elk location and to recognize that additional perspectives are useful in providing context and interpreting results produced from habitat suitability modeling. The concept of elk choice has significance when conceptualizing why elk are found where they are, but the importance and weight of individual choice is variably included in elk models. Discrete choice models calculate the probability of individual elk choices
given specific available resources (Cooper and Millspaugh 1999). Models that are based on elk point locations from Global Positioning System (GPS) collars are called presence-only models and they are inherently biased because there is no absence data, which is a traditional component for presence/absence location estimates (Friar et al. 2004, Hirzel et al. 2006).

The Westside Models were developed using ecological knowledge of elk presence information and calibrated with GPS presence data; specific absence data was not used to develop these models. Further, the gender of elk has been documented as affecting habitat choice (Unsworth et al. 1998, McCorquodale 2003), and many elk models, including the Westside Models, are based on female elk nutritional requirements (Beck et al. 2006, Boyd et al. 2011, Rowland et al. 2012). Anderson et al. (2005) explored a variety of resource selection function (RSF) models and concluded that, in reality, elk are making different choices at different spatial scales. They found that at landscape level scales, elk avoid wolves and roads, and look for high biomass forage (Anderson et al. 2005). However, in smaller spatial areas elk favor locations with a higher ratio of cover-forage edge (Anderson et al. 2005). Additional factors affecting elk habitat choice include annual seasonality (Ager et al. 2003), predator avoidance (Anderson et al. 2005), avoidance of human activity (McCorquodale 2003), and elk social dynamics (Franklin et al. 1975). Other models besides the Westside Models were not used in this research, however the concepts mentioned of elk choice, scale, season, predators, and presence-only data were kept in mind during the interpretation of results from the Westside Models.
The Westside Models

The Westside Models are a set of GIS habitat suitability models composed of 4 separate “toolboxes”: an Elk Nutrition Toolbox, an Elk Covariate Toolbox, an Elk Use Toolbox, and an Update Base Vegetation Toolbox. The Westside Models were developed by researchers at the U.S. Forest Service’s Pacific Northwest Research Station in LaGrande, Oregon, and are designed to be used by elk wildlife managers to evaluate habitat suitability in Western Washington and Oregon. The Westside Models were developed to be used in a defined area, with a minimum scale (at least 100 km²), and to predict habitat suitability for female elk in the summer months (June, July, and August) (Rowland et al. 2013).

The Westside Models were designed to be used for much of Western Washington and Oregon with regional modifications in order to best incorporate the variation in location influences on vegetation: Nooksack, Springfield, and Willapa Hills (covering both Washington and Oregon) (Fig. 7). The study area is almost entirely within the Nooksack regional analysis area so the specific Nooksack Nutrition Toolbox is used for this project. (There is a small portion that is 200 km², or 2% of the total study area, that is not covered by the Westside Models. This area is on the eastern edge of the study area and is outside the core elk range.) The Westside Models were designed for a spatial scale appropriate for a regional population of elk so the developers recommend that the minimum analysis area is at least 10,000 hectares / 100 km² which is easily accommodated by the 8,600 km² of the study area, and the 800 km² of the model calibration area (Rowland et al. 2013). The output suitability raster map has a 30m x 30m
Figure 7: Location of the three vegetation modeling zones used in the Westside Models (Rowland et al. 2013). Data sources: basemap (US National Park Service), model region (PNWRS 2013).
pixel resolution which the researchers determined is reflective of the smallest spatial scale, or granularity, at which elk respond to landscape features (Boyd et al. 2011). The developers of the models also provide recommendations on how to symbolize and summarize the predicted habitat use outputs from the models (Rowland et al. 2013).

The toolboxes are designed to be run in order starting with the Nutrition Toolbox, then the Covariate Toolbox, and finally the Use Toolbox (Fig. 8). The final output from these main three toolboxes is a predicted habitat suitability coverage raster which ranks the study area landscape from low to high suitability. If vegetation conditions change, or different habitat management scenarios need to be evaluated, then the Update Base Vegetation Toolbox can be used prior to the Nutrition Toolbox to indicate the locations which need to be different (Fig. 8). Because the total predicted habitat suitability for a study area is distributed across the landscape, changes in vegetation or management scenarios calculated using the Update Base Vegetation Toolbox can be directly compared to the original output in order to quantify the relative impact of the change (Rowland, USDA Forest Service, personal communication).

The Elk Nutrition Toolbox predicts the amount of dietary digestible energy (DDE) available to female elk during the summer based on the vegetation input data (Rowland et al. 2013). The model calculations were developed using data from elk grazing studies in Western Washington and Oregon (Cook et al. 2014 in press). The Nutrition Toolbox calculates the DDE based on four inputs: percent canopy cover, proportion of hardwoods, existing vegetation type, and potential natural vegetation (PNV).
Figure 8: Diagram of the Westside Models showing the data inputs and outputs for each of the toolboxes (modified from Rowland et al. 2013).

Three of the vegetation data inputs – percent canopy cover, proportion of hardwoods, and existing vegetation type – are provided by an information rich raster called a gradient nearest neighbor (GNN) data that is produced by the Landscape Ecology Modeling and Mapping Analysis (LEMMA) team based out of the Forestry Science’s Lab at Oregon State University (LEMMA 2013). This GNN data was developed from a multivariate gradient model, which includes coverage of forest species and stand characteristics determined from field plots, environmental conditions, and satellite imagery, and is based on vegetation conditions from 2006 (LEMMA 2013). For this project it was important to ground truth the GNN to verify that it accurately describes existing vegetation communities.
Additionally, in order to calibrate the Westside Models and evaluate habitat management scenarios based on current conditions, it was important to update the GNN data to reflect current conditions. The vegetation updates focused on identifying new areas of forest which had been clear cut since 2006 using Landsat satellite imagery and then running the Vegetation Update Toolbox on these new areas. Leckenby et al. (1985) found that elk habitat maps derived from Landsat satellite imagery were more precise and consistent than those extrapolated from traditional field transects.

The fourth vegetation data input into the Westside Models, the potential vegetation zone (PNV), is a raster dataset that delineates the general vegetation community which would naturally occur in an area based on the elevation, soils, and climate (USDA Forest Service 2009). This PNV data is a generalized habitat zone data that is useful for landscape level analysis and was accepted without change for use in this project.

The Habitat Covariate Toolbox creates 3 output rasters: distance to cover/forage edge, mean slope, and distance to public roads. This toolbox uses the same vegetation data as the Nutrition Toolbox (percent canopy cover, proportion of hardwoods, existing vegetation type, and potential natural vegetation) from the GNN and PNV datasets to calculate a raster coverage depicting distance from cover to forage edge across the study area. The slope data is derived directly from a raster digital elevation model (DEM) by the Elk Covariate Toolbox. This DEM is a standard format for elevation and slope data and was accepted as is for this project. The road data used in this project was developed from the 5 county transportation datasets that are found in the study area. The Westside
models require that roads are identified as open or closed, and this status is a proxy for the level of road use. Because road status in available GIS data was incomplete and outdated it was necessary to derive the likely road status based on road characteristics recorded in the county GIS transportation data. The method used for deriving road status is explained in Chapter VI.

The Elk Use Toolbox combines the three Habitat Covariate Toolbox outputs, distance to cover/forage edge, mean slope, and distance to public roads, with the DDE output from the Nutrition Toolbox, to create the final raster of the predicted level of elk use for the study area. The output is a continuous value raster where a higher value equates to higher predicted use by elk. Rowland et al. (2013) recommend displaying this output using five categories of use based on defined numerical breaks: Low, Medium-Low, Medium, Medium-High, and High.
CHAPTER IV
SYNTHESIS OF ELK LOCATION DATA

Introduction

WDFW collected elk location data as part of a study on elk movements in the North Cascades (Danilson, personal communication.). These data were collected using GPS collars (ATS G2000 model) fitted to individual elk between 2008 and 2010 (ATS 2014). The GPS collars recorded location fixes every 2.5 to 5 hours over the life of the collar, which ranged from a few months up to a year. WDFW retrieved the GPS point location data when the collars were recovered from the animals, by remote release mechanism, during re-capture, or after the elk had been harvested by hunter. WDFW provided the GPS point location data for this project as a GIS shapefile along with basic summary information indicating elk gender, elk ID, and location of initial collaring. I reviewed the elk GPS location shapefile, summarized the data, evaluated the data for outliers, and then used the data to create individual elk home range areas. I used the final GPS point locations and home ranges to support the vegetation verification (Chapter V) and model calibration (Chapter VI) steps, as well as provide a reference for elk location and habitat choice throughout this project.

Methods

In ArcGIS, I isolated and reviewed the location points for each individual elk, both spatially and chronologically, in order to identify potential outlier points that were recorded by the collar before it was put on the elk or after it was removed from the elk. I
used time and distance between fixes, or GPS location captures, to determine the likelihood that a movement from one point to another was a result of an elk or human movement (Bjornerass et al. 2009). Only the points at the beginning and end of each capture sequence were candidates for removal from the dataset because these times are when a collar could have been activated but not attached to an elk (e.g. a collar could have been turned on and driven around prior to affixing to an elk), or may have been recovered from an elk and driven back to the office or lab before being turned off.

Results

I identified a total of 82 GPS points (0.004% of the total) from the original 20,193 as erroneous points and removed them from the dataset. A map of cleaned summer elk locations shows that the majority of the final points were within the core range of the North Cascade elk (Fig. 9).

After I removed the outlier locations from the elk collar GPS data, I summarized the number of locations by elk identification (ID) number and grouped the locations into summers (June, July, or August) by year. One of the goals for this step was to identify the summer with the most female GPS locations which would be used to calibrate the Westside Models. The Westside Models were designed specifically to predict distribution for female elk in the summer so it was important to isolate female summer GPS locations (Chapter VI). With the points grouped by year and summer season, it was evident that the summer of 2009 had the most total points and so this data subset was selected to create home ranges for vegetation sampling and model calibration (Table 2 and Fig. 10).
Figure 9: Elk GPS locations (2008 through 2010). Data sources: basemap (ESRI, USGS, NOAA), core range (WDFW 2002), elk GPS locations (WDFW 2010), study area (WDFW 2013).
Table 2: Summary of elk GPS collar fixes from 2008 through 2010 (WDFW 2010).

<table>
<thead>
<tr>
<th>ID</th>
<th>Sex</th>
<th>Collar ID(s)</th>
<th>Start Date</th>
<th>End date</th>
<th>Fixes 2008</th>
<th>Fixes 2009</th>
<th>Fixes 2010</th>
<th>Total fixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>409</td>
<td>Bull</td>
<td>22248, 22369</td>
<td>5/19/08</td>
<td>10/15/09</td>
<td>407</td>
<td>835</td>
<td>0</td>
<td>2,527</td>
</tr>
<tr>
<td>414</td>
<td>Bull</td>
<td>22249</td>
<td>4/9/08</td>
<td>9/21/09</td>
<td>257</td>
<td>375</td>
<td>0</td>
<td>1,549</td>
</tr>
<tr>
<td>888</td>
<td>Bull</td>
<td>22368</td>
<td>4/10/09</td>
<td>4/6/10</td>
<td>0</td>
<td>300</td>
<td>0</td>
<td>1,101</td>
</tr>
<tr>
<td>410</td>
<td>Cow</td>
<td>22252, 22374</td>
<td>4/8/08</td>
<td>4/8/10</td>
<td>427</td>
<td>772</td>
<td>0</td>
<td>4,635</td>
</tr>
<tr>
<td>413</td>
<td>Cow</td>
<td>22257</td>
<td>4/9/08</td>
<td>12/24/08</td>
<td>436</td>
<td>0</td>
<td>0</td>
<td>1,196</td>
</tr>
<tr>
<td>425</td>
<td>Cow</td>
<td>22253, 22372</td>
<td>4/9/08</td>
<td>3/21/10</td>
<td>12</td>
<td>412</td>
<td>0</td>
<td>1,610</td>
</tr>
<tr>
<td>426</td>
<td>Cow</td>
<td>22256, 22375</td>
<td>4/9/08</td>
<td>8/7/10</td>
<td>422</td>
<td>415</td>
<td>254</td>
<td>2,577</td>
</tr>
<tr>
<td>427</td>
<td>Cow</td>
<td>22254</td>
<td>4/9/08</td>
<td>5/24/09</td>
<td>419</td>
<td>0</td>
<td>0</td>
<td>1,891</td>
</tr>
<tr>
<td>514</td>
<td>Cow</td>
<td>22370</td>
<td>4/9/09</td>
<td>4/7/10</td>
<td>0</td>
<td>342</td>
<td>0</td>
<td>975</td>
</tr>
<tr>
<td>515</td>
<td>Cow</td>
<td>22373</td>
<td>4/9/09</td>
<td>12/8/09</td>
<td>0</td>
<td>376</td>
<td>0</td>
<td>786</td>
</tr>
<tr>
<td>555</td>
<td>Cow</td>
<td>22255</td>
<td>3/6/08</td>
<td>12/11/09</td>
<td>427</td>
<td>34</td>
<td>0</td>
<td>1,260</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,807</td>
<td>3,861</td>
<td>254</td>
<td>20,107</td>
</tr>
</tbody>
</table>

I calculated elk home range areas for the 2009 summer female elk locations as a way of identifying areas to perform the vegetation transects for the Vegetation Verification step (Chapter V) (Fig. 11). I created these home ranges using the Kernel Density Estimation (KDE) technique with a Likelihood Cross-Validation (CVh) smoothing factor smoothing factor and a 95% isopleth (Cresswell and Harris 1988, Anderson et al. 2005). I selected this home range estimate approach because the KDE function identifies the utilization distribution of an individual (Worton 1989), which helps identify the areas the elk spend most of their time. The CVh smoothing factor has a relatively narrow bandwidth smoothing factor compared to the other selections, but I wanted to ensure that the vegetation transects for the vegetation verification step occurred in areas that had been utilized by elk. I created the kernel density home ranges using the
Figure 10: Elk GPS point locations from summer 2009. Data sources: basemap (ESRI, USGS, NOAA), core area (WDFW 2002), Elk GPS locations (WDFW 2010), study area (WDFW 2013).
KDE function in the Geospatial Modeling Environment (GME) (Hawthorne Beyer, Spatial Ecology LLC) in conjunction with the statistical analysis software R and ArcGIS 10.1. (A summary of the KDE estimation technique evaluation performed for this project and reasoning behind the choices is in Appendix A.) The resulting 95% isopleth polygons defined the boundaries within which the vegetation sampling transect locations would be selected.

Discussion

The vast majority of the GPS points were located in the core area. While the GPS collars were only from a small sample of elk, 11 individuals from an estimated population of 1,450, these recorded locations are extremely valuable because they can be overlaid with habitat conditions which were recorded at the same time the elk were there. In the Model Calibration step (Chapter VI) I overlaid these elk locations with the habitat suitability data in order to calibrate the models. The elk home range data is also very useful because it helps identify specific areas of the landscape to visit for vegetation transects. The value of the KDE method of home range estimation is that it emphasizes areas of higher use which was useful for identifying locations for vegetation transects (Chapter IV). It is interesting to note the variation in sizes and shapes of the six home ranges created, much of which is a result of the varying number of GPS points available for each elk.
Figure 11: Home range areas created from 2009 summer cow elk GPS point locations. Data sources: basemap (ESRI, USGS, NOAA), core area (WDFW 2002), elk GPS locations (WDFW 2010), study area (WDFW 2013).
Conclusion

The elk point locations were cleaned of obvious outliers, and the summer 2009 cow home ranges were successfully created using a KDE function with a CVh smoothing factor. Additional analysis could be performed with the elk point location data including analyzing movement vectors, daily and seasonal movement patterns, and comparing male and female location patterns. However, these additional analyses are outside the scope of this project.
CHAPTER V
VERIFYING VEGETATION DATA

Introduction

An important step in the modeling process was to verify that the input data correctly reflects reality. The vegetation data required to run the Westside Models, the GNN data, was created at a landscape level, so I wanted to verify that the data accurately reflected conditions on the ground. I achieved this verification by conducting a small number of vegetation transects in the study area focusing on woody vegetation, which is the focus of the GNN data. The attributes of the GNN data that are utilized in the Westside Models are hardwood percentage, canopy cover, and stand height. In order to verify the GNN data, it was important to collect the same data in the field. I also collected data to determine dominant vegetation type as an additional check to compare with the dominant vegetation estimated in the GNN data. To address the gap in time between when the GNN data was collected (2006) and when the field data was collected (2013), I used satellite imagery from both years to narrow down the potential field transect locations within the 2009 home range areas to locations where the forest had not been visibly altered between 2006 and 2013. This vegetation verification step was designed to be a reality-check on the GNN data, and not a statistically significant survey of the vegetation.

The general location for vegetation verification was identified using the elk home range polygons derived from 2009 cow elk GPS point locations, minus the home range
for cow elk ID #555 (Fig. 12). The 2009 summer range for cow elk #555 was 20 km southeast of the core range and the rest of the 2009 summer elk locations, so this area was

Figure 12: Summer 2009 cow elk home range areas used to identify potential locations for vegetation verification transects. Data sources: basemap (ESRI, USGS, NOAA), elk (WDFW 2010), hydrology (USGS 2011), roads (WSDOT 2011), study area (WDFW 2013).
removed from consideration for vegetation transects in order to focus the field sampling effort. From an analysis perspective, it was important to select a focused study area that had documented elk because the situational knowledge of the habitat gained while running transects in this location informed my understanding of what type of habitat the elk selected. Additionally, the ability to confidently visualize and describe this area provided context for my interpretation of the data inputs into, and outputs from, the Westside Models.

Methods

*Selecting Transect Locations*

Habitat in some areas of the vegetation verification area changed due to logging between when the vegetation data was created (2006) and the time of field work (2013), so it was important to identify areas that looked the same in current aerial imagery as they did in 2006. By selecting sampling locations that have not been logged or dramatically altered, it was possible to make a strong assumption that the location is relatively similar to what it was 7 years ago in 2006, except for 7 years of vegetative growth. Most of the vegetation verification area was on managed timber land, and in these areas if the monoculture stands of Douglas-fir were already well established (over 20 years old) then the composition of dominant tree species would not change significantly in 7 years.

I compared current aerial imagery from Google Maps online imagery (June 2013) to Landsat 5 TM imagery (July 28, 2006) to identify forest areas within the elk home range polygons that had not been logged since 2006. This comparison resulted in the potential transect areas shown in Figure 13.
Figure 13: Potential vegetation verification transect areas. Data sources: basemap (ESRI, USGS, NOAA), hydrology (USGS 2011), roads (DNR 2006, WSDOT 2011).

Using the potential transect areas, I created a series of field maps in ArcGIS using Bing streaming aerial imagery, USGS topographic maps, and detailed road system data from Department of Natural Resources (WADNR 1996). WDFW personnel reviewed these field maps and identified the potential areas that were accessible as
mainly occurring on managed timber forest north of Hamilton, Washington, owned by Sierra Pacific Industries (SPI). Through talks with WDFW personnel and SPI personnel I learned which areas were accessible for transects and could be sampled in a few days. I then obtained the proper keys and permission necessary to access the managed forests.

Field Data Collection

I conducted initial sampling on July 12 and 13, 2013, and then returned to the area for additional sampling on October 18, 2013. Once on SPI land, I selected the sites for the vegetation transects based on accessibility and feasibility of completing transects approximately 40 m long (5 sampling points, each 10 m apart). I located areas that fell within the potential vegetation transect polygons, and then once at the site, identified an area that was representative of the forest stand and could contain a transect of 40 m long and approximately 10 m wide. I established the transect by measuring out 40 m, and at each 10 m interval starting with zero, marked a sample point with a pin flag, for a total of 5 sample points. At each sample point I conducted a point-center quarter (PCQ) transect: I measured the distance to the nearest tree in each quadrant, recorded the tree species, and diameter breast height (dbh) (Cottam and Curtis 1956). I calculated tree species frequency, density, and importance values from the PCQ data (Brower et al. 1997).

I collected comparable data from the GNN data by creating simulated transects and sampling points in the approximate location of the PCQ transects. During field work, I recorded one GPS point location (latitude and longitude) at the start of each field transect and these GPS points were converted to point shapefiles in ArcGIS and used to establish the digital transect I used to sample the GNN data. Because there was only one
GPS point for each transect, I created the additional sample points in ArcGIS to approximate the rest of the field sample transect locations (also 40 m long, with a sampling point at each 10 m interval starting at zero). At each sampling point I used the ArcGIS Identify tool to click on the GNN data and identify the values for dominate tree species, hardwood percentage, canopy cover, and stand height. I also recorded the Potential Natural Vegetation (PNV) value for each sampling point (USDA Forest Service 2009). The resolution of the GNN data is 30 m x 30 m so the digital sampling transect was adequate for capturing the relatively coarse scale GNN data (LEMMa 2013).

Results

There were a total of 32 GPS point locations recorded for all of the areas visited during the field work. Only a portion of the original potential transect area was accessible due to road closures in some areas and high logging traffic in other areas. The majority of the locations that were visited were just north of Hamilton and up the CP-100 road along the Nooksack River (Fig. 14). A total of 8 PCQ transects were completed over the 2 field work events and they all were within the home range of the same elk, cow elk #425 (Fig. 15).

Of the areas that were accessible, only a subset were suitable for conducting vegetation transects. The limitations encountered included: finding locations that were consistent enough to support 40 m transects without significantly changing in forest composition or slope, extremely dense 2 m to 3 m tall understory vegetation which was
Figure 14: Location of all areas visited during field work in July and October 2013. Data sources: basemap (ESRI, USGS, NOAA), hydrology (USGS 2011), roads (WSDOT 2011, DNR 1996).

not practical for PCQ transects (Fig.16), and eventually finding locations that were compositionally different than the locations I already sampled. I did sample a number of locations that had tall regularly-spaced, Douglas-fir with a relatively open understory of ferns and downed wood (Fig.17), but after sampling a number of these areas I attempted tried to find other types of forest compositions in which to run transects, but the remainder of what I saw were locations with tall (25 m – 50 m) trees with either open
understory with ferns or dense brambles, or younger trees (3 m – 5 m) that were too dense to sample effectively (cannot move or see) or safely (potential bear encounters).

Figure 15. Location of the eight Point-Center Quarter (PCQ) sites. Data sources: roads (DNR 1996), aerial imagery (ESRI).
Figure 16: Stand of tall Douglas-fir with dense understory vegetation.

Figure 17: Stand of tall Douglas-fir with open understory dominated by sword ferns.
Douglas-fir (*P. menziesii*) is the dominant tree species at all 8 transect locations and is the only tree species at sites 2, 3, 4, and 6 (Table 3). This Douglas-fir dominance exactly matches the GNN 2006 data for the same locations (see Table 4). Interestingly, the PNV data indicates that all of the sites would be Western Hemlock if they had been left in a natural state instead of replanted with Douglas-fir after timber harvesting.

### Table 3: Point Center Quarter calculations for the 8 transect sites (Brower et al. 1997).

<table>
<thead>
<tr>
<th>Site</th>
<th>Species</th>
<th>n</th>
<th>Relative Density</th>
<th>Relative Frequency</th>
<th>Relative Coverage</th>
<th>Importance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>P. menziesii</em></td>
<td>18</td>
<td>0.9</td>
<td>0.714</td>
<td>0.887</td>
<td>2.501</td>
</tr>
<tr>
<td></td>
<td><em>T. heterophylla</em></td>
<td>2</td>
<td>0.1</td>
<td>0.286</td>
<td>0.113</td>
<td>0.499</td>
</tr>
<tr>
<td>2</td>
<td><em>P. menziesii</em></td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td><em>P. menziesii</em></td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td><em>T. heterophylla</em></td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td><em>P. menziesii</em></td>
<td>18</td>
<td>0.9</td>
<td>0.714</td>
<td>0.76</td>
<td>2.374</td>
</tr>
<tr>
<td></td>
<td><em>T. heterophylla</em></td>
<td>1</td>
<td>0.05</td>
<td>0.143</td>
<td>0.12</td>
<td>0.313</td>
</tr>
<tr>
<td></td>
<td><em>T. plicata</em></td>
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<td>0.05</td>
<td>0.143</td>
<td>0.12</td>
<td>0.313</td>
</tr>
<tr>
<td>6</td>
<td><em>P. menziesii</em></td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td><em>P. menziesii</em></td>
<td>7</td>
<td>0.35</td>
<td>0.417</td>
<td>0.65</td>
<td>1.417</td>
</tr>
<tr>
<td></td>
<td><em>T. heterophylla</em></td>
<td>1</td>
<td>0.05</td>
<td>0.083</td>
<td>0.007</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td><em>T. plicata</em></td>
<td>11</td>
<td>0.55</td>
<td>0.417</td>
<td>0.343</td>
<td>1.309</td>
</tr>
<tr>
<td></td>
<td><em>Cornus nuttallii</em></td>
<td>1</td>
<td>0.05</td>
<td>0.083</td>
<td>0</td>
<td>0.133</td>
</tr>
<tr>
<td>8</td>
<td><em>P. menziesii</em></td>
<td>8</td>
<td>0.4</td>
<td>0.417</td>
<td>0.667</td>
<td>1.483</td>
</tr>
<tr>
<td></td>
<td><em>T. heterophylla</em></td>
<td>5</td>
<td>0.25</td>
<td>0.25</td>
<td>0.204</td>
<td>0.704</td>
</tr>
<tr>
<td></td>
<td><em>T. plicata</em></td>
<td>7</td>
<td>0.35</td>
<td>0.333</td>
<td>0.129</td>
<td>0.812</td>
</tr>
</tbody>
</table>

The PCQ data for each transect location was compared to the GNN data for the same locations (Table 4). The field work PCQ data was averaged across all sampling points for each transect location to get 1 field work (FW) data value for each transect location. The GNN data was recorded at each of the 5 sampling points at each transect.
but the values were identical at each sampling point, so Table 4 shows only 1 GNN data value for canopy cover (gnn_cc), hardwood percentage (gnn_HW), stand height (gnn_SH), and dominant tree species (gnn_Dom). The identical values at each transect were due to the coarse resolution of the GNN data. All transects were conducted on Sierra Pacific Industries timber property, which is forest land managed for timber production. Most of the forest is covered with relatively even-aged timber so the field work stand height measurements were a good representation of the stand height of the whole stand area being sampled.

Table 4: Summary comparison of Point-Center Quarter field data and Gradient Nearest Neighbor digital data (FW = field work, cc= canopy cover, HW = hardwood, SH = stand height, Dom = dominant).

<table>
<thead>
<tr>
<th>Site</th>
<th>FW_CC</th>
<th>gnn_cc</th>
<th>FW_HW</th>
<th>gnn_HW</th>
<th>FW_SH</th>
<th>gnn_SH</th>
<th>FW_Dom</th>
<th>gnn_Dom</th>
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</thead>
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<td>1</td>
<td>95.84</td>
<td>96</td>
<td>0</td>
<td>15</td>
<td>34</td>
<td>53</td>
<td>PSME</td>
<td>PSME</td>
</tr>
<tr>
<td>2</td>
<td>92.3</td>
<td>62</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>19</td>
<td>PSME</td>
<td>PSME</td>
</tr>
<tr>
<td>3</td>
<td>80.45</td>
<td>62</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>19</td>
<td>PSME</td>
<td>PSME</td>
</tr>
<tr>
<td>4</td>
<td>92.03</td>
<td>72</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>17</td>
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<td>PSME</td>
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<tr>
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<td>7</td>
<td>0</td>
<td>7</td>
<td>4.5</td>
<td>3</td>
<td>PSME</td>
<td>PSME</td>
</tr>
<tr>
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<td>7.08</td>
<td>11</td>
<td>0</td>
<td>11</td>
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<td>5</td>
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<td>PSME</td>
</tr>
<tr>
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<td>92.51</td>
<td>72</td>
<td>1</td>
<td>80</td>
<td>28.9</td>
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<td>PSME</td>
<td>PSME</td>
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<td>94.6</td>
<td>92</td>
<td>0</td>
<td>18</td>
<td>29.9</td>
<td>35</td>
<td>PSME</td>
<td>PSME</td>
</tr>
</tbody>
</table>

The field work measurements for canopy cover and stand height are similar to the measurements recorded in the GNN data, however the GNN data significantly overestimated the proportion of hardwood at half of the locations. At 4 sites (1, 5, 6, 8)
the actual and estimated canopy cover was within a few percent of each other, but at the other four sites (2, 3, 4, 7) the field work canopy cover was more than 20% greater. The GNN stand height at 5 of the locations was very similar to the field data collected (2, 5, 6, 7), but at 2 of the locations (3 and 4) the GNN data is almost 15 m shorter than the field data, and at 2 locations (1 and 8) the GNN data was actually greater than the field data. The GNN data estimated 0% hardwood at 3 locations (2, 3, 4) which matches the field work data, but the field work data revealed that there were no hardwoods present at all but 1 location (7), while the GNN data indicated that 5 locations did have hardwood (1, 5, 6, 7, 8), with site 7 listed as 80% hardwood.

Discussion

Some of the variation between the PCQ data and the GNN data can likely be attributed to the fact that there has been 7 years between when the vegetation data used for the GNN data was surveyed (2006) and when the PCQ transects were conducted (2013). The sites chosen for the transects had not visibly changed according to comparisons of aerial imagery from 2006 to 2013, so the only substantial change would have been increase in tree height and potentially canopy cover over the 7 years from 2006 to 2013. There were generally larger numbers for canopy cover and stand height in the field work data as compared to the GNN data, and this is consistent with the idea that trees would have grown bigger (both taller and increased branch and needle coverage) over the last 7 years. Some of the data was inconsistent with this idea of increased growth
over time, sites 1 and 8, where the stand height was over 15 m greater in the GNN data than in the field work data.

The GNN data was successful at identifying the dominant tree species (Douglas-fir) at all transect locations, even when the PNV for all transect locations is Western Hemlock. Also, approximately half of the canopy cover, stand height, and hardwood proportion measurements matched the field work data. Overall, for the GNN data having been created at a landscape level, it appears to have generally captured the vegetation community in the Vegetation Verification Study Area.

If I had additional time for an increased field sampling effort I could have produced a more robust field data set to compare with the GNN data. This larger dataset would have enabled me to develop a statistically significant evaluation of the similarity of the two data sets (paired t-test). Ideally, I would use a restricted random sampling protocol to sample at least 10 sites within each forest stand age category in order to have an adequate sample of each forest age class (Elzinga 1998). I would overcome the issues of dense understory vegetation by sampling these locations in the fall after senescence, or in the early spring before leaf regrowth.

Conclusion

As stated in the introduction to this chapter, the field work to verify the vegetation was designed to determine if the attributes of the GNN data that are used by the Westside Models are a reasonably accurate reflection of the actual conditions on the ground. Based on the comparison of the field work data with the GNN dataset, the GNN data is a
reasonable depiction of actual vegetation conditions. The GNN data was created at a landscape level with a multitude of data inputs, however, for all the transect locations the dominant species was correct, and at half of the field sample locations, the canopy cover, stand height, and hardwood proportion was similar to the GNN digital data. At the other half of the locations these measurements were off by over 20% (canopy cover) or 15 m (stand height). If I had more time to conduct more robust vegetation sampling, I would have been able to develop a statistically significant comparison of the field data with the GNN digital data. However, the field work did serve its intended purpose of providing a reality check on the GNN data and I was able to verify that the dominant tree species, stand height, and canopy cover measurements collected in the field were similar to the values in the GNN data at the same locations. As a result of the similarity between the field data and GNN digital data, I concluded that the GNN digital data is reliable as the base input vegetation data for Westside Models in the study area.
CHAPTER VI

CALIBRATING THE WESTSIDE MODELS

Introduction

The PNWRS spent considerable time and effort developing and testing the Westside Models, however, before I could confidently use the Westside Models to create elk habitat suitability maps, I wanted to compare the output from the Westside Models with known elk point location data. The available elk point location data is from 2008 to 2010, with the majority of the summer points from 2009, but the vegetation input data for the Westside Models is based on conditions from 2006. In order to effectively compare the elk location data with the output from the Westside Models it was necessary to update the vegetation data using the Vegetation Update tool and acquire suitable road status data which reflected conditions in 2009. I then compared the habitat suitability based on the 2009 vegetation and roads to the known elk locations to determine how successful the Westside Models are at predicting elk locations.

Model Calibration Area

I delineated the model calibration area by drawing a rectangle around the known elk locations from summer 2009 and then adding a 4 km buffer as per the Westside Model guidelines (Rowland et al. 2013) (Fig. 18). The 4 km buffer is important because the characteristics of the landscape within 4 km from the designated study area influence the habitat suitability calculations for the study area. Both cow and bull elk locations
from summer 2009 were used to define the study area and were compared to the model output. Even though the Westside Models were specifically designed for cow elk habitat suitability predictions it was interesting to see if the model outputs were correlated with bull elk locations. Cow elk #555 was not included in this model calibration step because there were only 34 summer GPS point locations, these locations were over 30 km outside
the core elk range, and extending the study area to include these points would have significantly increased the size of the calibration study area.

Methods

Updating Vegetation

The Vegetation Update tool in the Westside Models is primarily designed to update the base GNN data with polygons delineating forest areas where the trees have been removed, which in this region is often a result of timber harvesting. While it would have been possible to manually digitize the forest cut areas from aerial imagery, it would have been time consuming for the 1,100 km$^2$ model calibration area with 4 km buffer, and it would have been an even more significant task to achieve for the 8,600 km$^2$ study area that I needed to model for this project. Instead, I developed a method for extracting early seral stage (ESS) areas (Hall et al. 1995) from satellite imagery using spectral analysis and supervised classification of Landsat satellite imagery with Erdas Imagine software (Thomas et al. 1976, Cook et al. 2014 in press, Rowland personal communication). One of the goals for developing this method was to create a method that was easily repeatable and which could be shared with other users of the Westside Models and GIS professionals. (See Appendix B for a detailed explanation of the method used to identify early seral stage areas.)

The most cloud-free satellite image available for 2009 was Landsat 5 Thematic Mapper (TM) satellite imagery from August 16, 2009 (Fig. 19). The ESS areas were extracted from the image by performing a hybrid parameteric/non-parametric supervised
classification (Kloer 1994) in Erdas Imagine and then converting the classified raster to a polygon feature class (Fig. 20). Only ESS polygons greater than or equal to 2 acres were included in the final ESS dataset (Fig. 21).

Figure 19: Landsat 5 TM image from August 16, 2009 used to identify early seral stage areas. Data sources: Landsat (USGS 2014), roads (WSDOT 2011).

It is important to note that agriculture lands and high alpine meadows have been included in the ESS classification because during the supervised classification process the
spectral response pattern of soil covered with low vegetation is similar for clear cuts, agriculture land, and high alpine meadows. However, elk are likely responding to all of these low growing vegetation areas in the same way so it was reasonable to maintain all

Figure 20: Early seral stage areas identified through supervised classification of Landsat 5 TM imagery from August 16, 2009. Data source: basemap (ESRI, USGS, NOAA). of these young ground cover vegetation areas in the cut areas polygons (Rowland personal communication). I evaluated the option of masking out the cut area polygons
that overlapped with agricultural parcels, or using elevation thresholds to mask out low elevation agriculture lands and high elevation alpine meadows, however these masks could not be systematically applied to the whole landscape due to variation in agriculture parcel designation and variation in elevation of agriculture parcels and alpine meadows. Therefore, in order to avoid an unsystematic manual selection and masking of remaining

Figure 21: Early seral stage areas greater than 2 acres identified through supervised classification of Landsat 5 imagery from August 16, 2009. Data source: basemap (ESRI, USGS, NOAA).
parcels I made the decision to use all polygons classified as ESS as is. (For a smaller study area classification could be ground-truthed, but the goal for this area was to capture general ESS patterns across a large landscape.) This 2 acre threshold was used because the supervised classification process resulted in thousands of areas smaller than 2 acres which were creating a lot of noise in data and obscuring the larger patterns of ESS patches on the landscape. Additionally, Rowland et al. (2013) stated that the Vegetation Update tool was not designed to update cut areas on a pixel by pixel basis, rather it was designed to update on a forest stand basis. Comparison of the original Landsat image with the supervised classification revealed that many of the ESS areas smaller than 2 acres were often road shoulders or bends in the road. In contrast, areas that were larger than 2 acres generally appeared to be actual timber harvest areas in the forest.

The Vegetation Update Tool was run with the 2 acre or greater ESS area polygons and then the output from this step was used in place of the original GNN data as the input vegetation data for the Nutrition Tool component of the Westside Models (refer back to Fig. 7 for model workflow). The Habitat Covariate Tool was run using this updated vegetation output in place of the original GNN data.

**Updating Roads**

Rowland provided a portion of the road status data from 2009 (which was based on the Bureau of Land Management (BLM) road data) and I developed the remainder of the road status data by systematically querying road coverage data from the Department of Natural Resources (DNR). The PNWRS had used a portion of the WDFW elk point location data to validate their model, and in doing so had spent considerable time
updating a subset of the BLM roads dataset in order to identify what roads were open or closed. This open vs. closed classification was developed by Rowland et al. (2013) as a proxy for road usage meaning that a road that is gated and closed to public use, but has high logging traffic, would be considered open, while a dead end country road with only a few houses could be considered closed (Jennifer Hafer, USDA Forest Service, personal communication). The open or closed road status is the variable that is analyzed by the Habitat Covariate Tool, and one of the outputs from this tool is a coverage map showing the distance from public roads. This distance value is weighted and taken into consideration by the final tool, the Habitat Use Tool, in order to predict elk habitat suitability.

I combined the classified road status data from the PNWRS with a current DNR roads dataset that I had classified using a systematic series of queries. I made the assumption for this step that although a 2009 road dataset was not readily available, there is probably a high likelihood that the road status has not changed drastically in 4 years for most (if not all) roads in the model calibration area. In the DNR road dataset, there is an attribute field for “status” but approximately only 10% of all roads had any data entered in this field so it was necessary to develop a system to classify all roads as either open or closed. In order to classify the remaining roads as open I performed the following series of queries on the BLM roads data in the following order:

- Set a definition query as "TRANS_RTE_TY" = 10 , to select out just roads (not trails or ferry routes)
- Selected all roads within the city boundaries and classified as open
- Selected all roads with "ROAD_SUR_TY" = 1, to select paved roads, and classified as open
- Selected all roads with "ROAD_CLASS_CD" IN ( 1, 2, 3) , to select primary highway (1), secondary highway (2), and light duty roads (3), and classified as open
- Selected "ROAD_ACT_STAT_CD" = 10, to select roads that are active and classified as open
- Selected "ROAD_ACC_CD" = 1 to select roads that are open year round with no gate, and classified as open
- Selected "ROAD_ACC_CD" IN (2,3,4) to select roads that have temp gate (2), are management access only (3), are not drivable by 4 wheel drive (4), and set to closed
- Selected "ROAD_MAINT_CD" = 3 to select roads that are decommissioned, and set to closed
- Selected "ROAD_ACT_STAT_CD" IN (20, 30, 40) to select roads that are inactive (20), abandoned (30), or orphaned (40), and set to closed
- Everything that has not been categorized as open at this point was classified as closed

After the series of selection steps and classifications were completed, I reviewed the resulting road status map and verified that it consistently classified main arterial roads as open and lower use rural roads as closed, capturing the general patterns road of activity
observed in the area (Fig. 22). Once the vegetation and roads data had been updated, I ran the Westside Models and then compared the resulting habitat suitability output with the known elk locations.

Figure 22: Final road status map for the model calibration area. Data sources: roads (derived from BLM, Pacific Northwest Research Station 2009, and Department of Natural Resources 1996), terrain (ESRI, USGS, NOAA).
Results

The output from the final tool in the Westside Models, the Habitat Use Tool, is a raster of continuous values indicating the predicted level of use, with higher values equaling higher levels of use. Rowland et al. (2013) offer a few qualifications to help understand what the results mean:

1. The values are continuous across the study area modeled, but are not standardized and so cannot be compared between study areas.
2. It may be useful to divide the study area into sub-areas, and then sum the predicted use by sub-area as a way of identifying the relative predicted use for sub-areas.
3. The best method for classifying and displaying the variation in the prediction values will depend on the data (5 classes of equal area or quantiles were provided as examples).

Rowland et al. (2013) explains that using the equal area classification can be difficult to see resulting variations between the different map categories. To illustrate this, I displayed the predicted habitat use with 5 equal interval categories (Fig. 23) and then with 5 quantiles (Fig. 24). With the equal interval categories, it appears that most of the landscape has a low predicted use, but with the quantile classification, there appears to be a lot more variation in the predicted use. Feedback from Rowland (personal communication) confirmed that the quantile approach was a conventional way of displaying this data, so I choose to use quantiles to display all the predicted habitat use output data in this step, and all subsequent steps.
Figure 23: Predicted elk habitat use in 2009 displayed using equal interval classification.

The 2009 predicted habitat use was overlaid with elk GPS point locations from summer 2009 in order to determine if there was a relationship (Fig. 25 shows 2009 summer home range areas instead of GPS point locations so that predicted use values are
Figure 24: Predicted elk habitat use in 2009 displayed using quantile classification. The numbers of cow and bull elk found in each classification, from low to high predicted use, are shown in Table 5. A bar chart, Fig. 26, helps visually convey that there is a correlation between higher predicted level of use classifications and higher numbers
Figure 25: Summer 2009 elk locations, represented by home range areas, overlaid with predicted habitat use.

of cow elk found. The Pearson product-moment correlation coefficient test for cow elk exhibited a significant correlation ($r = 0.947$, $p = 0.014$) with the predicted levels of habitat use. This significant correlation provides support for the ability of the Westside Models to effectively predict cow elk habitat suitability. In contrast, the bull elk locations
did not have a significant correlation ($r = 0.458$, $p = 0.437$) with the predicted levels of habitat use. Bull elk appear to be more strongly correlated with a medium predicted level of use.

Table 5: Number of summer 2009 elk GPS points in each predicted habitat use classification.

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Med-Low</th>
<th>Med</th>
<th>Med-High</th>
<th>High</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009 Cow</td>
<td>68</td>
<td>339</td>
<td>486</td>
<td>737</td>
<td>683</td>
<td>2313</td>
</tr>
<tr>
<td>% Cow</td>
<td>2.94%</td>
<td>14.66%</td>
<td>21.01%</td>
<td>31.86%</td>
<td>29.53%</td>
<td>100.00%</td>
</tr>
<tr>
<td>2009 Bull</td>
<td>103</td>
<td>296</td>
<td>424</td>
<td>455</td>
<td>232</td>
<td>1510</td>
</tr>
<tr>
<td>% Bull</td>
<td>6.82%</td>
<td>19.60%</td>
<td>28.08%</td>
<td>30.13%</td>
<td>15.36%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Total</td>
<td>171</td>
<td>635</td>
<td>910</td>
<td>1192</td>
<td>915</td>
<td>3823</td>
</tr>
</tbody>
</table>

Figure 26: Number of cow and bull elk summer locations per predicted habitat suitability classification in 2009.
Discussion

There is a strong correlation \((r = 0.947, p = 0.014)\) between known cow elk summer locations and areas of high predicted habitat use. The Westside Models were rigorously tested by the PNWRS, and there was a strong assumption going into this evaluation that the Westside Models would be successful for predicting areas of elk habitat suitability. However, this model calibration step was important in order to understand how known elk locations correlated with predicted habitat suitability within the study area. According to the calibration results, cow elk are more strongly associated with the higher habitat suitability classifications, while the bull elk are most strongly associated with the medium-high habitat suitability. The Westside Models were designed to target summer nutritional requirements for cow elk so it is appropriate that the cow elk locations are more strongly correlated with the outputs from these models than bull elk locations. However, it is useful to note that elk locations are not constrained solely to high habitat suitability. The elk in the North Cascades are considered to be non-migratory (WDFW 2012), however they are moving across the landscape, and the location of their movements coincide with patterns of predicted elk habitat suitability.

Conclusion

The output from the Westside Models, based on 2009 vegetation and road data, was significantly correlated \((r = 0.947, p = 0.014)\) with 2009 summer cow elk locations. By working through the data development steps necessary to create the data inputs into the Westside Models, and documenting how the predicted habitat suitability output from
the models correlated with known elk locations, I verified that the Westside Models function as expected. In conclusion, this model calibration effort demonstrates that the Westside Models are effective for producing elk habitat suitability landscape classifications which are highly correlated with summer cow elk GPS data.
CHAPTER VII

ELK HABITAT SUITABILITY IN 2013

Introduction

Prior to creating potential elk habitat management scenarios, it was necessary to update the elk habitat suitability data to reflect the most current conditions, which was summer 2013. The procedures used in Chapter V to update data for the model calibration step were also used for this step but were expanded to cover the whole study area. After updating the road status and cut vegetation data to 2013 conditions, I ran the Westside Models to produce a base predicted elk habitat suitability coverage for the study area. Discussions with WDFW then yielded preliminary landscape constraints regarding where forage enhancement areas should not be located with respect to agricultural areas and elevation, and these constraints were then overlaid on the 2013 predicted habitat suitability. The resulting figure provided the starting place for the discussions with WDFW and the Forage Enhancement Committee (FEC) of the North Cascades Elk Management Working Group to identify potential areas where forage could be enhanced to support WDFW elk management goals.

Methods

I used the same methodology as in the Chapter V Model Calibration step to update the vegetation and road data inputs into the Westside Models. I also used the same series of queries used in Chapter V to classify the DNR road data in order to produce the open or closed road status for each road in study area. The study area covers portions of 5 counties, and the DNR road data is grouped by county, so the queries were...
completed on each county individually and the resulting open or closed status was reviewed to ensure that the status results were consistent with the overall DNR primary, secondary, and tertiary road data. The vegetation data was updated using the same methodology as in the Chapter V Model Calibration step, but the supervised classification was run on Landsat 8 imagery from July 3, 2013 because this was the most cloud-free Landsat image from the summer of 2013. I then ran the Westside Models to create the predicted use for the whole study area.

After modeling predicted habitat use, I added forage enhancement site location constraints to the predicted habitat suitability for the entire study area. The objective of these constraints (suggested by WDFW) was to block out areas that are not likely to be considered for future forage enhancement due to the proximity to existing agriculture or location above a threshold elevation (Fig. 27). The agricultural buffer constraint of a half mile was suggested out of concern that enhancing forage near agricultural land could potentially attract elk to the neighboring agricultural areas and exacerbate existing agricultural damage issues or create new ones. A 2,000 ft elevation constraint was selected because snowpack during the winter months generally confines the distribution of the elk population to elevations of 2,000 ft and below. Forage enhancement sites below 2,000 ft are more likely to attract and retain elk in areas with low conflict potential by maintaining forage throughout the year. I identified these elevation areas by using the ArcGIS tool Raster Reclassify on the DEM and reclassifying the DEM to above 2,000, or 2,000 ft and below.
Figure 27: Agriculture and elevation constraints for locating elk forage enhancement areas. Data sources: agriculture parcels (WDFW 2014), basemap (US National Park Service), DEM (USGS 2013), roads (WSDOT 2011).
Results

The results from this analysis are a predicted elk habitat suitability coverage for the entire study area (Fig. 28) and a map showing the predicted suitability coverage overlaid with the elevation and agricultural buffer constraints requested by WDFW, the focus area (Fig. 29). The total area found within each predicted habitat suitability classification was calculated for the whole study area, and then clipped by the elevation and agriculture constraints to reveal the area remaining for consideration for forage enhancement (Table 6).

Table 6: Total area within each predicted habitat suitability class in the whole study area, and in the remaining focus area after the agriculture and elevation buffers were applied.

<table>
<thead>
<tr>
<th>Predicted Suitability</th>
<th>Study area (km²)</th>
<th>Focus area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1,984</td>
<td>535</td>
</tr>
<tr>
<td>Medium-Low</td>
<td>1,699</td>
<td>468</td>
</tr>
<tr>
<td>Medium</td>
<td>2,129</td>
<td>616</td>
</tr>
<tr>
<td>Medium-high</td>
<td>1,336</td>
<td>355</td>
</tr>
<tr>
<td>High</td>
<td>969</td>
<td>185</td>
</tr>
<tr>
<td>Total</td>
<td>8,117</td>
<td>2,159</td>
</tr>
</tbody>
</table>

Discussion

The constraints of the half-mile agriculture buffer and 2,000 ft elevation mask significantly limit the potential area available for elk forage enhancement. After applying these constraints to the 8,600 km² study area, there was 2,159 km² remaining for consideration for elk forage enhancement. The patterns of predicted habitat suitability
Figure 28: Predicted elk habitat suitability based on 2013 data. Data sources: basemap (ESRI, USGS, NOAA), roads (WSDOT 2011), study area (WDFW 2013).
Figure 29: Predicted elk habitat suitability in 2013 overlaid with agriculture and elevation constraints. Data sources: agricultural lands, (WDFW 2013), roads (WSDOT 2011), terrain (ESRI, USGS, NOAA).
within this 2,159 km² can be evaluated in two main ways: 1) by using the suitability rating to identify areas of low suitability that could be improved, and 2) by using the general patterns of suitability and elk use to guide the development of a high (or low) suitability corridor.

In areas of with low predicted suitability it is important to identify which of the factors are contributing to the low suitability rating: steep slopes, close distance to roads, and/or long distance to cover/forage edge. It is not practical to change the slope, so if steep slope is the main reason that there is low predicted suitability then this area will always be classified as having low suitability. If short distance to public (open) roads is the reason behind the low suitability rating for an area, then, in theory, habitat suitability would be improved by closing roads. However, feedback from WDFW staff regarding attempts to close roads for elk management in Ellensburg, WA indicate closing roads is difficult to achieve because of resistance from the public wanting to maintain access for recreation (William Moore, WDFW, personal communication.). However, predicted habitat suitability can be improved by clearing timber in forest patches, such as occurs with logging clear cuts. This reduces distance to cover/forage edge and increases forage quality by creating the forest opening that will produce highly nutritious early seral stage forage vegetation.

Another way the predicted habitat suitability can be analyzed is by identifying how patterns of low or high habitat suitability can be connected to achieve elk management goals. For example, if there are two patches of high suitability in an elk
tolerant area, separated by an area of low suitability, then it might make sense enhance forage in the low suitability area to increase the habitat connectivity for the elk.

Conclusion

The roads and vegetation input data were successfully updated to produce baseline predicted elk habitat suitability for the study area that reflects current conditions in the summer of 2013. This predicted suitability map was overlaid with the agriculture buffer and elevation constraints requested by WDFW which produced a map of all possible areas within the study area that were considered for elk forage enhancement.
CHAPTER VIII
ELK FORAGE ENHANCEMENT SCENARIOS

Introduction

The identification of potential elk habitat management scenarios evolved through a series of discussions with WDFW and the FEC. The FEC is composed of self-selected representatives of the following groups who are interested in elk forage enhancement efforts in the North Cascades: agricultural landowners, Department of Natural Resources, Puget Sound Energy, Skagit Land Trust, Stillaguamish Tribe of Indians, Swinomish Indian Tribal Community, Tulalip Tribes, Upper Skagit Indian Tribe, U.S. Forest Service, WDFW, and local citizens. The FEC was created by WDFW to develop recommendations for elk forage enhancement that would support WDFW elk management goals. Forage enhancement refers to creating forage areas for elk by: thinning forest, clear cutting, clearing slash piles, and seeding areas (clear cut area, roadsides, log landings) with a seed mix of site appropriate elk forage plants, which often includes ryegrass, orchard grass, and clover (USVEMG 2010). Forage enhancement can be short-term until the forest naturally regenerates, or can be maintained as a long-term site through mowing, seeding, and control of non-forage plants.

The scenarios modeled here focused on identifying on potential site locations for forage enhancement. I presented the baseline habitat suitability map to WDFW and the FEC, and this map served as a starting point for a dialogue regarding where to create focal Forage Enhancement Areas (FEAs). Through these discussions a number of
important factors were identified that needed to be considered when selecting locations for forage enhancement.

At the regional landscape scale it was important to consider land use patterns, topography, and potential elk movement patterns, and at local scale it was important to consider adjacent habitat patches, hydrologic features factors, slope and aspect. By working through the important factors at each scale I was able to identify two general areas for elk forage enhancement. Within each of these areas I created a set of potential forage enhancement sites, which, for modeling purposes, are early seral stage (ESS) polygons. I ran these potential ESS areas through the Westside Models and produced the predicted elk habitat suitability for each FEA. The results from this modeling exercise are not a recommendation to cut forest patches exactly where I have drawn them, but are to be used as a starting point for evaluating possible locations, patterns, site sizes, and impacts of forage enhancement areas.

Site Selection Process

*Study Area Scale*

I presented the baseline predicted habitat suitability for the study area to WDFW and the FEC, and through a series of discussions it was evident that the study area landscape could be divided into 6 generalized zones (Fig. 30). These zones were the general areas within the study area that were not covered by the 0.5 mile agricultural buffer, and were below 2,000 ft. During the discussions it became clear that 4 of the zones were unsuitable for forage enhancement (A, D, E, and F), and 2 of the zones were designated by WDFW as suitable for consideration for forage enhancement (B and C).
Figure 30: Baseline predicted elk habitat suitability showing six generalized landscape zones delineated to focus discussion regarding suitable forage enhancement areas. Data sources: agricultural lands (WDFW 2013), basemap (ESRI, USGS, NOAA), roads (WSDOT 2011).
Proximity to agriculture, outside of elk core range, and conflict history were the main reasons for unsuitable designation. Zone A, around the town of Acme, was eliminated as a candidate for enhancement sites because this area has had high numbers of elk damage claims. It would be counterproductive to create forage enhancement sites in Zone A where the landowners are trying to discourage elk. Zone D, southeast of Mount Vernon, is a large area of potential habitat, however, this area is adjacent to a large concentration of agricultural lands. Additionally, there are currently no major elk conflict issues in this area because there are no elk in this area, and WDFW is not promoting elk expansion outside the existing core range at this time. It does not seem wise to create a potential elk conflict situation in this zone by augmenting habitat because of the likelihood that the elk will opportunistically forage in the agricultural areas as well.

Zone E, north of Darrington, was discussed for a while because there is a lower concentration of agriculture land in this area, and although this is outside of the elk core range, elk have been consistently documented here (Danilson, personal communication.). However, there were the two important negatives for Zone E: this area is outside the core range and this area is between two concentrations of agriculture land.

Zone F, between Arlington and Monroe, is a large, long, area inbetween agricultural land and the 2,000 ft elevation threshold. The concerns in this area were that any elk encouraged by forage enhancement here would also opportunistically forage in the adjacent agricultural lands, and that the area is outside of the core elk range. As a
result of the various concerns mentioned, Zones A, D, E, and F were removed from consideration for elk forage enhancement.

Further distance from agriculture, location within the core range, and low conflict history were the main reasons that two of the zones were deemed suitable for potential forage enhancement. Zone B, south of Acme and north of Hamilton, is a candidate for forage enhancement because it is within the core elk range, and the area along the South Fork of Nooksack River is not adjacent to any agriculture lands. Zone C, north of Concrete and around Lake Shannon and Baker Lake, is within the core elk range area and there is only one agricultural landowner just north of Concrete. Zones B and C became the focus for the next step of evaluation with the goal of identifying specific sites that would be suitable for forage enhancement. These zones are hereafter referred to FEA B and FEA C.

Local Scale

In focusing in on FEAs B and C, it became evident that there were local scale level considerations for siting elk forage enhancement areas, such as local land use and elk movement patterns. In FEA B, there is a large area north of Hamilton that could potentially be considered for forage enhancement. However, this area is adjacent to a high density of agriculture land and State Route 20, and elk damage issues and traffic collisions are of concern in this area. North of this area is a higher elevation ridgeline, with Mt. Joesphine, oriented on a west to east axis which could serve as a potential natural barrier for elk. While this is a permeable barrier because elk are not strictly constrained by high elevations and will move back and forth via Lyman Pass on a
seasonal basis (Danilson, personal communication) elk will often choose to move parallel
to a slope because moving perpendicular to a slope requires more energy (Anderson et al.
2005). Employing the idea of guiding elk movement using the landscape it made sense to
locate the forage enhancement sites along the north side of the South Fork of the
Nooksack River (Fig. 31). The goal would be to encourage and retain elk movements
within the South Fork of the Nooksack River valley to counter tendencies to move south
towards the agriculture lands along the Skagit River.

The goal for the forage enhancement sites in FEA C would be to keep elk from
moving south out of the Lake Shannon area toward Concrete, so the sites would ideally
attract and maintain elk numbers away from the agricultural lands along State Route 20.
In FEA C there is only one large agriculture property so it would be important to create a
corridor of high quality habitat that guided the elk away from the agriculture land (Fig.
32).

Forage Enhancement Site Selection

Forage enhancement site selection was achieved by working through a series of steps
to identify potential site locations, evaluating their potential to contribute to the overall
elk forage enhancement goal, and finally ensuring that site characteristics are favorable
for enhancement areas. First, I used the predicted habitat suitability to identify areas of
lower habitat suitability that could be improved with enhancement. Then using a
topographic map, I identified general characteristics about the area that would affect site
placement, such as slope and hydrology. Finally I overlaid the ESS data (created during
Figure 31: Forage Enhancement Area B. Data sources: agriculture parcels (WDFW 2013), core range (WDFW 2002), elevation (USGS), hydrology (USGS 2011), roads (WSDOT 2011).
Figure 32: Forage Enhancement Area C. Data sources: agriculture parcels (WDFW 2013), core range (WDFW 2002), elevation (USGS), hydrology (USGS 2011), roads (WSDOT 2011).
the vegetation update in Chapter VI) with the predicted suitability and topography to help guide the placement of the FEAs.

I drew forage enhancement sites in FEAs B and C using a set of guiding principles. These guiding principles were either noted during discussions with WDFW and the FEC, discovered during research on elk movements and forage choices, or are from prior habitat management knowledge:

1) Sites cannot be too large or else they are hard to maintain (5 acres is small, 50 acres is large), and there is circumstantial evidence that elk prefer smaller forage areas (Tony Fuchs, Puget Sound Energy, personal communication.); Kendrick (2008) aimed for elk forage enhancement sites no larger than 15 acres.

2) Locations should be accessible by road or else they are hard to maintain. However, they should not be visible from the road so as to reduce potential hazing or hunting pressure (Kendrick 2008).

3) Elk prefer to move parallel to a slope instead of perpendicular (Anderson et al. 2005).

4) Mesic areas (Hanley 1984) and wet meadows are preferred elk forage areas (Collins and Urness 1983, Jenkins and Starkey 1984).

5) However, enhancement areas should be set back from hydrological features so that there is a forest buffer between forage areas and water (to minimize any potential increases in sediment load in the water) (Kendrick 2008).
6) Ideally locations should ideally be established as permanent forage enhancement areas in order to confer the most return on management effort and long term benefit for the elk (FEC, personal communication).

In addition to the guidelines mentioned, the general goal was to create sites in areas of lower habitat suitability. However, in an effort to explore how site locations changed the patterns of predicted habitat suitability, I drew some sites in areas of medium-low and medium suitability. From a management perspective, it is useful to understand how much the habitat suitability of an area can be altered with the addition of forage enhancement sites.

Initially, I considered land ownership and landuse restrictions when evaluating areas for potential sites. However, these concerns seemed premature and they detracted from developing scenarios which were most ecologically appropriate. As the forage enhancement site evaluation process progresses, it will become necessary to evaluate land ownership and landuse restrictions at all sites. However at this stage of analysis it was most useful to create scenarios based solely on the environmental and habitat characteristics of the landscape.

Forage Enhancement Area B: South Fork of the Nooksack River

The potential forage sites in FEA B follow the South Fork of the Nooksack River upstream with the intention of creating a corridor of improved forage that will draw the elk further up the valley (Fig. 33). Sites in the northern section of the focus area are located on the north side of the river to encourage the elk to stay north of the river instead of moving southward through Lyman Pass to the slopes north of Hamilton. The sites
further east in the valley are also along the north side of the South Fork Nooksack River, and the goal with these sites was to provide a corridor of improved forage that would retain the elk in this river valley. The majority of these sites are also in low elevations or on south facing slopes because these locations have a higher growing potential and so there is a higher likelihood that seeded forage plants will be successful. As low elevation sites, these areas will be available as forage locations during the winter. A total of 25 sites were drawn in FEA B, for a total of 278 acres (Fig. 34, Table 7).
Figure 33: Location of potential forage enhancement sites in Forage Enhancement Area B. Data sources: agricultural lands (WDFW 2013), hydrology (USGS 2011), roads (DNR 1996), topographic base map (National Geographic Society).
Figure 34: Potential forage enhancement site numbers in Forage Enhancement Area B. Data sources: core range (WDFW 2013), hydrology (USGS 2011), topographic basemap (National Geographic Society).

Table 7: Area (acres) of potential forage enhancement sites in Forage Enhancement Area B along the South Fork of the Nooksack River.

<table>
<thead>
<tr>
<th>Site #</th>
<th>Acres</th>
<th>Site #</th>
<th>Acres</th>
<th>Site #</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.1</td>
<td>10</td>
<td>18.3</td>
<td>18</td>
<td>13.6</td>
</tr>
<tr>
<td>2</td>
<td>8.1</td>
<td>11</td>
<td>10.2</td>
<td>19</td>
<td>11.4</td>
</tr>
<tr>
<td>3</td>
<td>7.1</td>
<td>12</td>
<td>9.9</td>
<td>20</td>
<td>12.6</td>
</tr>
<tr>
<td>4</td>
<td>4.7</td>
<td>13</td>
<td>9.3</td>
<td>21</td>
<td>11.9</td>
</tr>
<tr>
<td>5</td>
<td>6.5</td>
<td>14</td>
<td>10.1</td>
<td>22</td>
<td>8.8</td>
</tr>
<tr>
<td>6</td>
<td>9.3</td>
<td>15</td>
<td>19.8</td>
<td>23</td>
<td>12.8</td>
</tr>
<tr>
<td>7</td>
<td>9.7</td>
<td>16</td>
<td>14.7</td>
<td>24</td>
<td>10.2</td>
</tr>
<tr>
<td>8</td>
<td>5.8</td>
<td>17</td>
<td>13.8</td>
<td>25</td>
<td>16.4</td>
</tr>
<tr>
<td>9</td>
<td>9.4</td>
<td>Total</td>
<td>277.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Forage Enhancement Area C: Lake Shannon and Baker Lake

The sites drawn in FEA C were located to give the elk a high quality forage area that could attract and retain elk, providing an alternative to the agriculture areas near Concrete, WA. The potential forage enhancement sites were arranged in a line paralleling the banks of Lake Shannon in an attempt to create a forage corridor that is furthest from the agriculture land, and would draw elk away from the agriculture land. The majority of the land along the western banks of the lakes were south facing with low-angle slopes, so the main guiding goals in this area were selecting areas set back from water edges and roads (Fig. 35). A total of 30 sites were drawn in FEA C, for a total of 448 acres (Fig. 36, Table 8).

Table 8: Area (acres) of potential forage enhancement sites in Forage Enhancement Area C along the western banks of Lake Shannon and Baker Lake.

<table>
<thead>
<tr>
<th>Site #</th>
<th>Acres</th>
<th>Site #</th>
<th>Acres</th>
<th>Site #</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.6</td>
<td>11</td>
<td>21.4</td>
<td>21</td>
<td>13.3</td>
</tr>
<tr>
<td>2</td>
<td>13.3</td>
<td>12</td>
<td>18.6</td>
<td>22</td>
<td>18.0</td>
</tr>
<tr>
<td>3</td>
<td>9.5</td>
<td>13</td>
<td>20.2</td>
<td>23</td>
<td>12.7</td>
</tr>
<tr>
<td>4</td>
<td>6.8</td>
<td>14</td>
<td>14.7</td>
<td>24</td>
<td>22.1</td>
</tr>
<tr>
<td>5</td>
<td>13.3</td>
<td>15</td>
<td>14.3</td>
<td>25</td>
<td>22.7</td>
</tr>
<tr>
<td>6</td>
<td>10.1</td>
<td>16</td>
<td>10.6</td>
<td>26</td>
<td>16.9</td>
</tr>
<tr>
<td>7</td>
<td>7.3</td>
<td>17</td>
<td>16.9</td>
<td>27</td>
<td>25.8</td>
</tr>
<tr>
<td>8</td>
<td>5.8</td>
<td>18</td>
<td>18.0</td>
<td>28</td>
<td>10.1</td>
</tr>
<tr>
<td>9</td>
<td>21.1</td>
<td>19</td>
<td>20.1</td>
<td>29</td>
<td>15.9</td>
</tr>
<tr>
<td>10</td>
<td>13.1</td>
<td>20</td>
<td>12.4</td>
<td>30</td>
<td>8.2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>448.0</td>
</tr>
</tbody>
</table>

95
Figure 35: Location of potential enhancement sites in Forage Enhancement Area C. Data sources: agriculture parcels (WDFW 2013), hydrology (USGS 2011), roads (DNR 1996), topographic basemap (National Geographic Society).
Figure 36: Potential forage enhancement site numbers in Forage Enhancement Area C. Data sources: agriculture parcels (WDFW 2013), hydrology (USGS 2011), roads (DNR 1996), topographic basemap (National Geographic Society).
Potential Sites Evaluated Using the Westside Models

The 55 potential sites from both FEAs were added to the cut area polygons used to update the vegetation from 2006 to 2013 conditions (Chapter IV), and then the Westside Model tools were run creating the potential forage enhancement scenario (hereafter referred to as the scenario). The predicted habitat suitability output from the scenario is symbolized using the same quantile breaks used for the 2013 baseline predicted habitat suitability so that any changes between the baseline and scenario can be directly compared. A summary area was drawn around each of the enhancement areas, using the 2,000 ft elevation contour and lake edges as a guide where appropriate, in order to isolate the FEAs and compare the scenario impacts at the local scale (Rowland personal communication).

Results

In the Forage Enhancement Area B (South Fork of the Nooksack River) there was a net increase of 816 acres of higher habitat suitability (which includes medium, medium-high, and high suitability) and a net decrease of 816 acres of lower quality habitat (which includes low and medium-low suitability) (Table 9). The changes in habitat suitability patterns are evident in Fig. 37 which shows both the baseline habitat suitability and modeled changes. The results are displayed according to the boundaries of the summary area. The modeled changes are based on 25 forage enhancement sites, which comprise a total of 278 acres (1.13 km²) acres of proposed forage enhancement.
Table 9: Comparison of predicted habitat suitability classification areas in Forage Enhancement Area B between baseline in 2013 and the potential forage enhancement scenario.

<table>
<thead>
<tr>
<th>Predicted Suitability</th>
<th>Baseline (acres)</th>
<th>Scenario (acres)</th>
<th>Change (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>734</td>
<td>289</td>
<td>-445</td>
</tr>
<tr>
<td>Medium-Low</td>
<td>2768</td>
<td>2397</td>
<td>-371</td>
</tr>
<tr>
<td>Medium</td>
<td>1444</td>
<td>1944</td>
<td>500</td>
</tr>
<tr>
<td>Medium-high</td>
<td>584</td>
<td>900</td>
<td>316</td>
</tr>
<tr>
<td>High</td>
<td>124</td>
<td>124</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>5654</td>
<td>5654</td>
<td>0</td>
</tr>
</tbody>
</table>

In Forage Enhancement Area C (along the western edge of Lake Shannon and Baker Lake) there was a net increase of 1,773 acres of increased habitat suitability (medium, medium-high, and high) and a net decrease of 1,773 acres of lower habitat suitability (medium-low and low) (Table 10). The changes in habitat suitability patterns are evident in Fig. 38, which shows both the baseline habitat suitability and the changes created by the modeled scenario. The results are displayed according to the boundaries of the summary area. The modeled changes are based on 30 forage enhancement sites, which comprise a total of 448 acres (1.82 km$^2$) of proposed forage enhancement.

Discussion

The potential forage enhancement sites for both FEA B and C comprised a total of 726 acres (2.9 km$^2$) of direct enhancement, and produced a combined improvement of 2,589 acres (10.5 km$^2$) in habitat suitability. There was a 1,863 acre additional improvement to habitat suitability beyond the 726 acres of directly manipulated area within the whole study area; 2.57 acres of improved habitat for every acre of direct
Figure 37: Comparison of habitat suitability between baseline and modeled enhancement scenario using 25 potential forage enhancement sites along the South Fork of the Nooksack River. Data sources: elevation (USGS 2013), hydrology (USGS 2011).
Table 10: Comparison of predicted habitat suitability classification areas in Forage Enhancement Area C between baseline in 2013 and the potential forage enhancement scenario.

<table>
<thead>
<tr>
<th>Predicted Suitability</th>
<th>Baseline (acres)</th>
<th>Scenario (acres)</th>
<th>Change (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>982</td>
<td>266</td>
<td>-716</td>
</tr>
<tr>
<td>Medium-Low</td>
<td>3,307</td>
<td>2,250</td>
<td>-1057</td>
</tr>
<tr>
<td>Medium</td>
<td>2,050</td>
<td>2,914</td>
<td>864</td>
</tr>
<tr>
<td>Medium-high</td>
<td>1,524</td>
<td>2,393</td>
<td>869</td>
</tr>
<tr>
<td>High</td>
<td>355</td>
<td>395</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>8218</td>
<td>8218</td>
<td>0</td>
</tr>
</tbody>
</table>

manipulation. From a management perspective it is useful to understand that according to the Westside Models, forage enhancement efforts have the potential for improving habitat suitability beyond just the areas that are enhanced. This effect is a function of how the Westside Models calculate habitat suitability of an area by including the suitability of the surrounding sites (Rowland et al. 2013). This functionality produces the phenomena where an increase in 1 acre of enhancement can produce a greater than 1 acre total increase in habitat suitability. A forage enhancement site will increase the overall suitability of the land surrounding the site.

In FEA B (South Fork of the Nooksack River), the 25 forage enhancement sites totaled 278 acres and produced 816 acres of improved habitat suitability. There was a 538 acre additional improvement to habitat suitability beyond the 278 acres of manipulated area within the FEA B summary area; 1.94 acres of improved habitat for every acre of manipulation. The enhancement sites in FEA B produced a smaller impact on the total
Figure 38: Comparison of habitat suitability between baseline and the modeled enhancement scenario using 30 potential forage enhancement sites along the western edge of Lake Shannon and Baker Lake. Data sources: elk core range (WDFW 2002) elevation (USGS 2013), hydrology (USGS 2011).
habitat suitability of the FEA B summary area as compared to FEA C. The differences in impacts are related to differences in site characteristics between FEA B and FEA C, and these are explored in more detail later in the discussion.

In FEA C (Lake Shannon and Baker Lake) the 30 forage enhancement sites totaled 448 acres and produced 1,773 acres of improved habitat suitability. There was a 1,325 acre additional improvement to habitat suitability beyond the 448 acres of manipulated area within the FEA C summary area; 2.95 acres of improved habitat for every acre of manipulation. The enhancement sites in FEA C produced a greater impact on the total habitat suitability of the FEA C summary area as compared to FEA B. The differences in impacts are related to differences in site characteristics between FEA B and FEA C, and these are explored in more detail later in the discussion.

Since the Westside Models combine the 4 habitat covariate layers (DDE, distance to cover/forage edge, mean slope, and distance to roads) to create a final predicted habitat suitability it was useful to review each of the habitat covariate layers for FEA B and C in an effort to identify underlying factors that contributed to the greater impact of forage enhancement in FEA C than in FEA B.

**Forage Enhancement Area B Habitat Covariates**

The forage enhancement sites increased the mean DDE around the sites from low-marginal to high-marginal (Fig. 39), and the distance from cover/forage edge decreased around the potential forage enhancement sites (Fig. 40). The distance to public roads ranking shows that there is not much variability in distances to public roads, but there are some areas in FEA B which are closer to roads (eastern and western portions of the
summary area), and some areas which are further from public roads (central portion of the summary area) (Fig. 41). The mean slope raster (Fig. 41) shows that there are low angle slopes along the South Fork of the Nooksack River, but much of the area on the north side of the river, where the potential forage enhancement sites were drawn, are steeper slopes. Referring back to Fig. 37, which shows the comparison of predicted habitat suitability between baseline and scenario, it appears that the potential forage enhancement sites that were located in the steeper slope areas do not have a large effect on improving the habitat suitability. The idea that the slope has a strong influence on how potential forage enhancement sites can influence habitat suitability is supported when reviewing the habitat covariate rasters from FEA C.
Figure 39: Comparison of mean dietary digestible energy (DDE) between the baseline conditions and the forage enhancement scenario in Forage Enhancement Area B. Data sources: elevation (USGS 2013), hydrology (USGS 2011).
Figure 40: Comparison of distance to cover/forage edge between the baseline conditions and the forage enhancement scenario in Forage Enhancement Area B. Data sources: elevation (USGS 2013), hydrology (USGS 2011).
Figure 41: Distance to public roads and mean slope grid outputs from the Westside Models in Forage Enhancement Area B. Data sources: elevation (USGS 2013), hydrology (USGS 2011).
Forage Enhancement Area C Habitat Covariates

In FEA C the potential forage enhancement sites increased the DDE and decreased the distance to cover/forage edge around the sites (Fig. 42 and Fig. 43). The distance to public roads figure (Fig. 44) shows that there is a longer distance to public roads in many areas along the western edge of Lake Shannon and Baker Lake. The mean slope figure (Fig. 44) shows that there are medium angle slopes on the southern half of the summary area, along the western edge of Lake Shannon, and low angle slopes along the western edge of Lake Baker. Referring back to Fig. 38, which shows the comparison of predicted habitat suitability between baseline and scenario, it appears that the potential forage enhancement sites that were located in the steeper slope areas did not have as large an effect on improving the habitat suitability as the sites located on lower angle slopes.

The potential forage enhancement sites in FEA B were all between 500 ft (152 m) and 1,600 ft (478 m) and were generally on steeper slopes than the areas in FEA C. The potential sites in FEA C were all between 600 ft (183 m) and 1,000 ft (305 m) and were on shallower angle slopes. The distances to open roads in FEA B generally appeared to be closer than the distances to open roads in FEA C. In both FEAs, the variations in distances to public roads did not appear to have as much impact on habitat suitability as the variation in slope. In FEA C, the potential forage enhancement sites located in the areas with lower angle slopes on the western edge of Baker Lake appeared to have a greater impact on increasing habitat suitability than the sites located in higher angle slopes.
Figure 42: Comparison of mean dietary digestible energy (DDE) between the baseline and the forage enhancement scenario in Forage Enhancement Area C. Data sources: elevation (USGS), elk core range (WDFW 2002), hydrology (USGS 2011).
Figure 43: Comparison of distance to cover/forage edge between baseline and the forage enhancement scenario in Forage Enhancement Area C. Data sources: elevation (USGS 2013), elk core range (WDFW 2002), hydrology (USGS 2011).
Figure 44: Distance to public roads and mean slope outputs from the Westside Models in Forage Enhancement Area C. Data sources: elevation (USGS 2013), elk core range (WDFW 2002), hydrology (USGS 2011).
The goal of creating corridors of connected higher suitability habitat using the forage enhancement sites was strongly limited by the influence of slope. In both FEA B (Fig. 37) and FEA C (Fig. 38), the potential forage enhancement sites did improve the habitat suitability; however, in the areas of higher angle slopes, the improvements often only improved areas to medium quality habitat, which might not be enough of an improvement to attract and retain elk compared to habitat patches which have naturally occurring high habitat suitability. Additional consultation with the creators of the Westside Models, in conjunction with additional research, would be useful for delineating how habitat suitability varies with increases in slope.

Part of the forage enhancement evaluation process should include strategic fencing or hazing as part of the solution set to move elk away from conflict areas. In FEA B (Fig. 37) there are two areas of naturally occurring high habitat suitability that may act as natural corridors funneling elk from the South Fork of the Nooksack River south into the forest land north of agriculture areas along the Skagit River. If further research supported this hypothesis, it might be useful to set up strategic fencing to block this movement of elk and direct them back towards the South Fork of the Nooksack River. In FEA C (Fig. 38), it might prove useful to use strategic fencing to exclude elk from the agriculture area and encourage them to move further up the valley. These ideas of using the habitat suitability patches as corridors for elk movement should be tested in order to provide verification of the concept.
Conclusion

These preliminary FEA scenarios show that forage enhancement sites can increase the overall habitat suitability for an area by a magnitude of 1.94 (FEA B) to 2.95 (FEA C) and that the overall impact appears to be most strongly influenced by slope. While it appears possible to use forage enhancement sites to create corridors of improved habitat suitability, these ideas should be tested when the actual forage enhancement scenarios are created. This exercise demonstrates that the Westside Models are effective at guiding selection of forage enhancement sites. The scenarios suggested by this research provide a baseline for WDFW in evaluating how potential site locations may impact patterns of elk habitat suitability.
CHAPTER IX
SYNTHESIS AND RECOMMENDATIONS

The goal of this research was to use the Westside Models to evaluate elk habitat suitability in the North Cascades and to develop forage enhancement scenarios that could prescriptively help alleviate elk damage on agriculture areas. Throughout this research, it was important to also evaluate how effective the spatial data were at capturing reality. It was reassuring that through various stages of the research, specifically the Vegetation Verification and Model Calibration steps, I determined that the digital data and the Westside Models were appropriate for the task at hand. The GNN vegetation data was comparable to the vegetation data collected during field work and the predicted habitat suitability created using the Westside Models correlated strongly with known summer cow elk location data ($r = 0.95$, $p = 0.014$).

The Westside Models were used to model the impact of potential forage enhancement sites on habitat suitability in two potential forage enhancement areas in the North Cascades. This modeling scenario demonstrated that there is a range of habitat improvement impacts from forage enhancement sites. A 1 acre enhancement can produce a 1.94 to 2.95 acre increase in habitat suitability, and this range in impact is primarily a function of the slope of the area; there will be a greater return of enhanced habitat by investment in areas with lower angle slopes. The results of this research show the potential outcomes from forage enhancement and demonstrate the value and utility of the Westside Models to evaluate a variety of aspects of elk habitat management planning.
The habitat suitability maps developed in this project were used by WDFW and
the FEC to identify general areas for forage enhancement. The FEC meetings were
attended by representatives from various agencies, tribes, companies, and local
landowners. These representatives shared their interests, concerns, and viewpoints
regarding elk forage enhancement in the study area. Additionally, many of the attendees
shared that knowledge of this predicted habitat suitability could continue to be very
useful for them in their short and long term planning. Additional work with these
stakeholders is one way that the land ownership and land use considerations would be
evaluated. Currently, it is only possible to speculate which landowners are willing to
enhance forage on their property or how much money is available to purchase and
manage land for elk forage enhancement. Ideally additional modeling scenarios using the
Westside Models can be used to explore resource management options with the various
stakeholders.

In conclusion, the Westside Models are an effective way to model elk forage
enhancement scenarios in the North Cascades. The baseline predicted habitat suitability
outputs from the models was useful for evaluating the landscape in order to develop
potential forage enhancement scenarios. Additionally, this modeling effort demonstrated
that slope is an important factor to consider when selecting locations for forage
enhancement.
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APPENDIX A: ELK HOME RANGE ESTIMATION

Defining Home Range

A variety of terms and definitions are used to describe the concept of a home range, so it is important to clarify the meaning of the term and how it will be used in this research. A definition of home range was introduced in 1943 by W.H. Burt as “the area around the home site, over which the animal normally travels in search of food”. Burt contrasts this to the term territory which is “the protected part of the home range, be it the entire home range or only the nest” (Burt 1943). According to Altman’s (1952) behavioral study, elk do defend themselves; however, behavioral observations are not part of the GPS point location dataset so only the point locations themselves will be considered for the purposes of elk home range mapping in the North Cascades, (Altman 1952). An important concept from Burt’s discussion is that there can be multiple home ranges, and they can vary depending on age, gender, and season (Burt 1943). Dixon and Chapman (1980) also discuss the concept of core areas and that animals can have more than one core area.

Home Range Estimation Methods

Home range estimation methods evolved from basic quantifications of animal locations based on trapping data (Mohr 1947, Hayne 1949, Stickel 1954) to more mathematical estimations based on statistical analysis of location information (Van Winkle 1975, Anderson 1982, Dixon and Chapman 1980, Worton 1989). The idea of a minimum convex polygon was presented by Mohr in 1947 and is achieved by connecting the outside points of trap locations. In 1954, Hayne built on the boundary polygon idea
and added an averaging component to create a center of activity point that is the spatial average for all the known points. Also in 1954, Stickel presented the boundary strip method which builds upon the known trap locations by halving the known distances that the animal travels, and adding that buffer to either side of the known trap locations. However, these presence-absence point based estimates are not able to quantify density of use. Statistical methods for home range estimation were developed starting in the late 1960’s and began to incorporate frequency and probability into estimation techniques.

Statistical estimations of home range in the literature are often termed non-parametric, but do appear to be based on spatial and temporal distribution assumptions. In 1969, Jennrich and Turner presented the bivariate normal method which is based on the assumption that animal locations have a normal distribution, and a contour line can be drawn around the point locations that will contain 95% of the points; the resulting polygon is the home range of the animal. In 1975, Van Winkle presented an estimation method that built on early central place theory and added an assumption of normal distribution to create a utilization distribution estimate for home range modeling. Andersson (1978) expanded this model to an optimal foraging model which assumes that intensity of use declines with increasing distance from the central location. In 1980, Dixon and Chapman developed the harmonic mean technique that would allow for multiple centers, and the home range could be described by contours, or isopleths, of use. In 1989, Worton developed the kernel density estimate which incorporates the density of points into a ranking of the home range structure that can be shown with isopleths of decreasing use from location clusters. The kernel density estimation method is widely
used and considered to be reliable, but is sensitive to the choice of smoothing factor (Hemson et al. 2005).

Kernel Density Estimates

While there is significant discussion in the literature regarding the general importance of avoiding spatial autocorrelation in order to satisfy the statistical assumptions of probabilistic utilization, there is also discussion of how concerns of autocorrelation are not relevant to animal GPS location data (Worton 1989, De Solla et al. 1999). Dunn and Gipson (1977) were critical of transferring the idea of probabilistic utilization from trapping location data to radio telemetry data because they assert that with the “high sampling frequency, statistical independence seems impossible.” However, when Worton (1989) presented the kernel density estimate method he asserted that “kernel methods free the UD [utility distribution] estimate from the parametric assumptions and provide a means of smoothing location data.” In 1999, De Solla et al. aimed to nullify the autocorrelation discussion by demonstrating how creating sub-samples of telemetry data in order to avoid autocorrelation does not improve the home range estimates. De Solla et al. (1999) conclude that researchers should use all the location data when developing the home range estimates and should not be concerned with autocorrelation. Logically this conclusion makes sense because animals are not probability distributions (Getty 1981) and each location is related to previous locations, and all the locations reflect an animal’s range.

There are different types of kernel density estimates (KDE) but the different methods for smoothing the kernels can create vastly different depictions of home range
size and shape. In order to understand the effects of the smoothing factors, I ran KDEs on one of the North Cascades elk, ID #413 using the six different KDE smoothing options available in the ks (kernel smoothing) R Statistical package utilized by the Geospatial Modeling Environment (GME) (Hawthorne Beyer, Spatial Ecology LLC). The GME program was chosen because of the ability to manipulate the parameters of estimation for the KDE analysis. Additionally, there are three types of kernel estimates that can be used in GME - Gaussian (or normal), bivariate, or uniform - but only the Gaussian estimate creates a variable output for this dataset (the outputs from the other types are uniform rasters).

In the KDE estimation in GME, there are six smoothing options available for the Gaussian data: biased cross-validation (BCV), biased cross-validation 2 (BCV2), least-squares cross-validation (LSCV), smoothed cross-validation, PLUGIN, and likelihood cross-validation (CVh) (Duong 2007) (Fig. A1 and A2). The two BCVs and the LCSV have a larger areas estimated for the home range, PLUGIN and SCV smoothing produce a medium-sized area estimate, and CVh produces the smallest home range area estimate. I also created a 95% isopleth from each raster which outlines the home range areas that will contain the elk 95% of the time (Harris et al. 1988, Anderson et al. 2005).
Figure A1: Kernel Density Estimate (KDE) (with 95% isopleth) of home range for elk ID # 413 using four smoothing factors: BCV, BCV2, LSCV, and SCV.
Figure A2: Kernel Density Estimate (KDE) (with 95% isopleth) of home range for elk ID # 413 using two smoothing factors: Plugin and CVh.

While comparing the KDEs and trying to decide which would be most appropriate for elk in the North Cascades, I realized that what Sanderson (1966) says is true: “no one technique for location or analysis gives the best answer for all species in all situations.” For this North Cascades elk habitat suitability research, it was important to select the smoothing factor that produced the most condensed home range, which is the CVh, because it was valuable to identify and perform vegetation transects in exact areas that had documented elk presence. This smaller home range area is useful for identifying the specific habitat patch locations and movement corridors utilized by elk. For this reason, the KDE with the CVh smoothing factor was used to create the elk home ranges.
APPENDIX B: USING LANDSAT IMAGERY TO MAP
EARLY SERAL STAGE AREAS IN THE NORTH CASCADES

Introduction

Landsat imagery is a rich source of information about landscape patterns because it captures the spectral signatures of features. In the remote sensing image analysis program Erdas Imagine, it is possible to delineate locations that are representative of features on the landscape (such as water, snow, forest, rock, fields), and then use these sample locations to train the software to classify the whole image. The first goal of this imagery research was to monitor the change in spectral characteristics of a patch of early seral stage (ESS) forest over time as new trees grow and shade out the ESS vegetation. The second goal was to use this information to classify Landsat imagery and identify ESS areas. ESS vegetation provides forage for elk, but after 10 years the tree canopy growth can shade out forage plants (Thomas et al. 1976). By identifying trends in spectral response patterns as a forest stand re-grows following vegetation removal it is possible to relate Landsat imagery classification of ESS with potential elk forage patches.

Study Area

The study area for this research is a 500 km$^2$ subset of the 8,600 km$^2$ total elk modeling area located in the North Cascades of Washington State (Fig. B1). The study area is located north of Highway 20 and the Skagit River between the cities of Sedro-Wooley and Concrete in the North Cascades of Washington State. The study site is on timber land managed by Sierra Pacific Industries and as a result much of the vegetation
Figure B1: Landsat imagery study area. Data sources: hydrology (USGS 2011), Landsat 8 imagery (USGS 2014).
within stands tends to be similar height and density. I selected this area because I conducted vegetation verification fieldwork in portions of this area in summer and fall 2013, and therefore I have in-situ knowledge of the forest and landscape. The main forest zones in the area are Western Hemlock/Douglas Fir, Pacific Silver Fir, and Mountain Hemlock (Franklin and Dyrness 1988). The majority of the logging is in the Western Hemlock/Douglas Fir Zone (WDFW 2012). The information I gathered from the vegetation transects verified that there is a relationship between the spectral reflectance of the habitat patches and the structure of the vegetation communities on the ground.

Spectral Sampling Site Selection

Using site knowledge gained through fieldwork during October 2013, I selected a stand of young Douglas-fir trees as the sampling target for the spectral analysis (Fig. B2). This site was selected because it is a large, level (low slope), even-aged stand with an average tree height of 2-3 m (measured during the 2013 fieldwork). All of these factors would allow for the greatest possible level of spectral homogeneity. Also this size class at this site corresponded to tree re-growth following clear cut in 2002, and Landsat 5 TM imagery was available for this site from 2001 to 2011, which allowed me to track the spectral change of this site from pre-clear cut, clear-cut, and regrowth over 10 years. During field work in 2013, I observed tree height and density so it was possible to make a reasonable assumption of steady growth from ESS to current conditions. Additionally, this site was selected because there was elk GPS point locations recorded in the treatment patch in 2009.
This stand was also adjacent to a large, level, even-aged, 30 m-40 m tall stand of trees. The stand of young trees was the treatment, and the stand of mature trees was the control. It was important to have a control in order to help account for possible variations in spectral data between satellite scenes captured over time.

Figure B2: Location of treatment and control sampling points. Imagery is Landsat 8 OLI Natural Color Scene from 2013 (USGS 2014).
Satellite Imagery

Landsat imagery was selected for this project because of the temporal frequency (every 2 weeks), accessibility (free from Earth Explorer), and an appropriate spatial resolution for analyzing conifer forests (Cohen et al. 1998, Cohen et al. 2002, Wilson and Sader 2002). Landsat 5 Thematic Mapper (TM) was obtained from Earth Explorer for each year from 2011 extending back until 2001, the year before the treatment stand was harvested. Landsat 5 TM data was not available for 2012 or 2013, and the Landsat data that was available - Landsat 5 MSS for 2012, and Landsat 8 OLI for 2013 – did not have pixel number values which could be directly compared to the pixel values for the earlier Landsat scenes. Scenes from July or August were used because vegetative growth would be at its highest level and there was the lowest likely cloud cover (CC) during this time, however two of the scenes were from September (2002 and 2003), and one was from October (2010). The cloud cover in all except two of the scenes (2005 and 2009) was less than 0.07%; in both the 2005 scene (CC 7.06%) and 2009 scene (CC 17.18%) the clouds were not obscuring the study area portion of the scene.

Landsat Image Processing

The Landsat 5 TM images were not processed using dark pixel subtraction because all the images in all bands had a minimum pixel value of 1. The following bands were stacked for each scene prior to processing: Band 1 (blue), Band 2 (green), Band 3 (Red), Band 4 (Near Infrared (NIR)), Band 5 (Short Wave Infrared (SWIR) 1), and Band 7 (SWIR 2). The stacked images were then clipped to the 500 km² study area, and then
the Tasseled Cap Transformation was applied to each scene. The Tasseled Cap Transformation was chosen because this ratio captures spectral characteristics of vegetation and soil which can be related to plant phenology and growth stage (Kauth and Thomas 1976, Cohen and Goward 2004). The Tasseled Cap Transformation relates the raw bands of the Landsat 5 TM data and produces a new raster layer comprised of four layers: brightness, greenness, wetness, and other (also known as non-such).

Mean Pixel Values in Treatment and Control Stands

A vector sampling grid was created in ArcGIS in order to designate fixed locations for eight sampling points that were used to record Landsat 5 TM raw file pixel values and the Tasseled Cap transformation values; four points were in the treatment stand (points A,B,C,D) and four points were in the control stand (points E,F,G,H) (Fig. B3). Figure B4 shows a picture taken at the control stand, Fig. B5 shows the treatment stand in 2013, and Fig. B6 shows an example of a similar area 3 years after timber harvesting to show initial stages of vegetation re-growth.

Four sampling points were used for each stand because even though the stands were as homogenous as possible, there was still noticeable variation in the spectral patterns seen within the pixels of the Landsat scenes; multiple sampling points helped quantify the spectral variation more effectively. The sampling points were spaced 40-50 meters apart in order to capture the spectral variation across multiple pixels (which are 30m x 30m), and they were placed away from the known edges of the stands in order to minimize the likelihood of the spectral characteristics of the edges being captured in the
sampling points. A mean treatment and control file pixel value was calculated from the 4 points in the treatment and control stands for each year for the graphs and analysis.

Figure B3: Location of sample points in treatment patch (which was clear-cut in 2002) and in control patch (uncut 30 m tall Douglas fir stand). Landsat 5 TM Imagery from 2009.

Figure B4: Picture of control stand taken in October 2013, Douglas fir trees average 30 m tall.
Figure B5: Picture of treatment stand taken in October 2013, 12 years after clear-cut harvest. Douglas fir regrowth trees average 2-3 m tall.

Figure B6: Example of a clear-cut area 3 years after harvest.
Results

Comparison of the individual spectral bands between the treatment (ESS) and control (mature forest) sites indicates that most of the bands (except blue) showed distinctive differences in file pixel values between the 2 sites (Fig.B6 and Fig.B7). In the pre-treatment year, 2001, the file pixel values were similar in both the treatment and control sites, but in the years following the clear-cut, the file pixel values were generally greater in the treatment site as compared to the control site. The data from 2010 appears to be anomalous, likely because this scene was captured in October and there is less photosynthetic activity occurring so the spectral response patterns of the vegetation are less reflective. The following are general comparisons of the pixel values of individual bands between the treatment and control sites from 2001 to 2011:

- **Blue (0.45 – 0.52 µm):** There was a slight decrease in the first harvest scene (2002), followed by a slight increase the second year (2003), but the remaining years are mostly similar.

- **Green (0.52 – 0.60 µm):** Starting in 2002 the green values are 38% more in the treatment stand than in the control stand, and the gap steadily declines but is still 21% more in the treatment than in the control stand in 2011.

- **Red (0.63 – 0.69 µm):** Starting in 2002 the red values are 92% more in the treatment stand than in the control stand, and the gap steadily declines through to 2011 when the red values are 24% greater in the treatment stand.

- **Near Infrared (NIR 0.76-0.90 µm):** The treatment and control values were similar until the third year following harvest when the NIR treatment values increased to
41% greater than the control values, and continued increasing to 72% over control values in 2011.

- **Shortwave Infrared 1 (SWIR1 1.55-1.75 µm):** Starting in 2002 the SWIR1 treatment values were 152% greater than the control values, and this difference decreased slightly to 2011 when the treatment values were 85% greater than the control values.

- **Shortwave Infrared 2 (SWIR2 2.08-2.35 µm):** Starting in 2002 the SWIR2 values were 233% greater in the treatment than in the control, and this difference decreased to 69% greater in the treatment as compared to the control in 2011.

Figure B7: Mean (n= 4) pixel values at treatment site from 2001 to 2011.
Evaluation of the Tasseled Cap Transformation

The Tasseled Cap Transformation relates and transforms the bands of the Landsat 5 TM scene to produce a condensed set of new information bands which highlight properties of the scene that are highly correlated with vegetative growth (Kauth and Thomas 1976, Crist and Cicone 1984). The 4 outputs of a Tasseled Cap Transformation are Brightness, Greenness, Wetness, and Other (Non-Such).

Brightness of a pixel is the weighted sum total of pixel values from each band and is generally indicative of the soil reflectance (Crist and Cicone 1984). Greenness is the contrast between the Near Infrared (NIR) band and the visible bands (Blue, Green, Red), and high greenness values are correlated with high photosynthetic activity (Crist and
Wetness is the contrast between the visible and NIR bands with the
Shortwave Infrared bands (SWIR1 and SWIR2) and is correlated with soil and plant
moisture (Crist and Cicone 1984). Other (Non-Such) is likely associated with
atmospheric haze (Crist and Cicone 1984).

Comparison of the Tasseled Cap pixel values between the treatment and control
sites indicates that the brightness, greenness, and wetness values are all responsive to the
removal of vegetation and the regrowth of the Douglas fir stand (Fig.B9 and Fig.B10).
(Values for 2010 are again excluded in this summary because they are likely anomalous.)
The Brightness values in the treatment started increasing in 2002 from a pixel value of 98
to a high of 140 in 2009, meanwhile the brightness values for the control site decreased
from 103 in 2002 to values in the 70s and 90s, returning to 101 in 2009. This contrast is
compatible with the findings of Cohen et al. (1995) which indicate that clear-cuts have a
high brightness value in comparison to mature coniferous forests. As the trees increase in
height and diameter, the soil reflectance value represented by the brightness starts to
decrease, which starts to occur after 2009.

The Greenness values at the treatment site average a pixel value of 2 in the first
two years following the harvest, during this time the control values are 12 and 11. Then
starting in 2005 the treatment value increases to 28, which is higher than the control site
the control value of 17. After 2005 until 2011 the greenness values in the treatment site
are approximately double that of the control values. This increase in greenness is
compatible with observations of Crist et al. (1984) that greenness is associated with new
biomass.
Figure B9: Mean (n=4) Tasseled Cap pixel values at treatment site.

The Wetness values at the treatment site decrease into negative values starting with the year of harvest (2002), and slowly increase to attain a pixel value of zero by 2011. This contrasts with the wetness values of the control site which does not deviate far from a mean pixel value of 6 from 2001 to 2011. These results indicate that the wetness value of the Douglas fir forest are constant, but the moisture content of an area which has been clear-cut, and up to ten years after a clear-cut, is significantly lower than the forest.
Correlation of Spectral Response with Elk Foraging Behavior

Elk are known to forage in ESS areas which provide high quality food. Thomas et al. (1976) observed that the first 10 years following a clear cut are when high quality forage is available, but after 10 years the replacement trees have grown up enough that the forage becomes shaded out and that habitat has shifted from forage to cover. Cook et al. (2014 in press) conducted an extensive evaluation of elk foraging in conifer forests in Western Washington and Oregon and found that the conifer overstory closed 12 to 20 years after stand initiation. These studies correspond with the spectral response changes documented in the treatment area over time. Following a clear cut the spectral response
of a patch has high brightness values, and low wetness and greenness values. As the vegetation grows up in the ESS area these wetness and greenness values increase while the visible soil decreases. When the vegetation has grown up enough to completely block all visibility of the soil, at around 10 years, this coincides with the same time that the patch shifts from forage to cover. The linkage of this information is useful for the classification of elk habitat using Landsat imagery because it is possible to say that when soil is visible in the imagery (either in the original or TCT imagery), the habitat patch is likely to support high quality forage, when the soil is no longer visible the habitat patch has transitioned to cover.

Classification of Imagery

The Landsat imagery from 2009 was classified multiple times using both supervised and unsupervised classification methods, on both the original imagery and the tasseled cap transformed (TCT) imagery in order to determine which approach best captured the ESS areas on the landscape. Unsupervised classifications repeatedly failed to classify ESS areas in a consistent manner, resulting in only a portion of ESS areas being captured with the rest being grouped in with other forest areas. Attempts at supervised classifications were more successful. Numerous iterations of training sets were applied to both the original and the TCT imagery, and initially it appeared that the supervised classifications on the TCT imagery were successful. However, upon closer inspection of the results it was evident that the supervised classifications of the TCT imagery were not consistent enough to be reliable.
The TCT imagery showed the main landscape patterns, logging areas, mature forests, and agriculture areas, very distinctively (Fig. B11). The fact that the TCT showed clear visual distinctions between ESS areas (dark pink in Fig. B11) and agriculture areas (orange in Fig. B11) was exciting because it was not possible to distinguish between these two areas in either supervised or unsupervised classification of the original imagery. However, upon closer inspection of the outputs from supervised classification of the TCT imagery it was evident that there were large numbers of areas that had been identified as ESS, but when comparing these areas to both the TCT imagery and the original imagery, no visible sign of ESS areas were evident.

What was likely happening in these cases is that the band ratios in these areas produced similar values to those in the ESS areas. The problem with these false positives is that they also highlighted the likelihood of false negatives, and created the requirement that all the ESS areas in the classified data would have to be evaluated to determine if they were in fact ESS areas. This evaluation and decision process was attempted but it quickly became clear that it was not systematic or easily repeatable for the large landscape area of this project.

In contrast, the outputs from supervised classification of the original imagery were consistently capturing the ESS areas. Also, there was not a noticeable amount of false positives, areas of forest classified as ESS, and so it was easy to visually inspect the
outputs and verify the success of the supervised classification. In this approach, ESS areas included agriculture fields so it was important to recognize that this was occurring. All ESS areas do provide high quality elk forage, but the Westside Models apply a standard DDE value to agriculture areas, and if an agriculture area is updated (with an input polygon reflecting ESS areas) standard agriculture DDE is overwritten. However, this overwriting of the agriculture DDE values did not have much effect in the study area.
because the habitat suitability ranking in the agriculture areas is uniformly classified as high quality both before and after applying the ESS polygons.

**Conclusion**

This study showed that the Landsat 5 TM imagery adequately records the change in spectral values as forest patch transitions from elk forage to elk cover. The spectral patterns displayed in the Tasseled Cap transformed scenes are more distinctive than when individual spectral bands are analyzed in isolation, however supervised classification of Tasseled Cap transformed imagery was not consistently successful. Supervised classification of original Landsat 5 TM imagery was most successful at capturing ESS areas and mature forest, and this technique appears suited for capturing the ESS information that is important for elk habitat modeling using the Westside Models.

Based on this evaluation, supervised classification was used to identify the ESS polygons in the 2009 Landsat 5 TM imagery for the 2009 Model Calibration step, and in the 2013 Landsat 8 OLI imagery in order to create the 2013 baseline habitat. Within the supervised classification settings in Erdas Imagine, maximum likelihood was selected as the preferred decision rule (for the parametric data) and parallelepiped as the secondary decision rule (for the non-parametric data). Fifteen to 20 training polygons were used to classify the imagery into areas of ESS, forest, water, rock, and cloud. Classified raster outputs were converted to polygon shapefiles, and then the ESS areas were selected out. ESS polygons below 2 acres were removed to eliminate noise in the classification and
Focus on capturing the large ESS patches (Figure B12). The resulting ESS polygons were used to update the GNN vegetation layer using the Update Vegetation Toolbox.

Figure B12. Supervised classification of Landsat 2013 imagery showing early seral stage polygons greater than 2 acres. Data source: Landsat 8 OLI (USGS 2014).