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ELK SUMMER-AUTUMN HABITAT SELECTION IN THE CLEARWATER BASIN OF NORTH-CENTRAL IDAHO

A Thesis

Presented To

Eastern Washington University

Cheney, Washington

In Partial Fulfillment of the Requirements

for the Degree

Master of Science in Biology

By

Calla R. Hetzner Hagle

Winter 2016

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ABSTRACT

Since the 1960's, Rocky Mountain elk (*Cervus elaphus nelsoni*) populations have declined steadily in the Clearwater Basin in north-central Idaho. The Clearwater Basin Collaborative (CBC) was formed with the goal of restoring healthy elk populations to the Clearwater Basin. They initiated this study by collaring 53 cow elk from four distinct areas. I analyzed elk detection and GIS-based habitat data from June 15 – September 15 2014 to address one of the CBC's objectives: identifying elk habitat use responses on summer-autumn range. Ground-truth surveys are necessary to verify satellite-derived data are analogous to actual vegetation components. I used a proportion analysis to compare satellite derived cover type and forest cover to the true on-the-ground cover type and forest cover classification. All habitats had over 85% accuracy in the cover type validation analysis and 84% in the percent forest cover validation analysis. To assess the summer-autumn habitat selection of elk I used a new modeling approach with a use-availability design, the Synoptic model, to assess the importance of topography (valley and midslope), forage emergence and senescence (NDVI and NDVI*forest), the type of habitat (shrub, forested, or herbaceous), and forest cover (high and low) to elk habitat selection. The relative variable importance of habitat variables in descending order was: forest, valley, shrub, lowcover , NDVI and NDVI*forest, midslope, and highcover. I used a MANOVA to test for overall differences in mean habitat selection coefficients among populations. MANOVA results showed there was no significant difference in habitat selection among populations. Then, I examined how distribution patterns related to habitat variables by calculating a habitat suitability index (HSI) for each of the four populations. Overall, elk showed a positive relationship with shrub and forest, and a negative relationship with valleys and high cover in the four populations. The results of this study indicated that elk select for a juxtaposition of both forage and cover, and used high to moderate elevations during the summer. The CBC has attributed declines in the Clearwater Basin elk populations to the loss of early-seral shrub habitat and subsequent limiting effects of summer-autumn nutrition. Based on this analysis, elk populations would be enhanced by converting areas of contiguous forest cover to a diversity of seral communities, particularly early-seral shrubs with adjacent forest stands. These results will help us recognize resources important for elk conservation or habitat improvement, and inform ongoing research in identifying elk nutritional status and population responses on summer-autumn range.

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Central to the study of biodiversity, animal ecology, behavior, and ecosystem function is understanding an animal's utilization of its environment (Johnson 1980, Horne et al. 2008, Kays et al. 2015). Within a home range, many animals selectively use certain habitats more than others, i.e., habitat selection. One of the most common factors affecting habitat selection is the distribution of critical habitat components (Boyce and McDonald 1999, Horne et al. 2008). Both natural succession and anthropogenic land conversion can result in habitat loss and fragmentation leading to the loss of critical habitat (Huxel and Hastings 1999). To examine how a species might be affected by habitat limitations, often the result of human-dominated ecosystems, we must understand patterns of distribution and habitat selection. The observation and analysis of habitat selection patterns can inform the management of many species under changing conditions.

For many wildlife management agencies accurately monitoring ungulate populations is a main concern. Ungulates can play a major role in maintaining healthy ecosystems as well as providing aesthetic and economic value to the people and states in which they occur (Idaho Department of Fish and Game (IDFG) 2014). Given the flexibility in habitat selection and diet, large range of movement, and population numbers, ungulates can have a profound influence on plant community composition and structure at local and landscape scales (Irwin et al. 1994, Palmer et al. 2003). There is an extensive literature base which provides insight into ungulate population dynamics, animal health, animal movements, and habitat selection (Unsworth et al. 1998, Hebblewhite et al. 2008, White et al. 2010, Cook et al. 2013).

The topic of elk habitat selection in particular has prompted extensive research which has established a general understanding of factors that help explain the distribution of elk across different landscapes (e.g., McCorquodale et al. 1986, Unsworth et al. 1998, Alldredge et al.

2002, Boyce et al. 2003, Beck et al. 2013, van Beest et al. 2013). Elk are often described as habitat generalists in as much they can be found in a variety of disparate habitats from wet forests to dry shrubland steppe. Yet studies have shown they exhibit habitat selection at the local level; for example, avoidance of publicly accessible roads (Rowland et al. 2004) or selection of high-elevation northern aspects for thermal cover during the summer (Beck et al. 2013). One of the most critical features of elk habitat is forage. Elk utilize areas with increased forage created by wildland fire or timber harvest (Lowe et al. 1978, Wisdom et al. 2005), follow spatiotemporal patterns of new plant growth to increase nutrient intake during the spring and summer (Hebblewhite et al. 2008), and select certain grasses, forbs, and shrubs during the growing season which provide a more concentrated sources of energy (Cook 2002).

Despite higher levels of forage quality and quantity during the growing season, forage may still be insufficient to consistently satisfy high nutritional requirements during late summer and autumn (Cook et al. 2013). Cow elk have high nutritional requirements during the summer and autumn due to lactation and storing adequate fat to survive winter while sustaining a developing fetus. In a study of 57 captive cow elk, survival of cows over winter was more related to body fat at the onset of winter as it was to nutrition during winter (Cook et al. 2004). They found that the high nutritional requirements of cow elk during this time are often not satisfied by summer forage. Several studies have concluded that the limiting effects of summer-autumn nutrition on populations may be greater than those during winter in some ecosystems (Julander et al. 1961, Crête and Huot 1993, Parker et al. 1999, Alldredge et al. 2002, Cook et al. 2005, Cook et al. 2013). This may be the case for elk populations in the Clearwater Basin of Idaho.

The productivity and population size of many elk herds are declining (Irwin et al. 1994, Cook et al. 2004, White et al. 2010). Elk were once primarily a plains species, but in the early-to-mid 1900's land conversion in their historic habitat caused a population-level geographic range shift to large early-seral brush fields created by landscape-level fires in the northwestern U.S. Elk populations in Idaho increased with predator control and game hunting regulations. However, since peaking in the 1960s, elk populations across Idaho, but particularly in the Clearwater Basin of North-central Idaho, have declined by approximately 25% (Cook et al. 1999). Idaho's elk population is currently estimated at approximately 107,000 animals (IDFG 2014). Much of the decline in the Clearwater Basin elk populations has coincided with a loss of early-seral habitat, an increase in human occupation of low-elevation elk winter range, and the reintroduction of wolves to the area (Cook et al. 2012). This loss of early-seral habitat may escalate the limiting effects of summer-autumn nutrition on elk populations in the Clearwater Basin of Idaho.

In response to decline of elk, the Clearwater Basin Collaborative (CBC) was formed with the goal of restoring healthy elk populations to north-central Idaho. The CBC is a coalition of federal state agencies, private landowners, tribal nations, hunting conservation groups, and timber, agricultural and livestock producers. In addition to their ecological influences, elk are an economically valuable big-game species. In Idaho, elk hunting generates over 70 million dollars annually in hunting-related income (IDFG 2014). Therefore, maintaining robust elk populations is a principal interest for wildlife management agencies and the people of Idaho alike.

The CBC has developed a set of objectives for monitoring elk nutritional status, habitat use and population conditions in the Clearwater Basin. One of the CBC's primary goals is to examine elk habitat use responses on summer range. They initiated a study by collaring 53 cow elk from four distinct areas representing climatic, topographic, and vegetation succession gradients (Fig. 1). The Clearwater Basin is an area spanning approximately 2,430,490 hectares and encompassing four major river drainages stretching across a large portion of north-central Idaho. Current technological advances of monitoring and data collection systems are particularly applicable to objectives such as those of the CBC: studying animals ranging across landscapes. For instance, GPS technology has enabled managers to observe the relatively fine-scale movement of species such as mule deer (*Odocoileus hemionus)* (Kie et al. 2002) or migratory patterns in species as wide ranging as polar bears (*Ursus maritimus*) (Wilson et al. 2014).

Researchers can now combine this movement information with remotely-monitored information about the environment to reveal detailed characteristics of animal habitat selection (Kays et al. 2015). Satellite-derived data can be used to produce vegetation maps that cover large regions. A growing number of studies have examined a wide variety of vegetative characteristics (including mapping vegetation cover) by using remotely-sensed data (e.g., Wardlow and Egbert 2003, Barrett and Gray 2011). Although remote sensing technology has tremendous advantages over traditional methods in vegetation mapping, ground-truth surveys are necessary to verify that satellite-derived data are analogous to actual vegetation components for use in a habitat selection analysis (Xie et al. 2008).

This study was initiated with the objective of addressing one of the CBC's primary goals of examining the summer-autumn habitat selection of elk in the Clearwater Basin. To address the CBC's goal I developed four specific objectives:

1) to assess the utility of National Land Cover Data (NLCD) for use in the elk habitat selection analysis
2) to assess the relative importance of specific habitat variables to individual cow elk within four populations in the Clearwater Basin

3) to examine how the elk selection of habitat characteristics differs among the four populations in the Clearwater Basin
4) to examine how summer-autumn distribution patterns relate to habitat variables within the four populations in the Clearwater Basin.

2. METHODS

2.1. STUDY AREAS

Elk were captured at four distinct locations representative of four populations: Craig Mountain, Southfork, Dworshak, and Northfork (Fig. 1). The four area boundaries were delineated by the occurrence of elk rather than by administrative boundaries. These areas are managed for a suite of uses including cattle grazing, timber harvest, agriculture, and recreation. Elevation ranges from 200m to 1700m. This elevation gradient encompasses a diversity of plant communities.

CRAIG MOUNTAIN

Craig Mountain is located at the confluence of the Snake and Salmon Rivers and lies within Nezperce, Lewis, and Idaho counties of Idaho, Wallowa County of Oregon, and Asotin County of Washington. The Craig Mountain Wildlife Management Area (CWMA) encompasses the majority of the range for elk in this area. There is a large elevation gradient in this area; lower elevations are primarily steep canyon grasslands mixed with rimrock and talus slopes. As elevation increases, slopes are progressively intermixed with bunchgrass, shrub, and forested communities concluding on a large forested plateau. In August 2014, the Big Cougar Fire burned 28,328 hectares of primarily bunchgrass steppe (Fig. 2).

According to Idaho Department of Fish and Game's (IDFG) 2014 Idaho Elk Management

Plan (IEMP), elk populations in Craig Mountain have been declining after years of being robust, with nearly double the calf: cow ratios in 2002 (38:100 from 1991-2002; 26:100 in 2009) compared to 2013 (17:100). Predator densities are lower in this area than elsewhere. However, this area is experiencing an aggressive invasion of non-native annual grasses which may be precipitating a density dependent decline in the population (IDFG 2014).

SOUTHFORK

The second area, the Southfork, is located along the Southfork of the Clearwater River in Idaho County. Vegetation in this zone is highly variable. Higher and mid-elevations are mostly forested with dense mixed-conifer stands. Shrub cover types at these elevations and on northerly aspects at lower elevations tend to be tall shrub communities, largely resulting from timber harvests or wildfire. Steep, southerly aspects at lower elevations are dominated by dry, open, park-like ponderosa pine (*Pinus ponderosa*) stands with bunchgrass understories.

According the IDF&G's 2015 IEMP populations in Southfork are stable with calf:cow ratios of 21:100 in 2008; a slight decline from the previous calf:cow of 27:100 from 1987-2006. Predator populations are robust but are closely managed. This elk population is thought to be primarily limited by habitat, predation and culling due to agricultural depredation (IDFG 2014).

DWORSHAK

Dworshak is located near Dworshak Reservoir and the Northfork of the Clearwater River in Clearwater and Shoshone counties of Idaho. This area is dominated by dense mixed-conifer stands interspersed by many large seral brush fields created by logging. Drainage bottoms are characterized by dense stands of Western redcedar (*Thuja plicata*), *Populus* spp., and tall shrub species, such as Alder (*Alnus* spp.) or chokecherry (*Prunus virginiana*).

Elk populations in Dworshak are one of the most stable in the Clearwater Basin with calf:cow ratios of 26:100 in 2007, and 20:100 in 2011 (IDFG 2014). According to IDF&G's 2015 IEMP this stability may be due to an abundance of early seral habitat created by logging and high levels of recreation and hunting which may reduce predator populations in this area.

NORTHFORK

The final area, the Northfork, is located near the Northfork of the Clearwater River in Clearwater county of Idaho. Forested vegetation is similar to that in the Dworshak area with primarily a mix of conifer stands, with some large seral brush fields created by logging or fire, but less acreage than in the Dworshak area. Drainage bottoms are characterized by dense stands of Western redcedar (*Thuja plicata*), *Populus* spp., and tall shrub species.

Elk populations on the Northfork have been on a long-term decline with calf:cow ratios falling from 27:100 in 2006 to less than half, 13:100 just four years later, in 2010 (IDFG 2014). According to IDF&G's 2015 IEMP this may be primarily due to a loss of early seral habitat, an effect that may have been intensified by high elk predation rates by black bears, mountain lions, and wolves.

2.2. ELK CAPTURE

During capture efforts, IDF&G attempted to select adult cow elk evenly across the winter range area to avoid oversampling of specific social (family) groups. Each elk was fitted with either a Vectronic Global Positioning System (GPS) telemetry collar (GPS Plus, Vectronic Aerospace GmbH, Berlin, Germany), a Lotek GPS telemetry collar (Life Cycle, Lotek Wireless Inc., Ontario, Canada), or a Telonics or Lotek store-on-board collar (Table 1). Unfortunately, 15 of the Lotek collars, primarily from the Southfork population, had extremely low transmission rates. To address this problem, IDF&G re-collared 17 elk, and collared 9 new elk with Vectronic collars in April 2014. Lotek and Vectronic GPS collars were programmed to record fixes

(Latitude and Longitude) at 23-hour intervals. Store-on-board collars from the Northfork population were set to provide a detection every 12.5 hours.

A total of 82 cow elk (21 cow elk from Craig Mountain, 20 cow elk from the Southfork, 22 cow elk from Dworshak and 19 cow elk from the Northfork) were captured and fitted with GPS radio collars during separate capture events in December 2012-January 2013 and April 2014 (Table 2). I was not able to use detection data from all 82 collared elk as fix rates from many of the collars were not optimal, indicating they were potentially biased. Frair et al. (2004) and Nielson et al. (2009) found that fix rates that are less than 90% of the intended frequency can affect habitat selection estimates due to habitat bias. Bias occurs because some locations, such as canyon bottoms or densely forested sites are more likely to prevent receivers from communicating with global positioning satellites. Fix rates of elk in Southfork and Dworshak populations were consistently lower than 90%, which would have excluded these populations from the analysis (Table 3). However, I attributed this bias to the sub-optimal fix rates from Lotek brand radio collars that were used primarily in the Southfork and Dworshak populations. It was difficult to account for this bias directly as the selection for habitat components can differ significantly between individual elk. However, by testing for differences in the habitat selection between the four populations I could assess whether selection within the four habitats is similar or not. If habitat selection among the elk populations was similar this may indicate less of a bias in habitat selection (i.e., selection of dense canopies or valleys), and more of a bias in the performance of certain Lotek GPS collars. The Northfork population resides in the most densely canopied area where we would expect fix rates to be most inconstant but because these elk were collared with a store-on-board type collar, rather than a Lotek GPS collar, their fix rates were consistently above 90%. There are no differences among these four habitats that would suggest a substantial bias in the estimation of habitat selection using detections for collars with sub-optimal fix rates. Therefore, I included elk with collar fix rates of > 0.65 occurring over at least 8 weeks of the 13 week study period. I included eighteen cow elk from Craig Mountain, eight cow elk from the Southfork, eighteen cow elk from Dworshak, and nine cow elk from the Northfork (n=53) in my analysis.

2.3. HABITAT VARIABLES

I identified a set of habitat variables to predict elk habitat selection based on previous research of elk biology (e.g., McCorquodale et al. 1986 , Unsworth et al. 1998, Boyce et al. 2003, van Beest et al. 2013) and on the availability and consistency of attribute data for the study areas (Wardlow and Egbert 2003). The variables used to develop models of elk habitat selection were topography, distance to roads, forage emergence and senescence, type of habitat (forested, shrub, or herbaceous/agriculture), the amount of forest cover, and recent fire or timber harvest activity (Table 4).

TOPOGRAPHY

The aspect data layer was derived from the 2013 USGS and ISU digital elevation model (DEM) at 30 x 30 meter resolution using the Aspect tool in Arc GIS 10.1 Spatial Analyst toolbox. This layer was then reclassified into four categories using the Reclassify tool in Arc GIS 10.1 Spatial Analyst toolbox, North (315-0˚ and 0-45˚), East (45-135˚), South (135-225˚), and West (225-315˚).

Topographic position index (TPI) was derived from an aggregate DEM at 360 x 360 meter resolution using the Aggregate and Reclassify tools from the Topographic Position Index Toolbox from “Land Facet Corridor Designer for ArcGIS 10” by Jenness et al. (2013). The TPI tool classifies the landscape into three slope positions, valley, midslope and ridge. The valley position was characterized as valley bottoms and the lower third of rising terrain. The midslope position was characterized as the middle third of the sloped terrain. The ridge position was characterized as the upper third of the sloped terrain.

ROADS

Road data layers were collected from the national online roads database, TIGER/Line Shapefiles (2014), and updated with data from the Forest Service and Potlatch Timber Management Company. Roads were classified according to the descriptive surface type. Asphalt or gravel roads with an oil base were classified as primary roads. Loose gravel or dirt surfaces were classified as secondary roads. Traffic volume was expected to be highest on primary roads and become less with the decreasing road quality of secondary roads.

FORAGE EMERGENCE AND SENESCENCE

Spatial data for vegetation phenology are represented by using Normalized Difference Vegetation Index (NDVI) -derived data analysis, which is based on images of the earth's surface collected by satellites. Data are created using the images' reflectance to estimate photosynthetic level of vegetation. Vegetation greenness was measured by the eMODIS high-resolution NDVI which provides a measure of the herbaceous phytomass at 250 x 250 meter resolution. These seven day composites can correspond to spatiotemporal patterns of new plant growth (increase in photosynthetic level) and plant senescence (decrease in photosynthetic level), and thus, potential fluctuations in dietary quality and availability associated with primary productivity and greenness of vegetation (Hebblewhite et al. 2008). NDVI values range from +1.0 to -1.0. Areas of barren rock, snow, or water usually show very low NDVI values (≤ 0.1). Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate forests or vegetation at its peak growth stage (Pettorelli et al. 2005).

I was only interested in NDVI values that related to elk forage value during the summer, including grassland, shrubland, agricultural, and low forest cover (<25% cover) areas. Forested areas provide hiding or thermal cover but would not be expected to provide significant forage during the summer-autumn study period. Forested areas were expected to have high NDVI values which would confound the results, so I interacted the NDVI and forest values to produce an additional selection covariate, NDVI*forest. This covariate's notation is used throughout this analysis, to represent the selection of NDVI values where forest is absent. That is I use the inverse of the forest component in the interaction term, NDVI* (1- forest). The variable 'forest' was a categorical variable, i.e., either 1 for "present" or a 0 for "absent". When an area was designated as "non- forested" (i.e., the forest layer pixels had a value of zero), the corresponding pixels for NDVI*(1- forest) were given the original NDVI value assigned to that pixel (NDVI * 1). In contrast, when an area was designated as "forested" (i.e., the forest layer pixels had a value of one), the corresponding pixels for NDVI*(1- forest) were given a value of zero (NDVI * 0). For similar reasons, I removed NDVI values that overlapped with large reservoirs or major rivers. Bodies of water have very low NDVI values that are not related to plant emergence or senescence.

COVER TYPE AND FOREST COVER

I used the National Multi-Resolution (NLCD) Land Cover and Analytical Tree Canopy datasets (version: 2011) to analyze elk use of different cover types and forest cover classes for both forage and cover resources. The NLCD datasets provide a seamless national land cover data set, which was preferable over other land cover datasets (e.g., GAP) that are not designed for large study areas (Wardlow and Egbert 2003). I classified the datasets at 30 x 30 meter resolution using the Reclassify tool in Arc GIS 10.1 Spatial Analyst toolbox. I derived forest, shrub, herbaceous and agriculture cover types from the NLCD Land Cover dataset. Forested areas were classified as Deciduous Forest, Evergreen Forest and Mixed Forest. Shrub lands were classified as Shrub/Scrub and Woody Wetlands. Grasslands were classified as Grassland/Herbaceous and Emergent Herbaceous Wetlands. Agricultural areas were classified as Pasture/Hay and Cultivated Crops. Forested areas were classified as areas with >25% tree cover; therefore, areas with low (0%-24%) forest cover are classified as either shrubland or grassland, depending upon whether there was >25% shrub cover or <25% shrubs and >2% herbaceous, respectively. I derived high (60%-100%), moderate (25%-59%), and low (0%-24%) forest cover densities from the NLCD Analytical Tree Canopy dataset.

FIRE AND TIMBER HARVEST

Timber harvest data were collected from the Forest Service and Potlatch Timber Company. Historic fire data were collected from the USGS Geosciences and Environmental Change Science Center data cache. Fire boundaries and timber harvest units from 2011-2014 were included in the analysis, to capture only recent activity. To further restrict the analysis to fire with sufficient size and intensity to affect subsequent vegetation types and forage quality, I included only fire incidents that were classified as Type II status or greater, according to the US Department of Agriculture's Burn Severity Classification (NRCS 2015).

2.4. VALIDATING VEGETATION SATELLITE DATA

To assess the accuracy of National Land Cover Data (NLCD) for use in the elk habitat selection analysis (Objective 1) I collected field data for the vegetation validation at three of the four locations, as the Northfork area was added after vegetation data had been collected. These three sample areas are located along a climatic gradient and were sampled accordingly. Craig

Mountain was representative of the earliest plant phenology and driest climatic conditions and was sampled from June 23rd – July 12th 2014; the Southfork was sampled from July 16th – August 5th 2014; and Dworshak, representative of the latest plant phenology and wettest conditions, was sampled from August 13th – September 28th 2014.

The land use and land cover categories of interest were deciduous and coniferous forest, shrub and scrub land, and herbaceous and agricultural land. I used the data collected in the field to later validate the forest cover categories of 0-9%, 10-24%, 25-39%, 40-59%, and 60-100% cover. NLCD provided information on the distribution of broad vegetation types (forest, shrub and grass) and agricultural areas. NLCD canopy cover data were used to derive five canopy cover classes in the forest vegetation type. I validated the satellite-derived vegetation components by ground-truthing a subset of each vegetation class. Plots of the vegetation areas were selected by random sampling using the Random Point Generator tool in ArcGIS. I sampled a total of 150 points distributed in equal number within all vegetation type classes. Congalton and Green (2009) reported 50 points per cover type were appropriate for ground truthing. I used the 50 points from the forested vegetation type classification validation to retroactively validate NLCD percent forest cover.

From each center point I marked four points ten meters in each cardinal direction to create four quadrants (Fig. 3). In forested areas I estimated percent canopy closure using a densitometer at the center and at each of the four ten-meter points. In shrub areas I estimated percent cover and percent cover of invasive plant species using a visual assessment in two of the four quadrants (SW and NE). In open grassland areas I estimated percent cover and percent cover of invasive plant species using a nested one meter x one meter sample plot at the center and each of the ten-meter endpoints (Launchbaugh 2009). Each 20 x 20 meter field site was assigned a single cover type, and in forested areas, a percent forest cover classification.

Validation of the vegetation classification using field data was based on the dominant overstory species. Anderson et al. (1976) described a list of vegetation cover types for classifying NLCD satellite imagery. The NLCD vegetation description that most closely described the sample point was selected as the most appropriate class for each sample location. Plots with more than 25% tree cover were classified as forest. Shrublands had the combination of <25% tree cover and >25% shrub cover; and grasslands have <25% trees, <25% shrubs, and >80% herbaceous.

To validate the satellite-derived vegetation components I used a proportion analysis for vegetation type and percent forest cover to compare the satellite image vegetation type and percent forest cover classification to the true on-the-ground vegetation type and, percent forest cover classification. A proportion analysis is a measure of the classification accuracy based on the ratio of correctly classified (true positive) points to incorrectly classified (false positive) points. Congalton and Green (2009) states an accuracy of 80% or greater is sufficient for successfully validating NLCD data.

2.5. MODEL COMPONENTS

Following validation of remotely-sensed vegetation components, I developed the variables for a use-availability model (the Synoptic model, Horne et al. 2008) to evaluate elk seasonal habitat selection. To develop the model I determined the spatial and temporal scales for elk habitat selection. Next I derived habitat variables within the spatial and temporal scales for each of the elk detections and the defined extent.

2.5.1. SCALE OF HABITAT SELECTION

The first component of model development was to delineate an extent in which all elks’ home ranges would be included. Spatial scales at which ungulate responses are measured directly affect the interpretation of results (Boyce et al. 2002). I estimated habitat selection at one scale: selection of habitat components within the home ranges of the four elk populations in the Clearwater Basin (Horne et al. 2008). This scale was derived from Johnson's (1980) third order of selection. The third order selection examines selection of habitat components within the home range of an individual or population within their geographical range (hereafter, "home range scale").

Spatial scale refers to the extent (size of an area evaluated) over which an evaluation is conducted and the mapping resolution (accuracy of each mapping unit, or pixel) at which a response is measured at a given extent (Turner et al. 2001). I omitted detections for each individual elk for 15 days post-capture to minimize bias related to skewed behavior due to capture stress (Northrup et al. 2014). Based on these detection data, I defined the extent by creating a convex hull using the Minimum Bounding Geometry tool in the Features Toolbox in ArcGIS 10.1. I then aggregated the convex hulls by population and buffered each by 20 km (Fig. 4). This method was chosen as it closely delineates the pattern of the detection data without including large areas where elk were never present (Slaght et al. 2013). I then calculated the size of each extent in hectares of the four elk use areas in Arc GIS 10.1 using the Area tool. Based on these polygons, I also calculated the proportions of land ownership and observed which Game Management Units (GMU) were utilized by elk in the four areas.

In this analysis I converted polygons to raster using a 250 x 250 meter pixel mapping resolution which provided a broad interpretation of underlying habitat variables (Boyce et al. 2003). The computational time to derive a value from the centroid of each 250 x 250 meter pixel within the defined extent was very high when using a standard computer with 6 GB of RAM

(112 minutes/1 raster image). To improve computational time I used the Eastern Washington University Chemistry Department computer cluster with 8 CPU's each using 16 GB of RAM (32 minutes/1 raster image).

2.5.2. Selecting season

The second component of the model development was to define a temporal scale to represent one biologically significant season. Elk habitat selection may vary seasonally, so I analyzed data for one season: June 15-September 15. I started the analysis period on June 15 because the elk calving season is typically coming to an end in mid-June and this is a sensitive time for cow elk and may alter their habitat selection (Rearden et al. 2011). The analysis ending date was set at September 15 as hunting season is beginning and elk are entering their breeding season, both of which may cause changes in cow elk habitat selection (Proffitt et al. 2013).

Climatic conditions were variable across the four study areas; however, the summer-autumn of 2014 was characterized as one of the hottest and driest on record. Across Idaho County, a county central to the study areas, the mean summer temperature was 18.8° C and annual precipitation was 36.17 cm in 2014, compared to the mean summer temperature of 18.2° C and annual mean precipitation of 61.85 cm from 1985-2015 (NOAA 2016).

2.5.3. Deriving habitat Variables

The final step in the model development was to derive habitat variables within the home range (spatial) and summer-autumn (temporal) scales for available and used habitat. I used the statistical program R (R Core Team 2015) to collect variables spatially (for all) and temporally (for NDVI) values within the boundary of the defined extent of each area.

Then, I used R to extract the values of the habitat variables at the elk detections both spatially (for all of the variables) and temporally (for NDVI), these variables representing the values of habitat used. Assigning weekly NDVI images to the correct date was accomplished using the lubridate package (Grolemund and Wickham 2011). NDVI values are temporally changing just as the greenness or photosynthetic value of plants change over time. Therefore, elk detections were associated with the most closely occurring NDVI image to the date of the detection with code developed by K. Magori (Appendix 1). Collection of variables from all other raster layers was accomplished using the Raster package (Hijmans 2015) and sp package (Pebesma and Bivand 2005). Distance from elk detections to primary and secondary roads was calculated using the gDistance package (van Etten 2011). Covariate values were standardized to range from 0 to 1 in all variables except NDVI (1 to -1) and distance to roads (km) as these could be best represented with continuous values. Standardizing the values aided in model convergence and the interpretation of selection coefficients (Horne et al. 2014, Slaght et al. 2013).

2.6. SYNOPTIC MODEL: HABITAT SELECTION MODELING

I identified elk habitat use responses on summer range with a use-availability design to evaluate elk seasonal habitat selection (Johnson 1980, Manly et al. 2002, Horne et al. 2008). I used the Synoptic model (Horne et al. 2008) to determine the relative importance of habitat variables to adult cow elk, to compare how habitat selection patterns differ among elk as well as how the variables selected by elk differed among the four habitats.

Using the synoptic approach the probability density function is defined in first equation as the probability of being at spatial location x, a vector of x and y coordinates, at time t.

PROBABILTY DENSITY FUNCTION: $$f(x,t) = \frac{w(x,t) \times f_0(x)}{\int_x \, [w(x,t) \times f_0(x)]}$$

The probability of use was modeled in the first equation where $f_0(x)$is the null distribution of space use which models the probability of use in the absence of habitat selection, and $w(x,t)$ is a selection function that transforms $f_0(x)$ to $f(x,t)$ by selectively weighting areas based on habitat conditions that vary over time (NDVI values are updated weekly).

The second equation is the habitat selection function:

$$\text{HABITAT SELECTION FUNCTION:} \quad w(x,t) = Exp[H(x,t)'\beta]$$

The selection function, $w(x,t)$ was modeled using equation 2 where $H(x,t)$ is a vector of covariate values describing the habitat conditions at location x and at time t, and β is a vector of parameters (i.e., selection coefficients) to be estimated. The global (with all covariates) habitat selection model is:

$$w(x,t) = Exp\ [\beta_1 * \mathit{MIDSLOPE} + \beta_2 * \mathit{VALLEY} + \beta_3 * NDVI_t + \beta_4 * NDVI_t * (1 - Forest) + \beta_5 * \mathit{FOREST} + \beta_6 * \mathit{SHRUB} + \beta_7 * \mathit{HIGHCOVER} + \beta_8 * \mathit{LOWCOVER}]$$

I defined $f_0(x)$= BVN (θ) to be a time invariant bivariate normal distribution (BVN) with parameters θ describing the means and variances in the x and y dimensions and the covariance. By describing $f_0(x)$ in this way, the area considered available for selection can be thought of as a BVN distribution characterizing the entire home range of an individual. I estimated the parameters of the synoptic model (θ, β) for each elk separately with maximum likelihood via numerical optimization using R with code developed by J. Horne (see Slaght et al. 2013 for example code).

I developed models that directly incorporated ecological processes using the information theoretic approach as presented in Burnham and Anderson (2002) and Horne et al. (2008). To reduce the number of candidate models I took a three step approach. First, I created 18 univariate models. Secondly, I compared univariate models using Akaike's Information Criteria (AIC). For each covariate, I calculated the percent of elk whose univariate model (model including a particular covariate) had an AIC score that was substantially better than the Null model AIC score (i.e., an AIC score ≥ 5 AIC units relative to the Null model). A covariate was kept for further modeling if this percentage was > 20% (Table 5). Finally, with the variables that were conserved in the second step, I created fifteen mechanistic models derived from ecological theory (Table 6).

2.6.1. Population Level Inference

For each individual I averaged selection coefficients ($\hat{\beta}_{\overline{w}}$), across all 15 candidate models based on Akaike weights, i.e., mean selection coefficients (Burnham and Anderson 2002). To address my second objective, to assess the relative importance of habitat variables of individual cow elk across four populations, I measured the percent of individuals for which a variable was in at least one of their top (ΔAIC ≤ 2) models as a measure of variable importance as presented in Horne et al. (2014). To address my third objective, to examine how the elk selection of habitat characteristics differs among the four populations, I used model-averaged selection coefficients to test for overall differences in habitat selection coefficients among the four populations using a Pillai multivariate analysis of variance (MANOVA) (Hand and Taylor 1987, Horne et al. 2014).

2.6.2. Habitat Suitability Index

To address my fourth objective, I interpreted the mean selection coefficients using a probability ratio to examine how summer-autumn distribution patterns relate to the habitat variables in the four populations. The probability ratio estimates how much more likely an animal is to occur at a given location x with covariate values H(a) to an alternative location with a covariate values H(b). The probability ratio equation is derived from the probability density functions of covariate values H(a) and H(b):

PROBABILTY DENSITY FUNCTION AT H(A): $$f(x)_{H(a)} = \frac{Exp(H(a)\ \times \beta) \times f_0(x)}{\int_x\ [Exp(H(a)\ \times \beta) \times f_0(x)]}$$

PROBABILTY DENSITY FUNCTION AT H(B): $$f(x)_{H(b)} = \frac{Exp(H(b)\ \times \beta) \times f_0(x)}{\int_x\ [Exp(H(b)\ \times \beta) \times f_0(x)]}$$

Then I derived the probability ratio equation by dividing the two probability density functions by each other to estimate how much more likely an animal is to occur at a given location x with covariate values H(a) to an alternative location with a covariate values H(b):

PROBABILITY RATIO 1: $$f(x)_{H(a)} \div f(x)_{H(b)} = \partial_{a,b} = \frac{\text{EXP}[H(a) \times {'\beta}]}{\text{EXP}[H(b) \times {'\beta}]}$$

The probability ration equation can be further simplified for categorical variables to estimate the occurrence of an animal within a habitat component as opposed to being out. This second probability ratio equation is:

PROBABILITY RATIO 2: $$\partial_{1,0} = \frac{\text{EXP}[1 \times {'\beta}]}{\text{EXP}[0 \times {'\beta}]}$$

To further address my fourth objective, I conducted a habitat suitability index (HSI) analysis to examine how summer-autumn distribution patterns relate to the habitat variables in the four populations. I graphed the habitat selection model values to depict the hypothesized capacity of the habitat extent to support elk during the summer-autumn season. The HSI has a minimum value of 0 which represents unsuitable habitat and a maximum value of one which represents optimum habitat (U.S. FWS 1981). I used the mean selection coefficients across all individuals from each of the four populations (see Table 9, overall) to calculate a HSI for each of the four population extents (Horne et al. 2014). The HSI equation:

$$HSI(x,t) = \frac{Exp\left[H(x,t)'\widehat{\beta_{\overline{w}}}\right] - \min(Exp\left[H(x,t)'\widehat{\beta_{\overline{w}}}\right])}{\max(Exp[H(x,t)'\widehat{\beta_{\overline{w}}}])}$$

The HSI was modeled using the above equation where $\widehat{\beta_{\overline{w}}}$ is a vector of parameters (i.e., weighted selection coefficients) to be estimated, and $H(x,t)$ is a vector of covariate values describing the habitat conditions at location x and at time t. In this equation I used the standardized values (i.e., range 0 to 1) for all of the selection coefficients. I created raster images from the calculated HSI values in Arc GIS 10.1 using the Point to Raster tool. I created an HSI for each of the four populations with NDVI and NDVI*forest values from central week of the study period (week 6, July 20th-26th), and a later week within the study period (week 13, September 7th-13th) to compare changes in habitat suitability in mid-summer to habitat suitability in autumn.

3. RESULTS

3.1. CHARACTERIZATION OF STUDY AREAS

CRAIG MOUNTAIN

Based on the aggregated convex hulls of the monitored elk with a 20km buffer, I calculated the Craig Mountain population area to be approximately 806,000 hectares. This area is primarily managed by IDF&G, the Nez Perce Tribe, the Bureau of Land Management, Idaho Department of Lands (IDL) and private landowners (Fig. 5). The collared elk summer-autumn home range is approximately 75% publicly owned with the remaining 25% private. Craig Mountain is located in Hells Canyon Zone game management unit (GMU) 11 (Fig. 6).

I observed 19 grass, 32 forb, 18 shrub, 13 tree, and 4 agricultural species from 51 random survey points in the Craig Mountain area (Appendix 2).

Low elevations

Lower elevations were primarily composed of non-native Kentucky bluegrass (*Poa pratensis*) and two invasives: cheat grass (*Bromus tectorum*) and yellow star thistle (*Centaurea solstitialis*).

High elevations

High elevation southern aspects had ponderosa pine (*Pinus ponderosa*) stands and mixed bunchgrass and shrub communities dominated by blue-bunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), rough fescue (*Festuca scabrella*), green needlegrass (*Stipa viridula*), needle-and-thread grass (*S. comata*), non-natives timothy (*Phleum pratense*) and Kentucky bluegrass and cheat grass. The dominant native shrubs were snowberry (*Symphoricarpos albus*), huckleberry (*Vaccinium* spp.), and ninebark (*Physocarpus malvaceus*). The dominant native forbs were arrowleaf balsamroot (*Balsamorhiza sagittata*) and tailcup lupine (*Lupinus caudatus*). The most common exotic forbs were yellow star thistle (*Centaurea solstitialis*), spotted knapweed (*Centaurea maculosa*), cinquefoil (*Potentilla* spp.), and leafy spurge (*Euphorbia esula*). On the large forested plateau at upper elevations, grand fir (*Abies gradis*), lodgepole pine (*Pinus contorta*), Douglas-fir *(Pseudotsuga menziessii)*, ponderosa pine, and western larch (*Larix occidentalis*) were the dominant species.

SOUTHFORK

The Southfork area is approximately 622,000 hectares and is managed primarily by the US Forest Service (USFS) and private landowners (Fig. 5). The elk summer-autumn home range is approximately 90% publicly owned, 10% private, and is in Elk City Zone GMU 15 and 16 (Fig. 6).

I observed 11 grass, 11 forb, 11 shrub, 6 tree, and 1 agricultural species from 51 random survey points in the Southfork area (Appendix 2).

Low elevation, southern aspects

Lower elevation grasslands were primarily composed of blue-bunch wheatgrass, Idaho fescue, cheatgrass, and bracken fern (*Pteridium aquilinum*). Low elevation, south-facing shrublands have had much of the natural vegetation displaced by two invasive rose species dog rose (*Rosa canina*) and sweetbriar rose (*Rosa rubiginosa*). Low elevation, south-facing forests were typically dry and open park- like stands of ponderosa pine or Douglas fir.

Low elevation, northern aspects and high elevations

Northern aspects at low elevations were composed of tall shrub communities with alder (*Alnus* spp.), chokecherry (*Prunus virginiana*) and serviceberry (*Amelanchier alnifolia*) being dominant. Similar communities occurred on higher elevation shrublands. North-facing and high elevation forested areas were denser, with grand fir and Douglas fir dominating the overstory.

DWORSHAK

The Dworshak area is approximately 863,000 hectares and is primarily managed by Potlatch Corporation, IDL, and USFS (Fig. 5). The elk summer-autumn home range is approximately 40% publicly owned with 60% privately managed by various timber companies. It is located in Dworshak Zone GMU 10A and Panhandle Zone GMU 6 (Fig. 6). There was active timber management in this area and both open and closed road densities were high within this zone.

I observed 9 grass, 11 forb species, 7 shrub species, and 9 tree species from 51 random survey points in the Dworshak area (Appendix 2). Forested vegetation was primarily a mix of dense conifer stands, including white pine (*Pinus strobus*), Douglas fir, grand fir, and western hemlock (*Tsuga heterophylla*). There were many large early seral brush fields with redstem ceanothus (*Ceanothus sanguineus*) and shinyleaf ceanothus (*Ceanothus valutinus*) resulting from logging. Riparian areas were characterized by stands of Western redcedar (*Thuja plicata*) or stands of Alder *(Alnus* spp.), cottonwood and aspen (*Populus* spp.).

NORTHFORK

The Northfork area is approximately 630,000 hectares. The elk summer-autumn home range is managed by the USFS, and is 100% publicly owned (Fig. 5). This area is located in Lolo Zone GMU 10 (Fig. 6). This area was not included in the vegetation survey, however, based on prior knowledge of this area and NLCD; it is characterized as primarily forested with mixed-conifer cover type. The climatic conditions and vegetation composition are expected to be similar to those found in Dworshak. However, the Northfork has steeper topography and fewer early-seral brush fields created by logging and fire as indicated in the topography, harvest and fire data layers (Unsworth et al. 1998).

3.2. VALIDATION OF SATELLITE DATA

To assess the accuracy of National Land Cover Data (NLCD) for use in the elk habitat selection analysis (Objective 1), I used a proportion analysis to compare satellite-derived cover type to the true on-the-ground cover type classification (Fig. 7).

<u>Cover type</u>

Classification accuracy varied by habitat, and was highest for grassland and agriculture. The lowest accuracy was shrubland, where >35% on-the-ground shrub cover was necessary for satellite-derived shrubland classification. The error matrix shows the number of points correctly identified in each cover type category, and which of those were misidentified as a different cover type (Fig. 8). All cover types had over 85% accuracy for all cover types, with an overall accuracy of 96% in the cover type validation analysis.

Percent Forest Cover

I used a proportion analysis to compare satellite derived percent forest cover to the true on-the-ground percent forest cover classification (Fig. 9). Accuracy of classifications varied, and were highest for 10-24% cover and 25-39% cover. Accuracy was lowest, at only 60%, for the lowest percent cover class, 0-9%. It may be an artifact of inadequate sampling of this class, there were only 5 survey points classified as 0-9% cover. All other percent cover classes had over 80% accuracy for all percent cover categories, with an overall accuracy of 84% in the percent cover validation analysis. The error matrix shows the number of points correctly identified in each percent cover category, and which of those were misidentified as a different percent cover (Fig. 10). The proportion analysis had an overall accuracy of 87%.

3.3. RESOURCE SELECTION MODEL: DATA EXAMINATION

Fifty-three cow elk were captured in four separate areas; all four populations of elk occupied distinct ranges during my study (Fig. 4). The 53 individual elk had a total of 4,555 detections during the course of the study (Table 2).

In the univariate testing stage I eliminated variables that were not substantially better than the Null Model (i.e., less than 20% of individual elk with a model including the variable with an AIC score ≤ 5 relative to the null model score). With the remaining variables I constructed 15 candidate models to be analyzed for each of the 53 elk. Of the 795 candidate models, 22 (~3%) failed to converge during the optimization routine and were excluded from the results.

3.4. VARIABLE IMPORTANCE

My second objective was to assess the importance of habitat variables to elk resource selection. Relative variable importance was measured as the percent of individuals for which a covariate was in at least one of their top (ΔAIC $\leq$ 2) candidate models. The relative variable importance in descending order was: forest, TPI valley, shrub, lowcover, NDVI and NDVI*forest, TPI midslope, highcover (Table 7).

3.5. Differences in Resource Selection

To examine how the selection of habitat characteristics differs among the four populations, as well as address the potential habitat selection bias of low fix rates, I used a MANOVA to test for a population-level difference of habitat selection. MANOVA results indicated no significant difference in the mean selection coefficients among the four populations (Table 8).

3.6. Habitat Selection Patterns

Although there were no significant differences in the habitat selection coefficients, these relationships still indicate patterns in habitat selection. Therefore, I examined habitat selection patterns with the population-level selection coefficients (Table 9). In several instances, selection for or against habitat covariates was conserved between populations. All of the populations showed a positive relationship with shrub.

Elk from the Craig Mountain population showed a positive relationship with high NDVI and shrub. Elk from the Southfork population showed a positive relationship with forest and shrub. Elk from the Dworshak population showed a positive relationship with shrub and a negative relationship with high NDVI and dense forest cover. Elk from the Northfork population showed a positive relationship with shrub and forest, and a negative relationship with valleys. Selection coefficients indicated that there was a range in the selection of habitat components in the populations (Table 9). However, overall, elk showed a positive relationship with shrub, and were 1.07 times more likely to occur in shrublands than not. Elk showed a positive relationship with forest, and were 1.15 times more likely to occur in forested areas than not. Elk showed a negative relationship with valleys, and were 1.06 times more likely to occur outside of valleys. Elk showed a negative relationship with high cover, and were 1.04 times more likely to be outside of high cover than not (Table 10).

3.7. HABITAT SUITABILITY INDEX

To address my final objective, examining how summer-autumn distribution patterns relate to habitat variables within the four populations, I calculated a habitat suitability index (HSI) for each of the four populations (Fig. 11, 12, 13, 14). The final resource selection function used to calculate the HSI's in all four populations was:

$$w(x,t) = Exp\,[-0.01*\mathit{MIDSLOPE} - 0.06*\mathit{VALLEY} + 0.03*NDVI_t + 0.10*NDVI_t*(1-\mathit{FOREST}) + 0.04*\mathit{FOREST} + 0.07*\mathit{SHRUB} - 0.04*\mathit{HIGHCOVER} + 0.00*\mathit{LOWCOVER}]$$

In this equation I used the mean weighted selection coefficients ($\widehat{\beta_{\overline{w}}}$) across all individuals from each of the four populations, and $H(x)$ (i.e., midslope, valley, NDVI, NDVI*(1-Forest), Forest, Shrub, Highcover, and Lowcover) a vector of covariate values describing the habitat conditions at location x in the four population extents (Horne et al. 2014). The mean habitat suitability index values were different among the four populations. The Dworshak population utilized the highest levels of habitat suitability in both summer (July 20- 26th) and autumn (September 7-13th) weeks (mean= 0.61 (summer), 0.61 (autumn)) (Fig. 15), followed by Craig Mountain, Southfork and Northfork. The lowest habitat suitability index values utilized were in the Northfork population (mean= 0.29 (summer), 0.28 (autumn)), but likewise had lower habitat suitability values available within the Northfork extent (Fig. 14). The mean habitat suitability index values were 0.47 (summer) and 0.46 (autumn) for all elk detections and 0.38 (summer) and 0.37 (autumn) for all four study area extents. Therefore, elk utilized higher habitat suitability index values than those that were within the entire study area, and habitat suitability values were slightly lower in the autumn week (Fig. 16).

4. DISCUSSION

This study was initiated to better understand the underlying causes of declining elk numbers in the Clearwater Basin. By analyzing their use of available habitat in the four study areas within the Clearwater Basin, I was able to identify several factors that may be contributing to elk vulnerability. In most respects the elk in my study populations utilized their habitat as expected. The summer-autumn period, which was the subject of this analysis, is typified by lower quality forage and high daytime temperatures in the study areas. All of the elk responded to those conditions by selecting for a combination of shrub and forest cover.

The results of the home range scale habitat selection analysis of adult cow elk in four different environments indicate a utilization of mixed cover types. The collared cow elk appeared to be both generalists and specialists in their selection of habitat components. Within the diverse topographic, vegetative, and anthropogenically-influenced conditions that characterize the Clearwater Basin, elk occupy ranges throughout. Elk have successfully utilized the arid grasslands of Craig Mountain as well as the wetter, more densely forested areas of the Northfork and Dworshak. This indicates flexibility in their use of habitat and a generalist use of the landscape. This is supported by the historic range shift in northern elk populations in which elk populations were extirpated from their native plains habitat to become successfully established in diverse, largely forested landscapes with a variety of successional stages (IDFG 2014).

Despite their obvious flexibility in occupying four diverse study areas, the collared elk appeared to select a narrow range of habitat components within each area, and they demonstrated similar preferences across all four areas. The elk in all four study areas were consistent in their habitat selection and their most significant habitat variables. For example, they selected forest and shrub cover and avoided valleys during the summer-autumn season. This specific utilization of certain habitat components indicates a specialist selection, and may account for some of their vulnerability.

Cook et al. (2012) reported changes in the distribution and availability of critical elk habitat components in the Clearwater Basin. In particular, they indicated that elk population declines were associated with declines in early-seral shrublands and the subsequent limiting effects of summer-autumn nutrition. They tied these habitat changes to natural succession and anthropogenic land conversion. The resultant habitat loss and fragmentation have the potential to affect already declining elk populations. As indicated in both population numbers and low calf to cow ratios in Clearwater Basin elk populations as compared to stable or increasing populations elsewhere in the state. For example, calf:cow ratios in other Idaho GMU's south of the study area are typically higher and more stable (Sawtooth GMU (38:100 in 2013), Wieser River GMU (25:100 in 2013, 29:100 in 2007) (IDFG 2014), whereas average calf:cow ratios in Clearwater Basin elk are less than 20:100 in recent years. Populations that are in decline are more vulnerable to the negative effects of habitat loss than populations that are more stable (Berger 1990, Reed and Hobbs 2004).

Therefore, this study's primary objective was to examine the summer-autumn habitat selection of elk in the Clearwater Basin in order to assess the impact of changes in critical habitat components during a critical season. A secondary objective was to provide baseline information and data structure for future study and management of these populations. Although populations were once robust in all four areas, two of the four populations (Craig Mountain and Northfork) are in decline. Declines in the Craig Mountain and Northfork populations, may be due to of a loss of shrub and grassland habitat due to invasive weed incursion in the former, and natural succession in the latter.

4.1. VEGETATION VALIDATION

In order to use National Land Cover Data (NLCD) to describe the cover type and forest cover components, I first needed to determine the accuracy of these landcover datasets. Due to the large number of pixels in the NLCD classified image representing the four study areas, and the time required to collect data in rough and varied terrain, I could obtain ground-truth data for only a small portion of the study area. The more complex NLCD classification scheme, for example pasture/hay and cultivated crops, as opposed to simply agricultural, would have required excessive ground-truth data to correctly categorize and validate. I found that by combing similar classes in the classification scheme into simpler habitat cover categories (i.e., forest, shrub, herbaceous, and agricultural) I obtained acceptable results from the ground-truth data I was able to obtain. In addition, these categories were able to appropriately represent broad-scale habitat components that are important to elk. By combining similar classes, I consistently obtained accuracy rates of over 80% in both vegetation type and cover. These rates were comparable to other studies that conducted NLCD land cover accuracy assessments from agricultural areas in Kansas to the boreal regions of Alaska (Wardlow and Egbert 2003, Barrett and Gray 2011).

4.2. HABITAT SELECTION

I examined the relative importance of habitat variables to individual cow elk (objective

2), studied how the elk selection of habitat characteristics differed among the four populations (objective 3), and examined how summer-fall distribution patterns related to habitat variables within the four populations in the Clearwater Basin (objective 4).

Importance of Shrub Cover

In general, populations selected for similar habitat components. The populations also selected for habitat cover type and topographic features similar to results reported from other elk population studies. For example, Clearwater Basin elk show positive associations with shrub habitats, which have been found to be an important forage cover type for elk in other studies, with a relative variable importance of 81.1%. This habitat component was important for cow elk from the Lochsa herd, which resides near the Northfork study area (Unsworth et al. 1998) and the Hanford elk herd in the shrub-steppe of south-central Washington (McCorquodale et al. 1986). These two populations occupy different forms of shrubland habitat: in the Lochsa area shrubland takes the form of early-seral shrub habitat or clearcuts with grass-forb understories, whereas, in the Handford area shrubland takes the form of sagebrush-steppe or riparian areas. Yet this relationship with shrub habitat is conserved between the two distinct landscapes. This positive relationship with shrub habitat appears to be important for Clearwater Basin elk populations because their recent decline has coincided with a loss of early-seral shrub habitat (Cook et al. 2012).

The Southfork elk population showed less selection for shrub habitat than the other populations; I attribute this, at least in part, to the incursion of invasive rose species, dog rose (*Rosa canina*) and sweetbriar rose (*Rosa rubigino*sa), that I documented during field work in the Southfork River drainage. Additionally, the Natural Resource Conservation Service (NRCS 2014) has documented the spread of invasive blackberry species, Himalayan blackberry (*Rubus* *armeniacus*) and cutleaf blackberry (*Rubus laciniatus*), to the area. Astringency and tannin content were shown to be high in trailing blackberry (*Rubus ursinus*) in a study of forage quality for the western Oregon Roosevelt elk (*Cervus elephus roosevelti*) herd (Friesen 1991). Himalayan, cutleaf and trailing blackberry are closely related and may have a similar chemical makeup. Although these invasive shrub species were characterized as shrub habitat in the analysis, they do not necessarily provide the same forage value as other, more palatable, shrub vegetation such as serviceberry and redstem ceanothus (Alldredge et al. 2002).

<u>Importance of Forest Cover</u>

Elk require a juxtaposition of both forage and cover (Thomas et al. 1979). Although dense forest provides cover, it also results in a decrease in forage value due to the shading effects of canopy which limit understory plant growth. Elk have often been found to select foraging locations near forested edges (Mysteryd and Ostbye 1999), as was the case in this study. Elk selected for forested areas, with a relative variable importance of 92.4%. However, they had a negative relationship with high forest cover, and no selection for low cover areas, which indicates that elk selected for moderately dense canopy forested areas. A positive association with forest cover has been shown in elk herds from the Mount St. Helens blast zone (Merrill 1991) and the cedar- hemlock zone in northern Idaho (Irwin and Peek 1983). This association can be related to high summer temperatures causing elk to seek cooler forested sites, 2014 was a particularly hot and dry summer. Cook et al. (1998) found that elk in dense cover required less water than those in less protected areas. In addition to thermal protection, elk may use moderate forest cover as hiding cover (Mysteryd and Ostbye 1999). The calf-status of the collared cow elk in the CBC study was not known, but it is feasible that the elk with calves may have used forested areas to protect their young from predators (Thomas et al. 1979). It is also important to note that since deciduous and coniferous forested areas were combined in this analysis; detailed analysis of the specific forest type selected by elk would be necessary to fully evaluate the effect of forest type on elk habitat selection.

Elevation Effect

I found that elk selected for moderate to high elevation areas during summer-autumn period of study. The negative habitat selection association of the topographic position variables valley and midslope, with high relative variable importance (84.9% and 66.0%, respectively) was indicative of a positive relationship with the ridge topographic position. Higher elevations tend to stay cooler and the forage is greener due to the slow recession of the snow line throughout the early summer (Beck et al. 2013). Some research has speculated that ungulate movements to higher elevations, where breezes are more prevalent, may be as much related to avoiding harassment from biting flies as for searching out higher quality forage (Downes et al. 1986, Horne et al. 2008). Elk tend to forage horizontally, contouring along slopes, as opposed to foraging vertically down to valleys. Fortin et al. (2005) associated with the energy costs of traveling up and down steep topography.

Relationship with NDVI

There are many variables capable of influencing the habitat use and selection of elk; some of which have varying levels of effect dependent on scale or timing of a study. One of the variables measured in this study required a multifaceted interpretation of its relationship with the patterns of resource selection. NDVI provides a measure of vegetation greenness. High NDVI values correspond to dense vegetation such as forest canopies. The high forested NDVI values that relate to canopy cover are not typically available as a forage source for elk. To identify the selection of NDVI values where forest is absent, I use the inverse of the forest component in the interaction term, i.e., NDVI* (1- forest). The mean selection coefficients indicated no selection of the NDVI*forest covariate. The probability ratios for NDVI out of forest was 1.01 and NDVI in forest was 1.00, which indicates that elk were slightly more likely to occur in high NDVI outside of forested areas (Table 10). In this analysis elk did not seem to be substantially affected by NDVI within or outside of forests. Logically, NDVI is a likely predictor for suitable elk habitat. NDVI*forest was an important predicator variables of those included in this analysis; it occurred in 71.1% of the individuals top models. However, the period of June 15th – September 15th spans a large amount of phenological variation of plants in the diet of elk. Summer landscapes are typically nutrition rich in June through mid-July, and then become increasingly nutrition poor by late July through September. Habitat selection patterns may change dramatically across this June through September time period (Coe et al. 2011). Additional analysis may find very different habitat selection results, for NDVI in particular, if analyzed within more narrow time periods (e.g., early summer versus late summer/autumn).

4.3. Management Implications

Landscape-level changes in habitat quality appear to be partially responsible for the declining productivity of elk in the Clearwater Basin. From a management perspective, the importance of shrub habitat to elk provides an opportunity to improve habitat conditions though timber harvest or prescribed burning. Elk also selected for areas with forest cover; however, large areas of forest may not be important. Robinson (1960) found that small patches of cover adequately provided protection from heat stress in ungulates. Cook et al. (1998) considered forest cover even less important, urging biologists to focus efforts on providing adequate forage conditions because high thermal cover did not enhance the condition of captive cow elk in their study. Based on this analysis, elk populations would be enhanced by converting areas of contiguous forest cover to a diversity of seral communities, in particular palatable native early-seral shrubs with adjacent forest stands.

Roads, Timber Harvest, and Fire

The variables primary and secondary roads, timber harvest and fire were not included in this analysis because their effect on elk habitat selection was not as significant as the forage, cover, and topographic variables among all individual elk. However, I cannot discount the effect of these covariates. With regard to roads, several studies have indicated that elk avoid the less predictable and diverse forms of motorized traffic that occur on public roads (e.g., Rowland et al. 2004, Wisdom et al. 2005). This is in contrast to a 1989-1996 study on the Starkey Experimental Forest and Range in northeast Oregon which found that elk did not avoid the mainline timber harvest roads. The Starkey study area was closed to the public, and it is possible that elk became habituated to the predictable, consistent log-truck traffic (Wisdom et al. 2005).

I used only recent fire and timber harvest occurrences (2011-2014) in this analysis. This four year time period most likely captured only the immediate but short-term (one-three year) decline in forage availability that timber harvest and wildland fires are likely to cause. Increases in forage may not occur until four years post-harvest or fire (Wisdom et al. 2005). The effects of roads, timber harvest and fires are likely important, however, the importance of forage appears to outweigh these possible disturbances. The apparent lack of substantial disturbance from these activities supports the implementation of timber harvest and prescribed fire activities for the creation of improved forage opportunities.

Future Studies

Managers of the Clearwater Basin elk populations should continue to be vigilant in monitoring environmental changes and anthropogenic activities that may affect population demographics (e.g., reproduction, predation, immigration). Climate models predict an earlier and shorter duration of green-up coincident with warmer spring–summer temperatures and reduced spring precipitation in this area (Ault et al. 2014). This is consistent with observations of an unusually severe drought in the region, which may cause additional pressure to elk populations in these areas. Further analysis should be conducted at a finer-scale (individual movement paths) and during multiple seasons to evaluate the multi-scale, temporally dependent effect of variables used in this analysis. Future research should include creation and monitoring of early-seral shrub habitat, with emphasis on palatable native shrubs with low tannin content, to test whether improved forage opportunities will lead to increases in elk populations.

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Table 1. Summary of collar type statistics by elk population for the Clearwater Basin of North-central Idaho during December 2013 through April 2014.

Population	Sampling Dates	# Vectronic	# Lotek	# Store-on-board
Craig Mountain	DEC 18, 19 2013	18		
	APR 8, 2014		3	
South Fork	JAN 3,4, 2014		17	
	APR 9, 2014	3		
Dworshak	DEC 20, 2013	11		
	JAN 2 , 2014	8		
	APR 10, 2014		3	
Northfork	OCT 13, 2013			19
Total		**40**	**23**	**19**

Table 2. Summary of capture statistics by population in the Clearwater Basin of North-central Idaho during December 2013 through April 2014.

Population	Sampling Dates	New Animals	Recaptures	Total Captured
Craig Mountain	DEC 18, 19, 2013	18	0	18
	APR 8, 2014	3	6	9
South Fork	JAN 3, 4, 2014	17	0	17
	APR 9, 2014	3	6	9
Dworshak	DEC 20, 2013	11	0	11
	JAN 2, 2014	8	0	8
	APR 10, 2014	3	5	8
Northfork	OCT 13, 2013	19	0	19
			Total unique animals:	**82**
			Total capture events:	**99**

Table 3. Number of elk with fix rates (FR, the number of successful detections by a radio collar vs. the possible number of detections) ≥0.65 and ≥0.90, as well as the mean fix rate and number of detections (at the ≥0.65 fix rate) for each of the four Clearwater Basin elk populations in North-central Idaho.

Population	# Elk (FR≥0.65)	# Elk (FR≥0.90)	Mean Fix Rate	# Detections (FR≥0.65)
Craig Mountain	18	9	88.4% (range 72.8 – 97.8%)	1,572
Southfork	8	2	85.9% (range 76.1 – 94.6%)	680
Dworshak	18	1	79.8% (range 68.5 – 92.4%)	1,429
Northfork	9	9	99.0% (range 91.3 – 100%)	874
Total	53	21	88.3% (range 68.5 – 100%)	4,555

Table 4. Habitat attributes and distance classes for habitat selection analysis of elk in the Clearwater Basin of North-central Idaho.

#	Habitat Attribute	Distance (m) or attribute class	Collection Method	Resolution (m)
1	Aspect at elk detection (4 classes)	North (315-0˚, 0-45˚) East(45-135˚) South (135-225˚) West (225-315˚)	USGS and ISU digital elevation model (2013)	30 x 30
2	Topographic Position Index (3 classes)	Valley Midslope Ridge	USGS and ISU digital elevation model (2013), derived with Land Facet Corridor Designer	360 x 360
3	Primary roads: distance to paved roads	Distance to (km)	TIGER/Line Shapefiles (2014), updated with Forest Service and Potlatch Co.	Line
4	Secondary roads: distance to gravel roads	Distance to (km)	TIGER/Line Shapefiles (2014), updated with Forest Service and Potlatch Co.	Line
5	NDVI at elk detection (3 classes)	Low: >0.1 Moderate: 0.2-0.5 High: 0.6-0.9	eModis (direct download)	250 x 250
6	Forest: either 1 for present, or 0 for absent	0=absent 1=present	National Land Cover Data (2011), validated by ground truthing	30 x 30
7	Shrub: either 1 for present, or 0 for absent	0=absent 1=present	National Land Cover Data (2011), validated by ground truthing	30 x 30
8	Herbaceous: either 1 for present, or 0 for absent	0=absent 1=present	National Land Cover Data (2011), validated by ground truthing	30 x 30
9	Agriculture: either 1 for present, or 0 for absent	0=absent 1=present	National Land Cover Data (2011), validated by ground truthing	30 x 30
10	High Forest Cover: 60-100% cover	0=absent 1=present	National Land Cover Tree Canopy Data (2011), validated by ground truthing	30 x 30
11	Moderate Forest Cover: 25-59% cover	0=absent 1=present	National Land Cover Tree Canopy Data (2011), validated by ground truthing	30 x 30
12	Low Forest Cover: 0-24% cover	0=absent 1=present	National Land Cover Tree Canopy Data (2011), validated by ground truthing	30 x 30
13	Timber Harvest and Fire Boundaries	0=absent 1=present	Forest Service, State Forestry, and Potlatch Co. Shapefiles	Line

Table 5. Percent of elk whose univariate model (model including a particular covariate) had an AIC score that was substantially better than the Null model AIC score (Percent). N= number of elk with an AIC score ≥ 5 AIC units relative to the Null model for each covariate (ΣN=53). Shaded rows denote covariates that were kept for further modeling with a percentage > 20% (Table 5).

	Model	w(x)	Percent	N
1	Null: bivariate normal distribution		0%	0
2	North	$\beta_1 \times$ north	13%	7
3	West	$\beta_1 \times$ west	13%	7
4	South	$\beta_1 \times$ south	13%	7
5	East	$\beta_1 \times$ east	6%	3
6	Topographic Position Index: midslope	$\beta_1 \times$ TPImidslope	30%	16
7	Topographic Position Index: valley	$\beta_1 \times$ TPIvalley	36%	19
9	Primary roads	$\beta_1 \times$ prim_roads	0%	0
10	Secondary roads	$\beta_1 \times$ sec_roads	0%	0
11	NDVI	$\beta_1 \times$ NDVI	28%	15
12	Forest	$\beta_1 \times$ forest	24%	13
13	Shrub	$\beta_1 \times$ shrub	24%	13
14	Herbaceous and agriculture	$\beta_1 \times$ herb_ag	9%	5
15	Low forest cover	$\beta_1 \times$ lowcover	23%	12
16	Moderate forest cover	$\beta_1 \times$ modcover	13%	7
17	High forest cover	$\beta_1 \times$ highcover	34%	18
18	Fire and timber harvest	$\beta_1 \times$ fire_harvest	17%	9

Table 6. Candidate models for analyzing habitat selection of 53 elk in the Clearwater Basin of North-central Idaho. Models were developed based on ecological theory.

#	Model
0	Null: bivariate normal distribution
1	NDVI*Forest, forest, NDVI
2	NDVI*Forest, forest, highcover, NDVI
3	NDVI*Forest, midslope, forest, NDVI
4	NDVI*Forest, valley, forest, NDVI
5	NDVI*Forest, midslope, valley, forest, NDVI
6	NDVI*Forest, midslope, forest, highcover, NDVI
7	NDVI*Forest, midslope, valley, forest, highcover, NDVI
8	midslope, valley, forest,
9	midslope, valley, forest, highcover
10	midslope, shrub, lowcover
11	valley , shrub, lowcover
12	valley, shrub, highcover
13	midslope, shrub, highcover
14	midslope, valley, shrub, highcover
15	midslope, valley, shrub, lowcover

Table 7. Relative variable importance calculated from the top candidate models ($\Delta AIC \leq 2$) of habitat selection in individual elk in the Clearwater Basin of North-central Idaho. N = the number of elk with a variable in at least 1 of their top models. Rank= ranking of high to low relative variable importance. Percent= number of elk with variable in one of their best models divided by the total number of elk (53).

Variable	N	Rank	Percent
Topographic Position Index: midslope	35	6	0.66
Topographic Position Index: valley	45	2	0.85
NDVI+NDVI*forest	38	5	0.72
Forest	49	1	0.92
Shrub	43	3	0.81
Low forest cover	41	4	0.77
High forest cover	23	7	0.43

Table 8. MANOVA test results of difference in mean weighted selection coefficients between the four populations of elk in the Clearwater Basin of North-central Idaho.

Model	Df	Pillai’s Trace	F value	P value
Covariates ~ Populations	49	0.43	0.93	0.56

Table 9. Mean selection coefficients with 95% confidence interval, standard deviation (St. Dev.), and range (Min - Max) across individual elk for population-level habitat selection functions in the Clearwater Basin of north-central Idaho. The selection coefficients with some selection (positive or negative) are shaded.

Overall					
Variable	Values	95% CI	St. Dev.	Min	Max
Midslope	-0.01	0.01	0.05	-0.10	0.12
Valley	-0.06	0.03	0.12	-0.36	0.25
NDVI	0.03	0.20	0.75	-3.41	1.82
NDVI*forest	0.10	0.23	0.87	-1.10	5.25
Forest	0.04	0.03	0.11	-1.40	0.30
Shrub	0.07	0.02	0.07	-0.03	0.20
High cover	-0.04	0.02	0.07	-0.25	0.07
Low cover	0.00	0.02	0.06	-0.17	0.18
Craig Mountain					
Variable	Mean values	95% CI	St. Dev.	Min	Max
Midslope	-0.02	0.03	0.06	-0.10	0.09
Valley	-0.05	0.05	0.11	-0.24	0.25
NDVI	0.39	0.31	0.67	-1.21	1.82
NDVI*forest	-0.03	0.23	0.49	-0.66	1.67
Forest	0.02	0.06	0.13	-0.43	0.30
Shrub	0.10	0.04	0.08	0.00	0.20
High cover	-0.03	0.03	0.07	-0.25	0.03
Low cover	-0.02	0.02	0.03	-0.10	0.01
Southfork					
Variable	Mean values	95% CI	St. Dev.	Min	Max
Midslope	0.00	0.04	0.06	-0.07	0.12
Valley	-0.05	0.08	0.11	-0.23	0.14
NDVI	0.31	0.42	0.60	-0.26	1.69
NDVI*forest	-0.07	0.14	0.20	-0.32	0.19
Forest	0.06	0.05	0.07	-0.05	0.17
Shrub	0.02	0.01	0.02	0.02	0.05
High cover	-0.02	0.06	0.09	-0.24	0.07
Low cover	-0.01	0.05	0.07	-0.17	0.08

Table 9 cont.

Dworshak					
Variable	Mean values	95% CI	St. Dev.	Min	Max
Midslope	0.00	0.01	0.03	-0.04	0.09
Valley	-0.04	0.06	0.12	-0.36	0.11
NDVI	-0.40	0.38	0.83	-3.41	0.33
NDVI*forest	0.37	0.64	1.39	-1.10	5.25
Forest	-0.03	0.16	0.35	-1.40	0.57
Shrub	0.08	0.02	0.04	-0.01	0.18
High cover	-0.08	0.03	0.07	-0.18	0.06
Low cover	0.01	0.02	0.04	-0.06	0.12
Northfork					
Variable	Mean values	95% CI	St. Dev.	Min	Max
Midslope	0.00	0.03	0.05	-0.09	0.06
Valley	-0.11	0.08	0.12	-0.28	0.13
NDVI	-0.06	0.26	0.40	-0.87	0.66
NDVI*forest	-0.03	0.11	0.16	-0.34	0.13
Forest	0.09	0.07	0.11	-0.01	0.26
Shrub	0.09	0.05	0.07	-0.03	0.20
High cover	0.00	0.02	0.04	-0.05	0.06
Low cover	0.00	0.06	0.10	-0.10	0.18

Table 10. Interpretation of mean selection coefficients by relative probability ratio. The probability of occurrence within a habitat component as opposed to being out is shown for all variables except NDVI*Forest. The probability of occurrence at location x with an NDVI value of 0.5 versus an NDVI value of 0.4 is estimated for NDVI out of forest and NDVI in forest. To calculate probability ratio values I used the overall mean weighted selection coefficients across individual elk for population-level habitat selection functions in the Clearwater Basin of North-central Idaho.

Variable	Probability Ratio Equation	Values
Midslope	EXP $[\beta_{1\ (midslope)} * 1]$	0.99
Valley	EXP $[\beta_{2\ (valley)} * 1]$	0.94
NDVI	EXP $[\beta_{3\ (NDVI)} * 1 + \beta_{4(NDVI*Forest)} * 1]$	1.14
NDVI*forest (NDVI out of forest)	EXP $[\frac{\beta_{5\ (Forest)}*0+\ \beta_{3\ (NDVI)}*0.5+\beta_{4\ (NDVI*(1-Forest))}*0*0.5}{\beta_{5\ (Forest)}*0+\ \beta_{3\ (NDVI)}*0.4+\beta_{4\ (NDVI*(1-Forest))}*0*0.4}]$	1.01
NDVI*forest (NDVI in forest)	EXP $[\frac{\beta_{5\ (Forest)}*1+\ \beta_{3\ (NDVI)}*0.5+\beta_{4\ (NDVI*(1-Forest))}*1*0.5}{\beta_{5\ (Forest)}*1+\ \beta_{3\ (NDVI)}*0.4+\beta_{4\ (NDVI*(1-Forest))}*1*0.4}]$	1.00
Forest	EXP $[\beta_{5\ (Forest)} * 1 + \beta_{4(NDVI*Forest)} * 1]$	1.15
Shrub	EXP $[\beta_{6\ (shrub)} * 1\ ]$	1.07
High cover	EXP $[\beta_{7\ (highcover)} * 1\ ]$	0.96
Low cover	EXP $[\beta_{8\ (lowcover)} * 1\ ]$	1.00

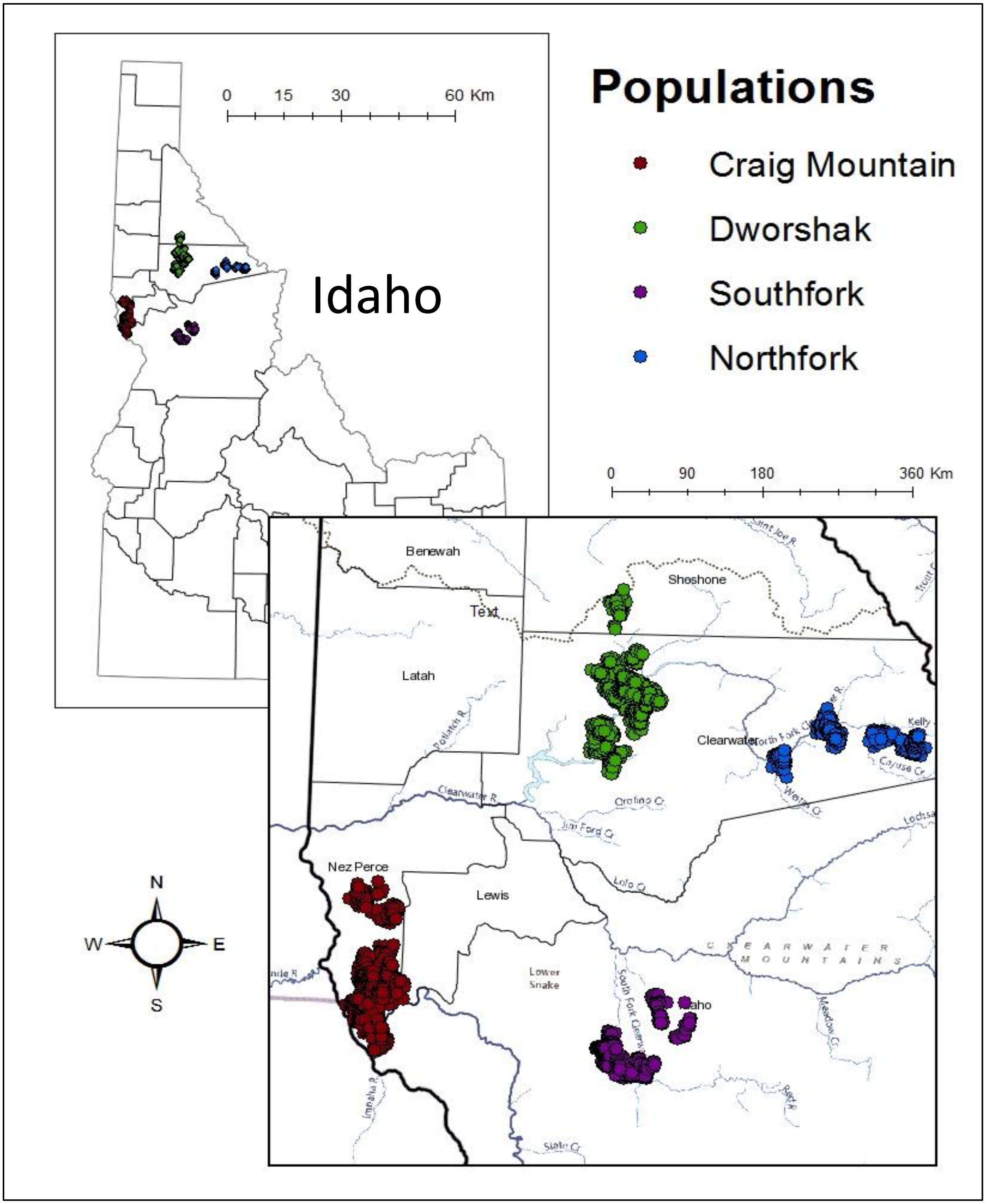


Figure 1. Elk were captured at four distinct locations, Craig Mountain, Southfork, Dworshak, and the Northfork, representative of four populations in the Clearwater Basin of North-central Idaho. Points on the map depict elk detection locations from June 15 – September 15, 2014.

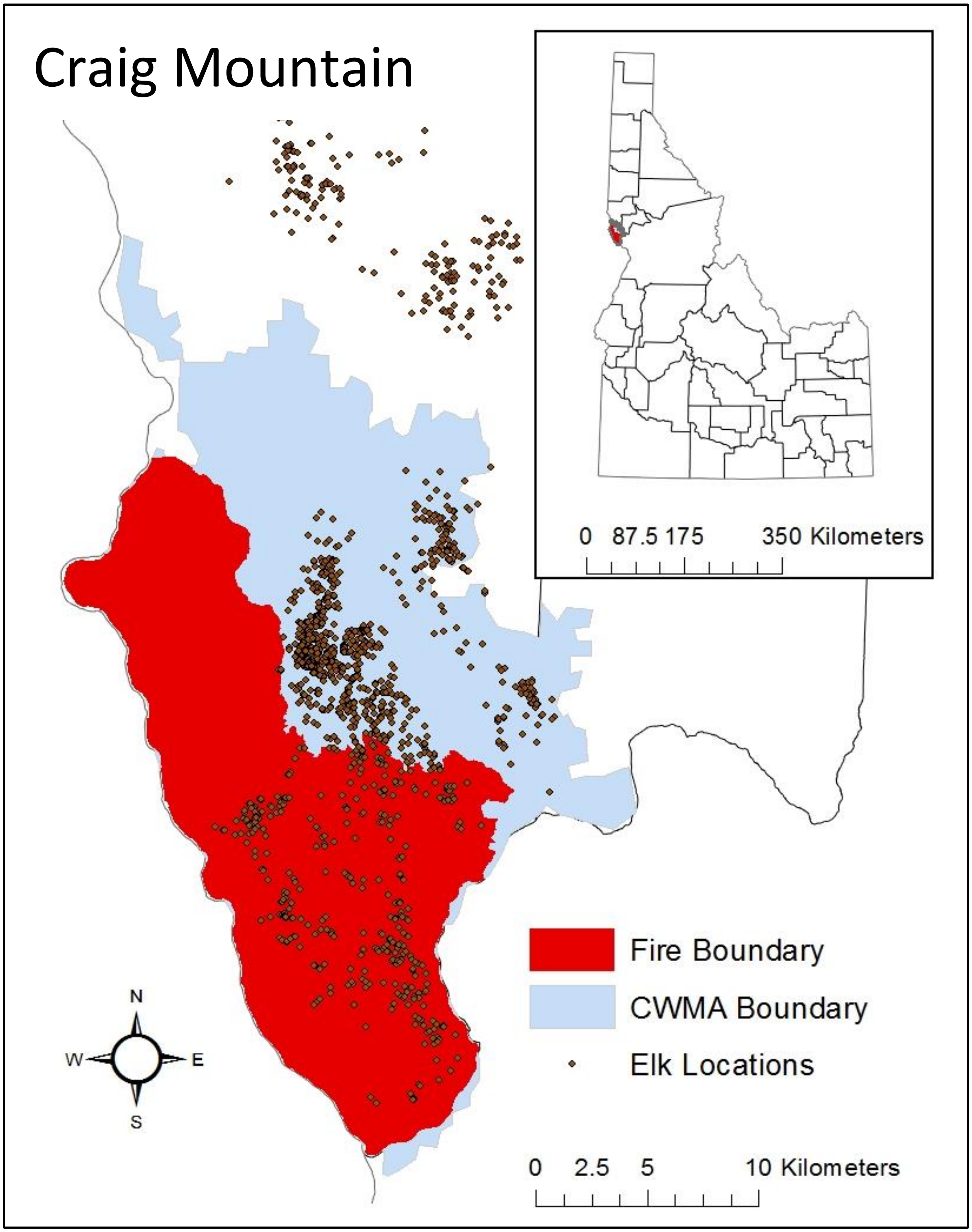


Figure 2. The Big Cougar Fire burned 28,328 hectares of the Craig Mountain Wildlife Management Area in August 2014 in North-central Idaho.

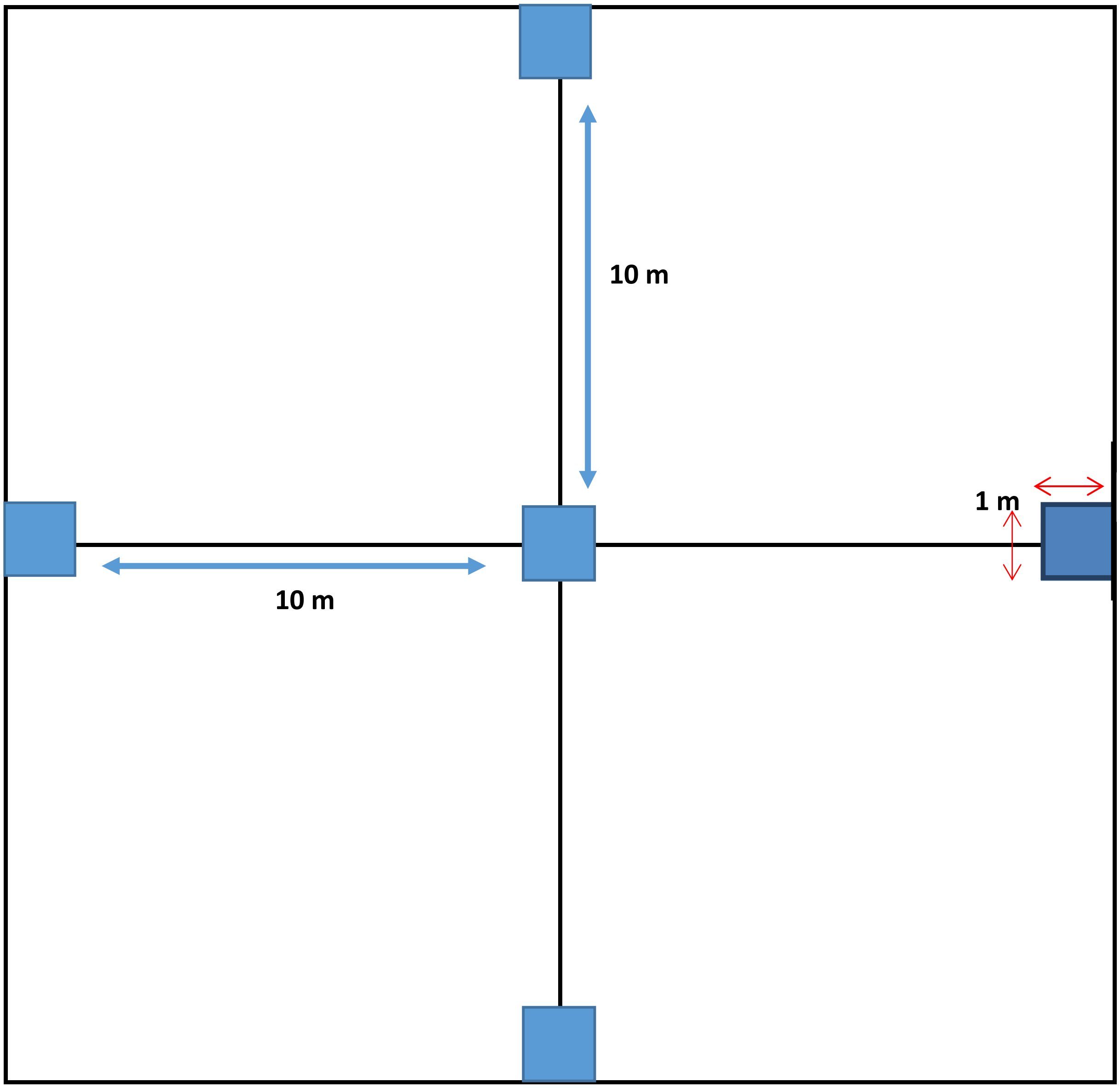


Figure 3. Diagram of a vegetation sampling plot. Four points ten meters in each cardinal direction create four quadrants from the center point with a nested one meter by one meter sample plot at the center and ends.

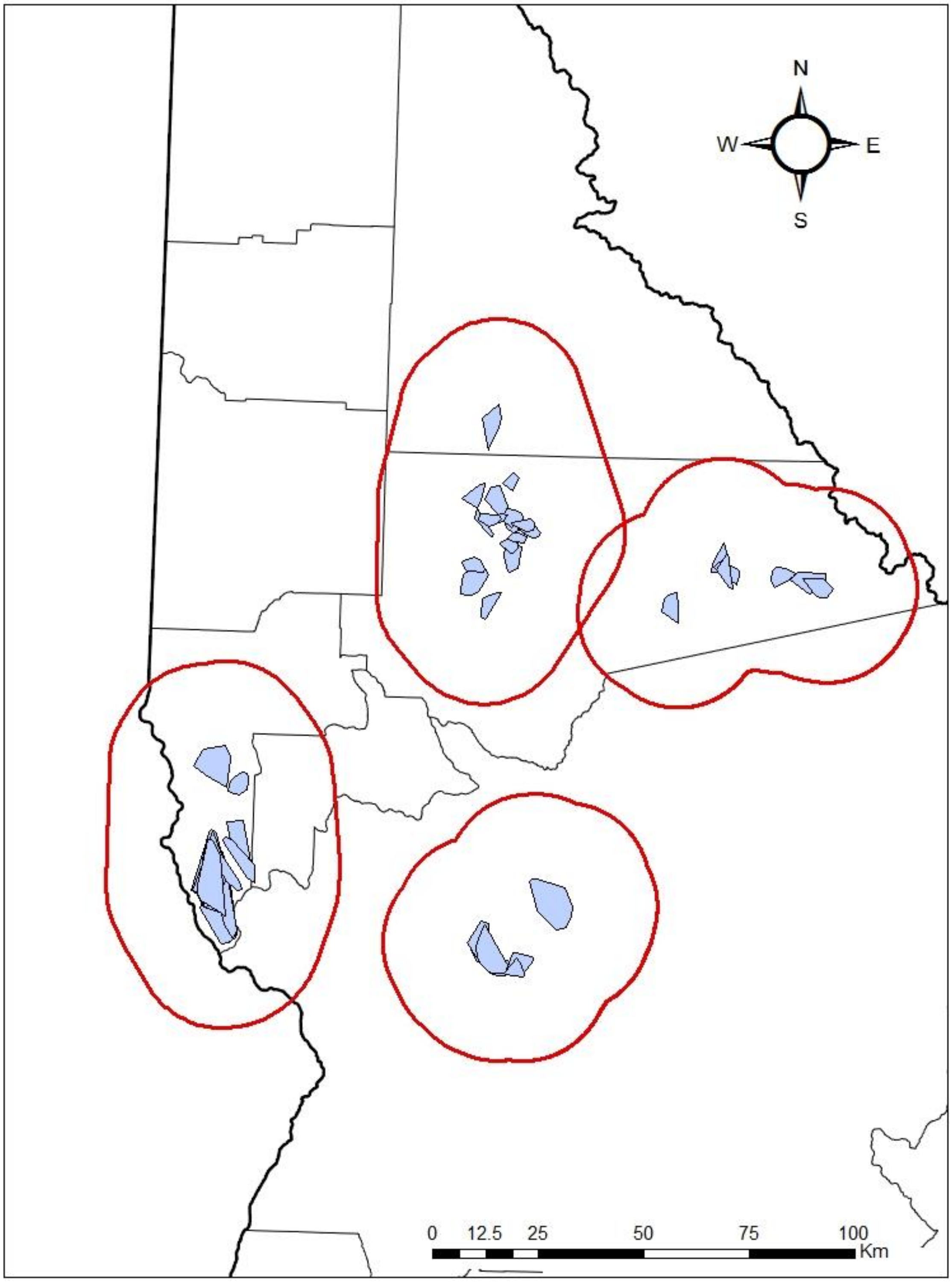


Figure 4. Home range estimates for 53 cow elk calculated by individual convex hulls which were aggregated by population then buffered by 20 km to delineate an approximate extent of summer-autumn habitat of elk in the four population areas in Clearwater Basin of North-central Idaho.

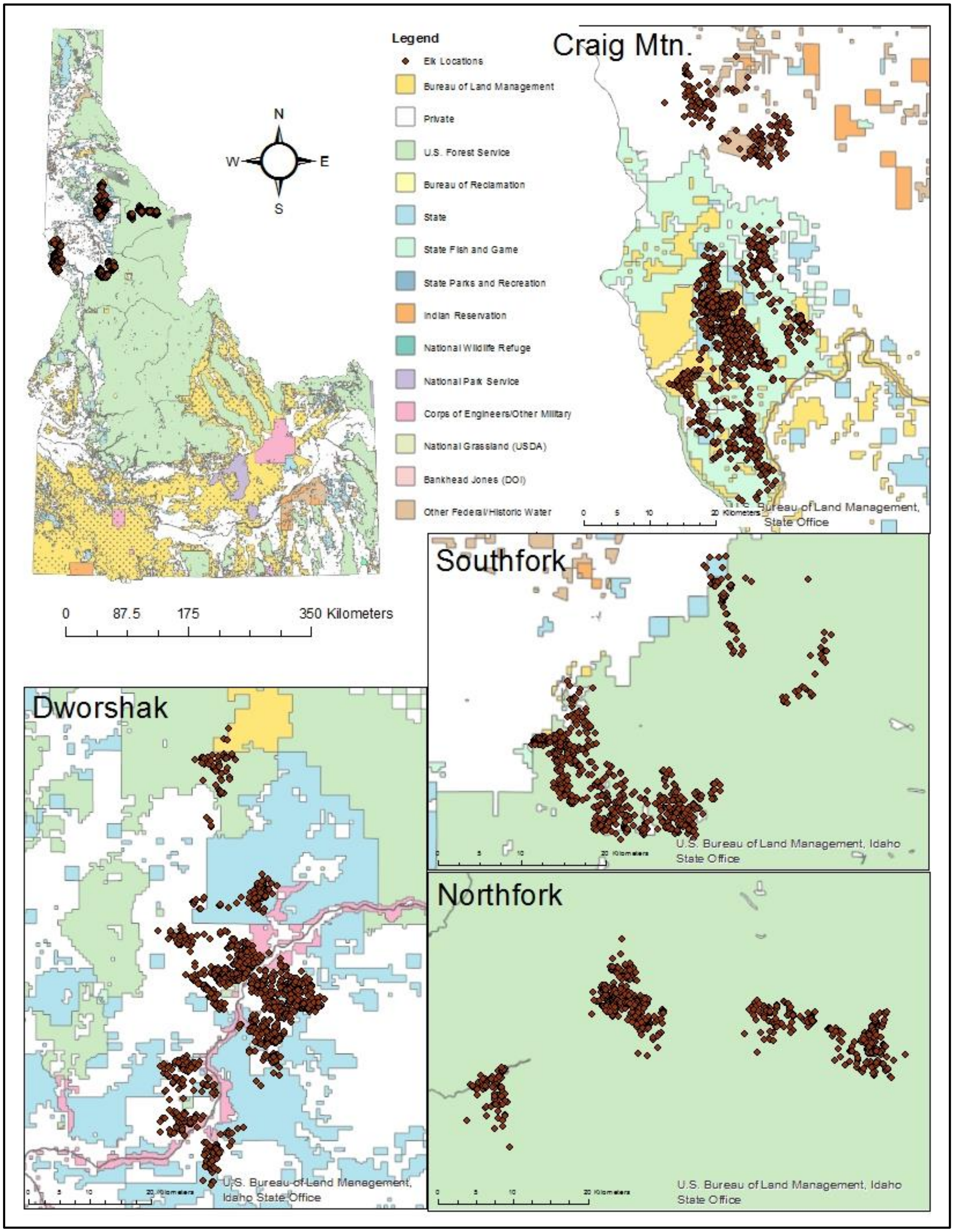


Figure 5. Land management agencies and ownership designations for the summer-autumn home ranges of four elk populations in the Clearwater Basin of North-central Idaho.

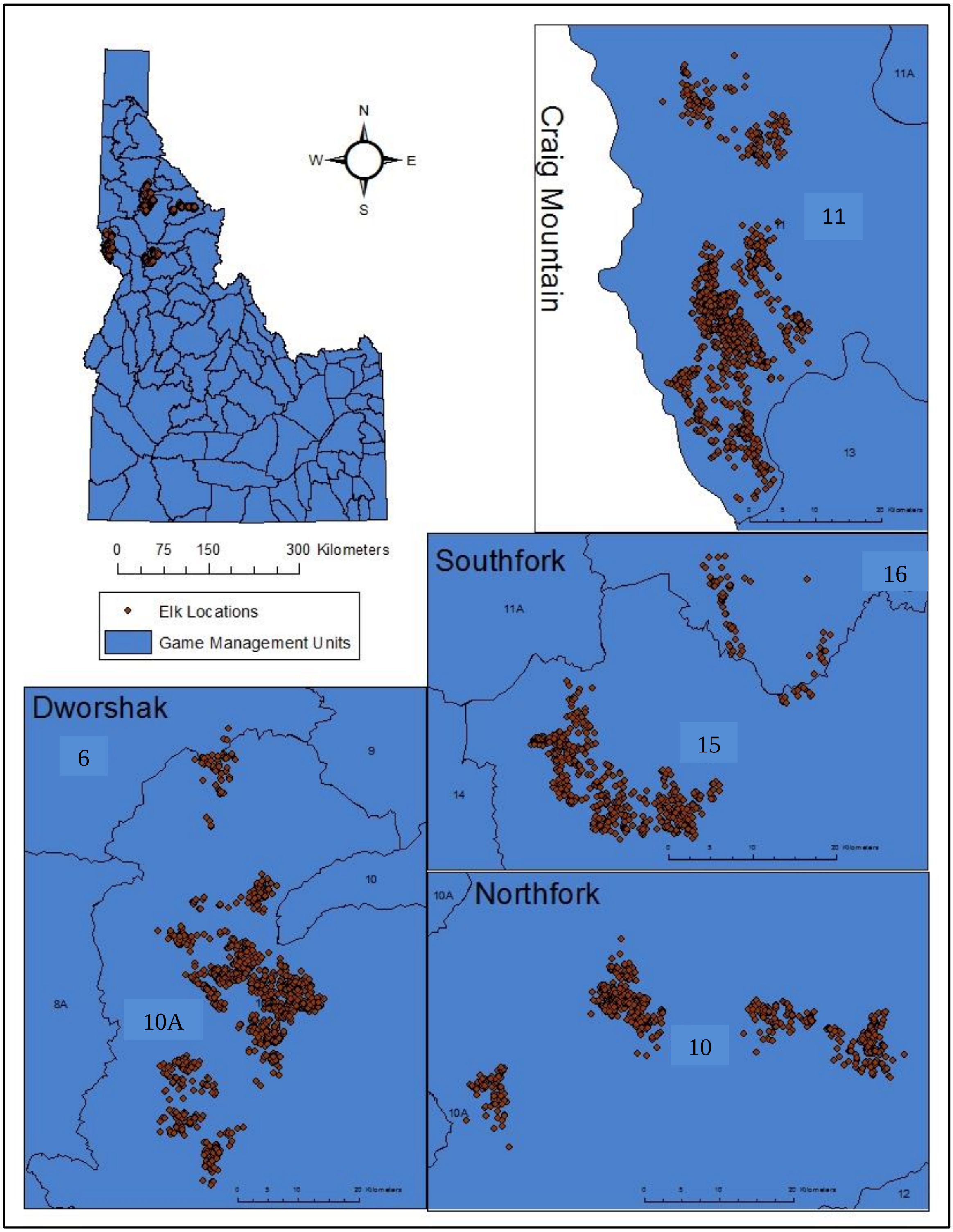


Figure 6. Game Management Unit designations for the summer-autumn home ranges of four elk populations in the Clearwater Basin of North-central Idaho.

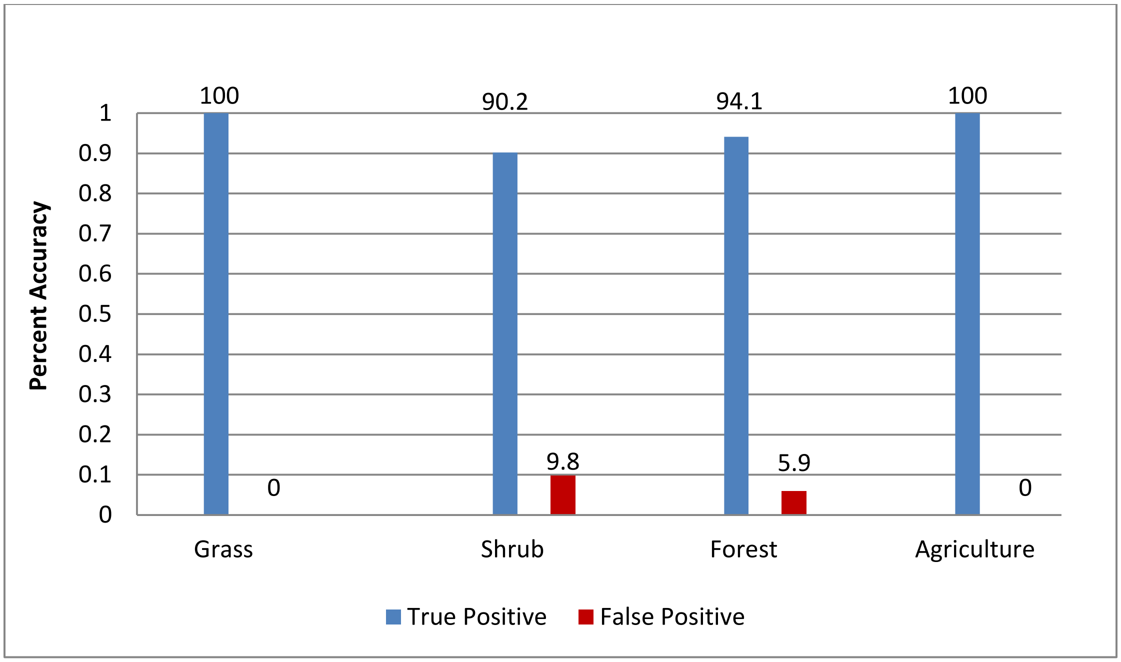


Figure 7. Proportion analysis comparing satellite-derived cover type to the ground-truthed cover type classification in a vegetation validation survey in North-central Idaho. Percent accuracy was based on the ratio of correctly classified (true positive) points to incorrectly classified (false positive) points.

	Grass	Shrub	Forest	Ag
Grass	51	5	0	0
Shrub	0	46	3	0
Forest	0	0	48	0
Ag	0	0	0	51

Figure 8. The error matrix compares the number of points correctly identified by the satellite data and which of those were misidentified in a vegetation validation survey in North-central Idaho. There was a total of 51 points in each cover type category: grass, shrub, forest and agriculture.

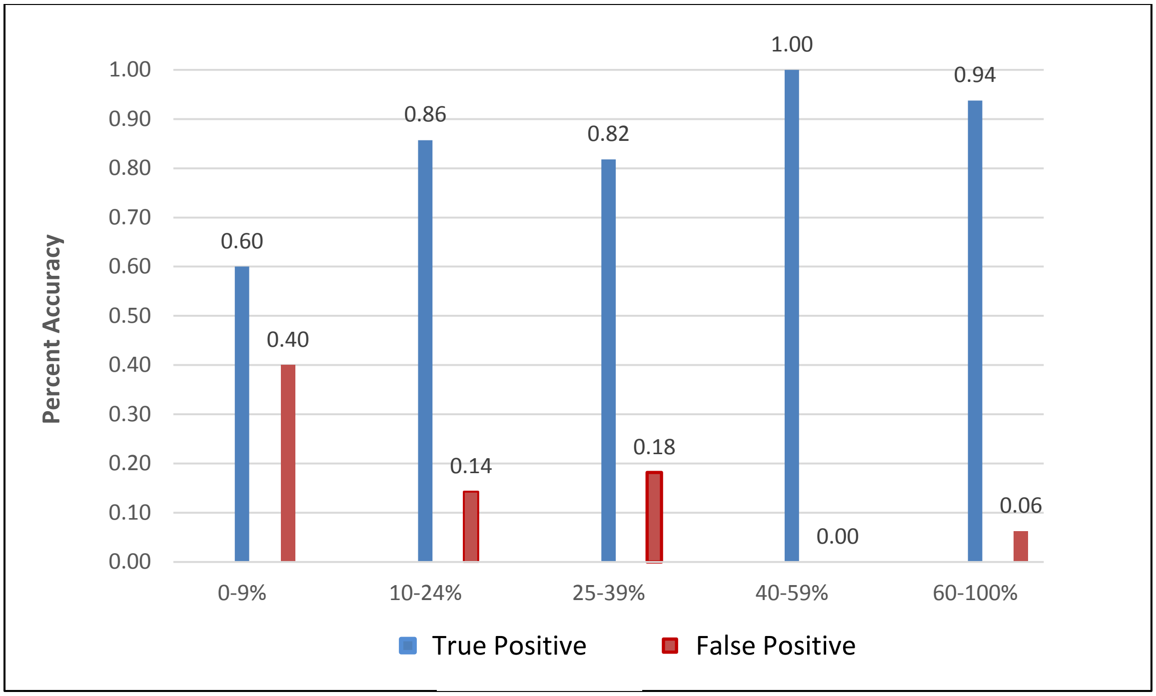


Figure 9. Proportion analysis comparing satellite-derived percent forest cover to the ground-truthed percent forest cover classification in a vegetation validation survey in North-central Idaho. Percent accuracy was based on the ratio of correctly classified (true positive) points to incorrectly classified (false positive) points.

	0-9%	10-24%	25-39%	40-59%	60-100%
0-9%	3	1	0	0	0
10-24%	2	7	0	0	0
25-39%	0	0	10	0	0
40-59%	0	0	1	11	1
60-100%	0	0	0	0	15

Figure 10. The error matrix compares the number of points correctly identified by the satellite data and which of those were misidentified in a vegetation validation survey in North-central Idaho. There was a total of 13 points in the low cover (0-24%), and 38 points in the moderate to high cover (25-100%) categories.

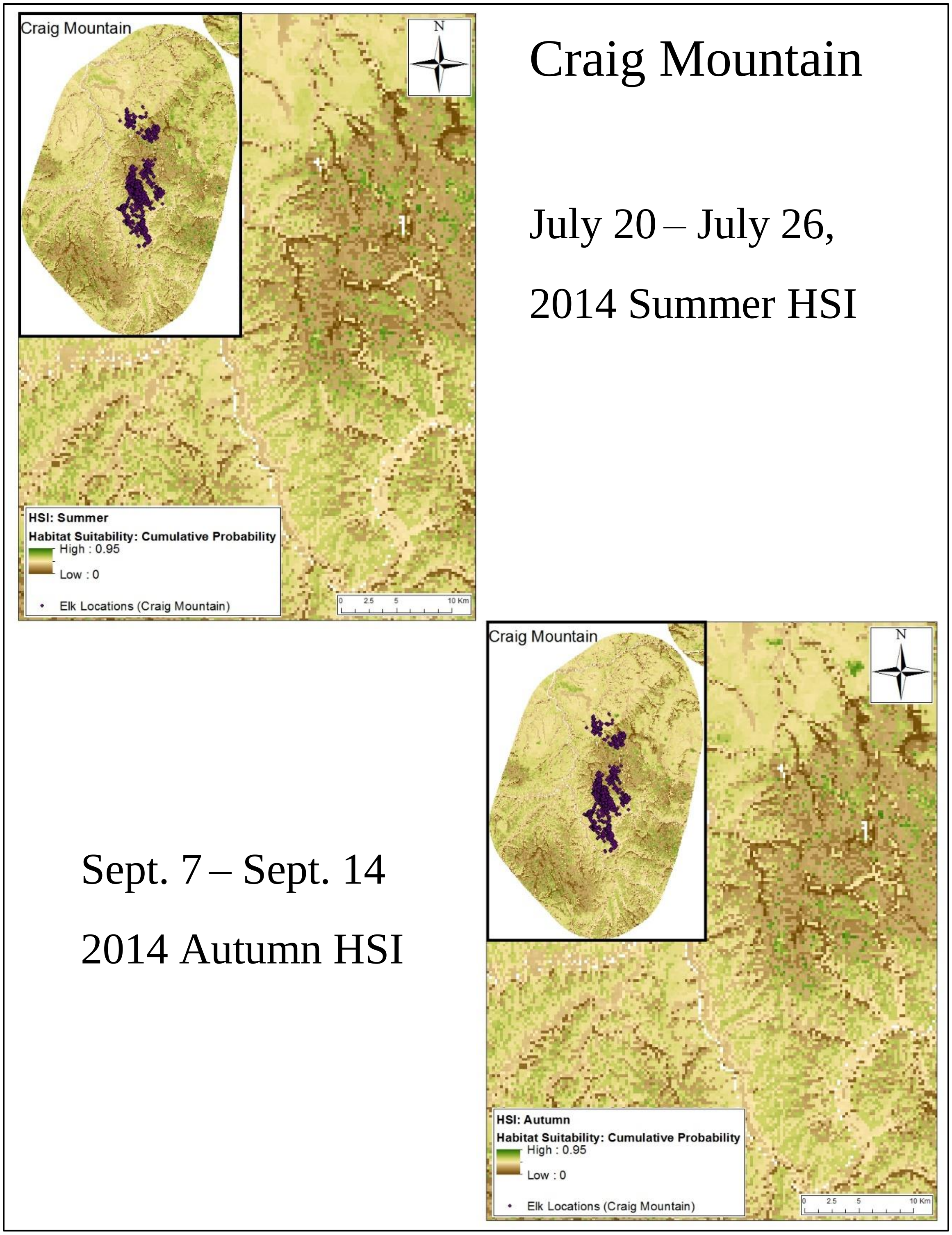


Figure 11. Craig Mountain habitat suitability index for elk indicating the relatively high or low habitat suitability and the cumulative probability of habitat use in summer and autumn for the Craig Mountain elk population in North-central Idaho.

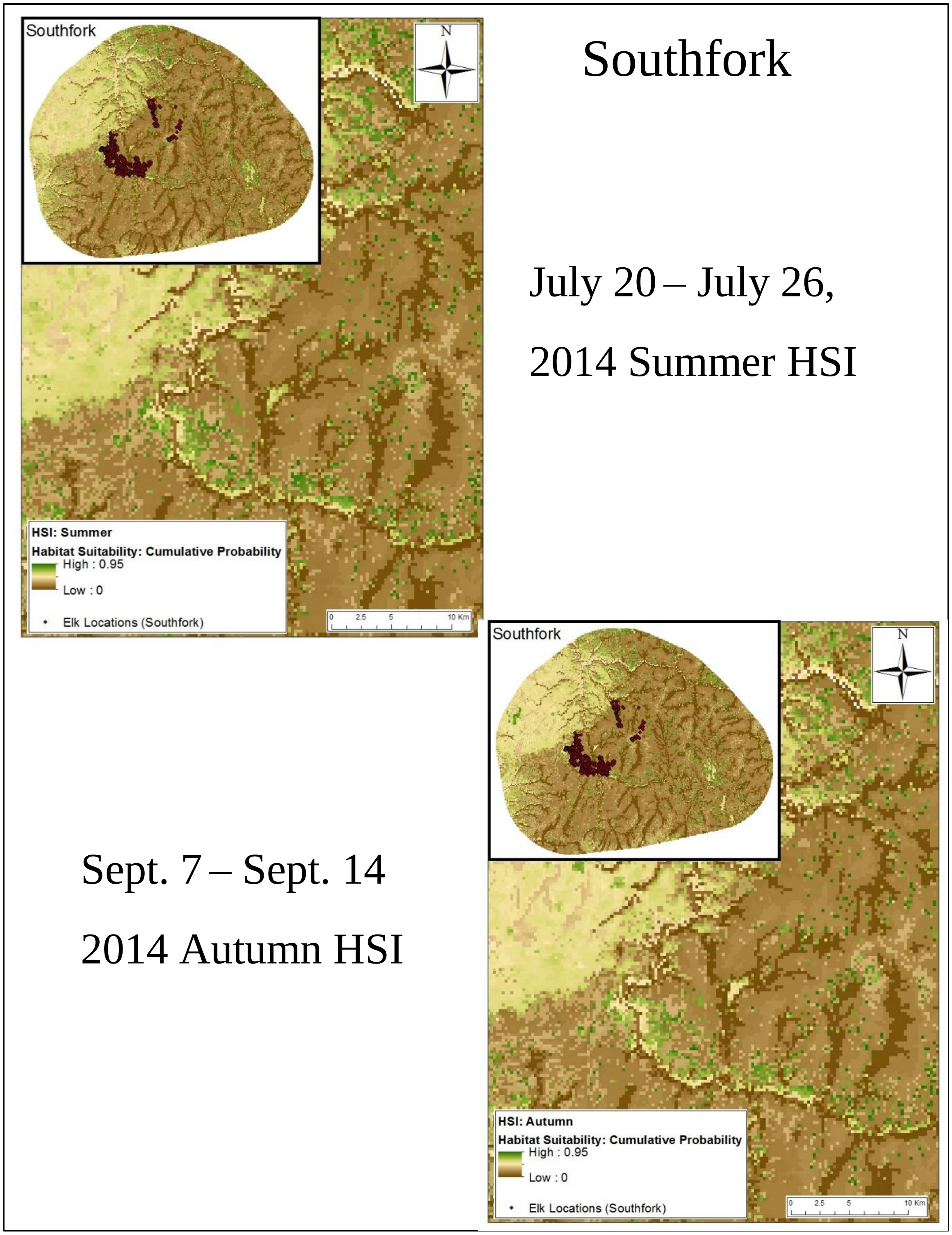


Figure 12. Southfork habitat suitability index for elk indicating the relatively high or low habitat suitability and the cumulative probability of habitat use in summer and autumn for the Southfork elk population in North-central Idaho.

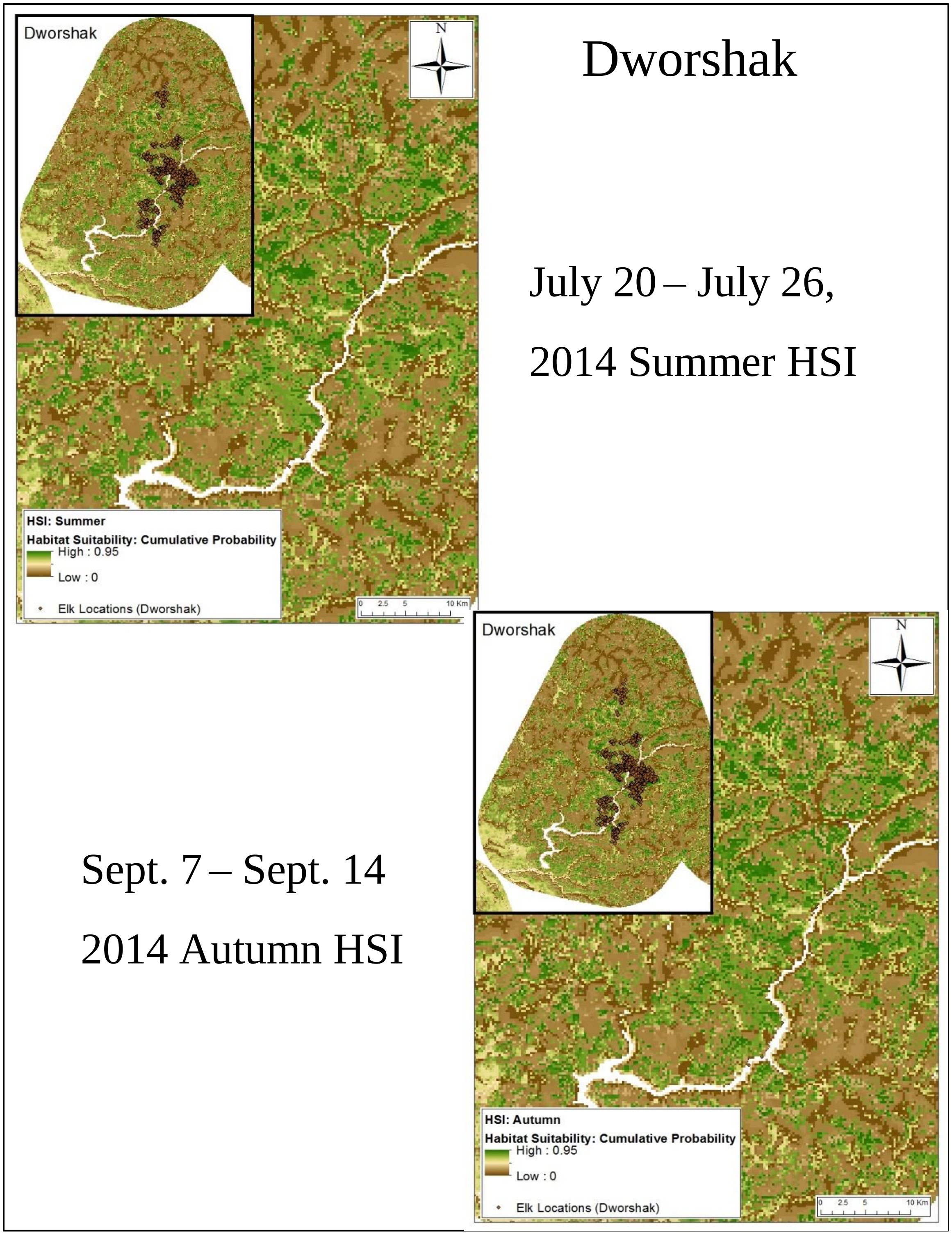


Figure 13. Dworshak habitat suitability index for elk indicating the relatively high or low habitat suitability and the cumulative probability of habitat use for the Dworshak elk population in North-central Idaho.

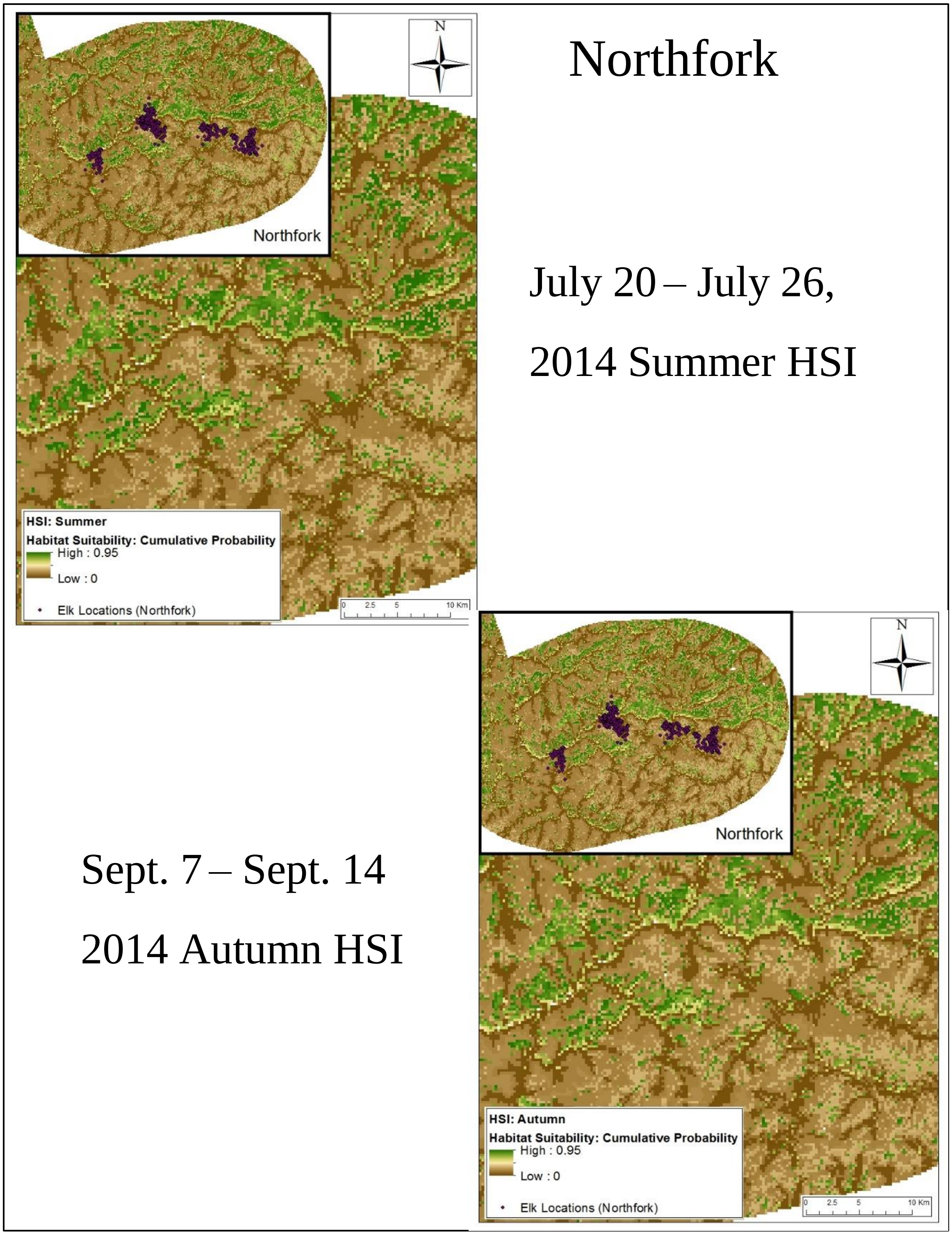


Figure 14. Northfork habitat suitability index for elk indicating the relatively high or low habitat suitability and the cumulative probability of habitat use for the Northfork elk population in North-central Idaho.

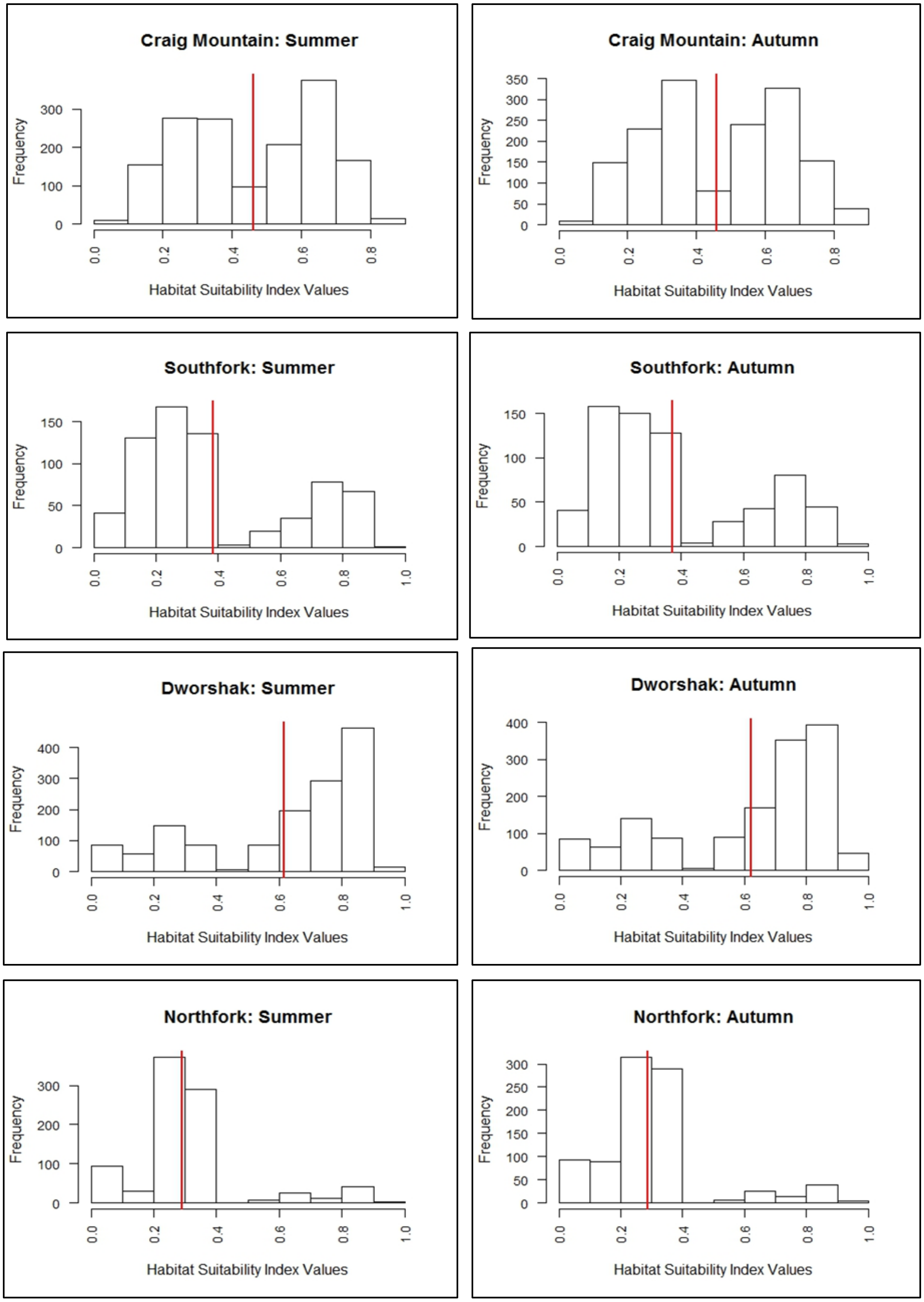
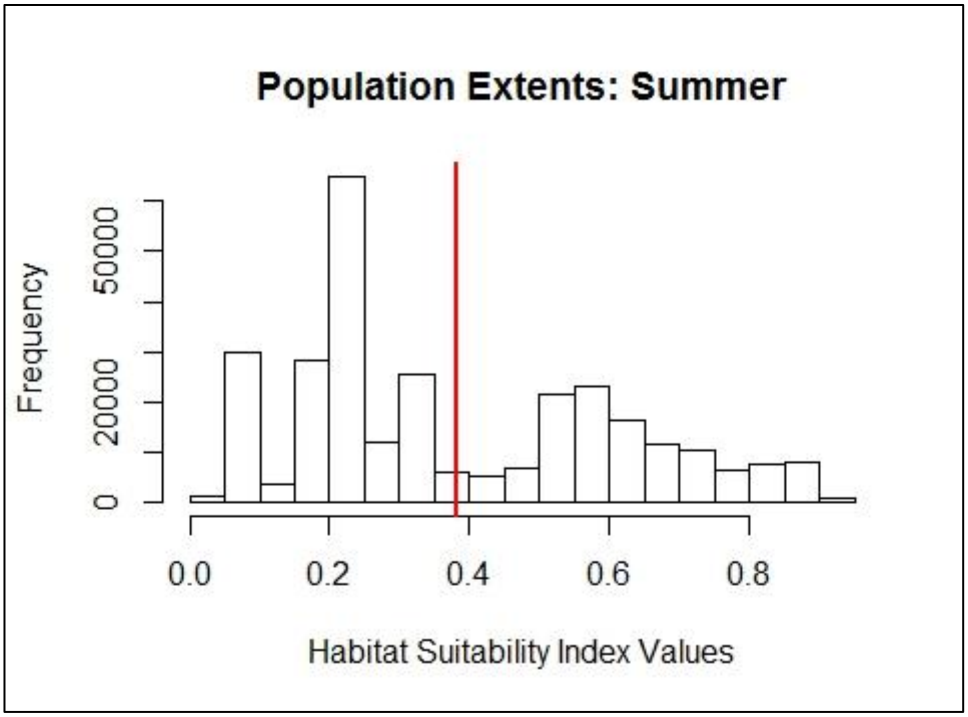


Figure 15. Habitat suitability index values for elk detections in each of the four populations in summer (July 20 – 26, 2014) and autumn (Sept. 7 – 13, 2014) in the Clearwater Basin of North-central Idaho.



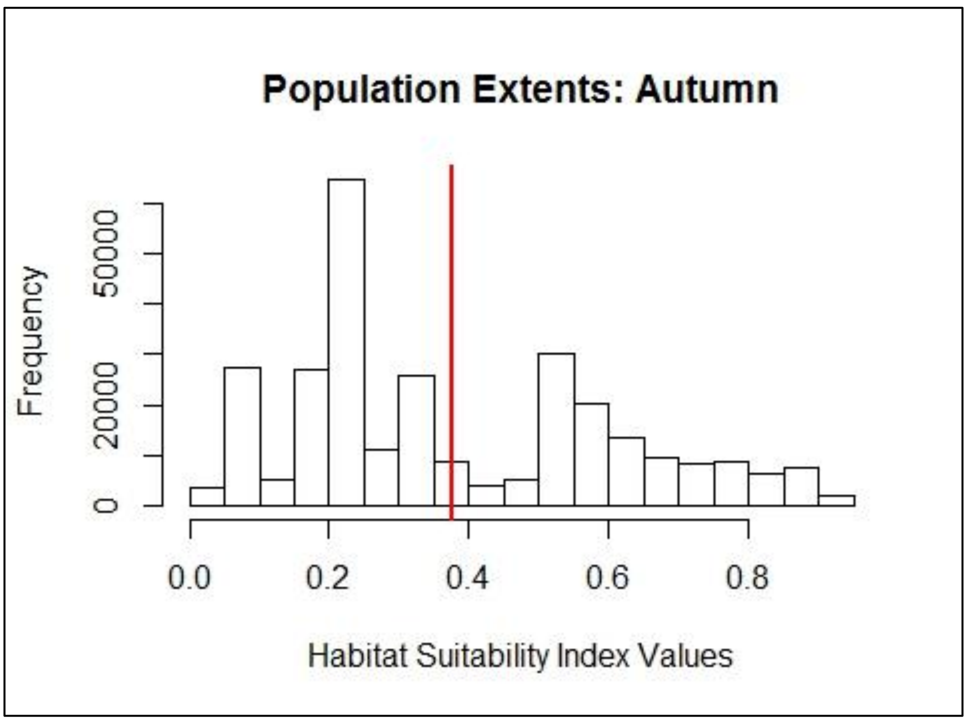


Figure 16. Habitat suitability values for all four study area extents in summer (July 20 – 26, 2014) (top) as compared to habitat suitability values for all four study area extents in autumn (Sept. 7 – 13, 2014) (bottom) in the Clearwater Basin of North-central Idaho

Appendix 1. Example R code developed by K. Magori to associate elk locations for a temporally varying habitat variable (NDVI) as well as other time invariant variables.

```
#load packages
library(rgdal)
library(raster)
library(sp)
library(rgeos)
library(lubridate)
#define projection for all files from existing raster
NDVI_temp=raster("NDVI_2014/NDVI_007_013_IDTM.img")
stateplaneproj=crs(NDVI_temp)
#load point locations
InputLocations = read.csv("AllLocations.csv", head = T)
#format date/time
InputLocations$DateTime=format(Dates,format="%m/%d/%Y %H:%M")
#Bind x,y locations and project
Animals=SpatialPoints(cbind(InputLocations$X,InputLocations$Y))
proj4string(Animals)=proj4string(NDVI_temp)
#get a week number for each animal from only one year
NewDates=as.POSIXct(as.character(InputLocations$DateTime),format="%m/%d/%Y")
InputLocations$start_date=as.numeric(format(floor_date(NewDates,"week"),"%j"))+2
InputLocations$year=format(NewDates,"%Y")
InputLocations=InputLocations[which(InputLocations$year=="2014"),]
#choose which weeks to include in the analysis
InputLocations = InputLocations [which(InputLocations$start_date >= 168 &
InputLocations$start_date <= 259),]
#call NDVI image by file name (weekly NDVI files are separated by 6 days)
InputLocations$NDVI_filename="";
InputLocations$NDVI=NULL;
        GetNDVI_filename<-function(x){
         number1=as.character(InputLocations$start_date[x])
        if (nchar(number1)==1) number1=paste("00",number1,sep="")
        if (nchar(number1)==2) number1=paste("0",number1,sep="")
        newdate=InputLocations$start_date[x]+6;
        if (newdate>365) newdate=newdate-365;number2=as.character(newdate)
        if (nchar(number2)==1) number2=paste("00",number2,sep="")
         if (nchar(number2)==2) number2=paste("0",number2,sep="")
paste("NDVI_",InputLocations$year[x],"/NDVI_",number1,"_",number2,"_IDTM.img",sep="")
}
```

```
#Extract NDVI spatial values by animal locations based on week number
InputLocations$NDVI_filename=unlist(lapply(1:dim(InputLocations)[1],function(x)
GetNDVI_filename(x)))
InputLocations$NDVI=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster(InputLocations$NDVI_filename[x]),Animals[x])))
#Extract all other variable values to animal locations
InputLocations$north=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/north.img"), Animals[x])))
InputLocations$west=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/west.img"), Animals[x])))
InputLocations$south=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/south.img"), Animals[x])))
InputLocations$east=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/east.img"), Animals[x])))
InputLocations$TPImidslope=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/midslope.img"), Animals[x])))
InputLocations$TPIvalley=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/valley.img"), Animals[x])))
InputLocations$herb_ag=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/herb_ag.img"), Animals[x])))
InputLocations$forest=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/forest.img"), Animals[x])))
InputLocations$shrub=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/shrub.img"), Animals[x])))
InputLocations$highcover=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/highcover.img"), Animals[x])))
InputLocations$modcover=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/modcover.img"), Animals[x])))
InputLocations$lowcover=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/lowcover.img"), Animals[x])))
InputLocations$fire_harvest=unlist(lapply(1:dim(InputLocations)[1],function(x)
extract(raster("Layers/fire_harvest.img"), Animals[x])))
#create column that indicates a year and week for which NDVI values were derived
InputLocations$extent_file=unlist(lapply(1:dim(InputLocations)[1],function(x) paste("Avail-
Year",format(NewDates[x],"%Y"),"-week",format(NewDates[x],"%U"),".txt",sep="")))
}
```

Appendix 2. Species of grass, forb, shrub, and forest cover types collected during the 2014 field season in three study areas, Craig Mountain (CW), Southfork (SF), and Dworshak (DS) in the Clearwater Basin of North-central Idaho. Noxious weed species were found in grass, forb and shrub types.

Common Name	**Scientific Name**	**CM**	**SF**	**DS**
Non-Invasive Grasses		15	7	7
Beardless wheatgrass	*Pseudoroegneria spicata spp. inermis*	x		
Bluebunch wheatgrass	*Pseudoroegneria spicata/ Agropyron spicatum*	x	x	x
Columbia needlegrass	*Achnatherum nelsonii*			x
Crested wheat grass	*Agropyron cristatum*	x		x
Green needlegrass	*Stipa viridula*	x		
Idaho fescue	*Festuca idahoensis*	x	x	
Kentucky bluegrass	*Poa pratensis*	x		
Meadow foxtail	*Alopecurus pratensis*	x	x	
Mountain brome	*Bromus marginatus*	x		x
Needle-and-thread grass	*Hesperostipa comata*	x		
Orchard grass	*Dactylis glomerata L.*	x		
Pine grass	*Calamagrostis rubescens*	x	x	x
Purple threeawn	*Aristida purpurea*	x		
Rough fescue	*Festuca scabrella*	x		
Smooth brome	*Bromus inermis*		x	
Timothy	*Phleum pratense*	x	x	
Tufted hairgrass	*Deschampsia cespitosa*	x	x	x
Western wheatgrass	*Pascopyrum smithii*			x
Invasive Grasses		4	4	2
Cheat grass	*Bromus tectorum*	x	x	x
Common chess	*Bromus secalinus*	x		
Dogtail grass	*Cynosurus echinatus*		x	x
Hairy Chess	*Bromus commutatus*	x		
Johnsongrass	*Sorghum halepense*		x	
North Africa grass	*Ventenata dubia (Leers) Coss.*	x	x	
Non-Invasive Forbs		23	6	8
Western yarrow	*Achillea millefolium*		x	x
Arrowleaf balsamroot	*Balsamorhiza sagittata*	x		
Common St. John's wort	*Hypericum perforatum*	x		
Creeping Oregon grape	*Berberis repens*	x		
Crown vetch	*Coronilla varia*	x		
Elk sedge	*Carex geyeri*	x	x	x
False hellebore	*Veratrum californicum*			x
Fireweed	*Chamerion angustifolium*			x
Hoary cress	*Cardaria draba*	x	x	

Indian paintbrush	*Castilleja* spp.	x		
Lava aster	*Ionactis alpina*	x		
Low larkspur	*Delphinium bicolor*		x	
Meadow death camas	*Zigadenus venenosus*	x		
Mules ear	*Wyethia amplexicaulis*		x	
Pathfinder	*Adenocaulon bicolor*	x		
Pearly everlasting	*Anaphalis margaritacea*	x		
Penstemon	*Penstemon* spp.	x	x	x
Poison ivy	*Toxicodendron radicans*	x		
Prairie smoke	*Genum triflorum*	x		
Syringa	*Syringa vulgaris*	x		
Tailcup lupine	*Lupinus caudatus*	x		x
Thick-leaf ragwort	*Senecio crassulus*	x		
Thimbleberry	*Rubus parviflorus*	x		
Western meadow aster	*Aster campestris*	x		
Western salsify	*Tragopogon dubius*	x		x
Western yarrow	*Achillea millefolium*	x		
Wild geranium	*Genranium viscosissimum*	x		x
Wild strawberry	*Fragaria vesca*	x		
Invasive Forbes		9	5	3
Bracken fern	*Pteridium aquilinum*		x	
Houndstongue	*Cynoglossum officinale*		x	x
Leafy spurge	*Euphorbia esula*	x		
Orange hawkweed	*Hieracium aurantiacum*	x	x	
Rush skeletonweed	*Chondrilla juncea*	x		
Scotch broom	*Cytisus scoparius*	x		
Scotch thistle	*Onopordum acanthium*	x		x
Spotted knapweed	*Centaurea maculosa/biebersteinii*	x	x	x
Sulfer cinquefoil	*Potentilla recta*	x		
Tansy ragwort	*Senecio jacobaea*	x		
Yellow starthistle	*Centaurea solstitialis*	x	x	
Non-Invasive Shrubs		17	9	6
Alder	*Alnus* spp.			x
Bitterbrush	*Purshia tridentata*	x		
Chicory	*Cichorium endivia*	x		
Chokecherry	*Prunus virginiana*		x	x
Cow Parsnip	*Heracleum lanatum*	x		
Curl-leaf mountain mahogany	*Cercocarpus ledifolius*	x		
Dog rose	*Rosa canina*		x	
Flowering crab apple	*Syringa reticulata*		x	
Green rabbitbrush	*Chrysothmnus viscidiflorus*	x		
Hackberry	*Celtis reticulata*	x		

Huckleberry	*Vaccinium* spp.	x		
Nine bark	*Physocarpus malvaceus*	x	x	
Nootka rose	*Rosa nutkana*	x		
Oceanspray	*Holodiscus discolor*	x	x	
Red elderberry	*Sambucus racemosa*	x		
Red-osier dogwood	*Cornus sericea L.*	x		
Redstem cenanothus	*Ceanothus sanguineus*	x		x
Serviceberry	*Amelanchier alnifolia*		x	x
Shinyleaf caunothus	*Ceanothus valutinus*			x
Sitka alder	*Alnus sinuata*		x	
Snowberry	*Symphoricarpos albus*	x	x	x
Sticky currant	*Ribes viscosissimum*	x		
Thin leaf alder	*Alnus incana tenuifolia*	x	x	
Utah honeysuckle	*Lonicera utahensis*	x		
Invasive Shrubs		1	2	1
Sweetbriar rose	*Rosa rubiginosa*		x	
Wood's rose	*Rosa woodsii*	x	x	x
Tree Species		13	6	9
Black cottonwood	*Populous trichocarpa*	x		x
Cottonwood	*Populus* spp.			x
Douglas fir	*Pseudotsuga menziessii*	x	x	x
Engelmann spruce	*Picea engelmannii*	x		
Grand fir	*Abies gradis*	x	x	x
Hawthorn	*Crataegus douglasii*	x		
Lodgepole pine	*Pinus contorta*	x	x	
Mountain ash	*Sorbus sitchensis*	x	x	
Mountain maple	*Acer glabrum*	x	x	
Ponderosa pine	*Pinus ponderosa*	x	x	x
Quaking aspen	*Populus tremuloides*			x
Scours willow	*Salix amygdaloides*	x		
Three-leaf sumac	*Rhus trilobata*	x		
Water birch	*Betula occidentalis*	x		
Western hemlock	*Tsuga heterophylla*			x
Western larch	*Larix occidentalis*	x		
Western redcedar	*Thuja plicata*			x
White pine	*Pinus strobus*			x
Agricultural Species		4	1	0
Alfalfa	*Medicago sativa*	x		
Common wheat	*Triticum aestivum*	x		
Cow pea	*Vigna unguiculata*	x		
Rapeseed	*Brassica napus*	x		
Timothy (agricultural)	*Phleum pratense*		x	

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