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Elk (Cervus elaphus) response to anthropogenic disturbance: hunting, land use, and climate change

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ELK (*Cervus elaphus*) RESPONSE TO ANTHROPOGENIC DISTURBANCE: HUNTING, LAND USE, AND CLIMATE CHANGE

A Thesis

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Cheney, Washington

In Partial Fulfillment of the Requirements

For the Degree

Master of Science in Biology

By

Katherine S. Farrell

Summer 2015
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MASTER’S THESIS

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ABSTRACT

Understanding factors underlying the distribution and abundance of wildlife species remains a central question of wildlife ecology and has become increasingly complex as humans continue to alter landscape conditions. During the past 50 years, elk in eastern Washington have expanded their year-long ranges into lower elevation areas of the Channeled Scablands. The persistence of this population is dependent upon core protected areas with surrounding low human density agriculture or rangeland. Over-reliance on core protected area leads to over-browsing, often resulting in management decisions designed to displace elk out of core areas. Use of human areas exposes elk to increasing land use practices that reduce habitat availability. Irrespective of land ownership, human-induced climate change threatens the distribution and abundance of habitats within both core protected areas and human use areas. I tracked elk on and around Turnbull National Wildlife Refuge (TNWR) via radio telemetry from 2012-2013 and combined these elk locations with elk locations collected from 2010-2011 to examine elk response to anthropogenic disturbances such as hunting, land use practices, and climate change. I determined that elk are disrupted during hunting and movement behavior suggests they may be beginning to relocate off-refuge. I found that parturient elk have the highest probability of occurrence in forage habitats. There are no off refuge patches where parturient elk have a high probability of occurrence, and there are four off-refuge patches where parturient elk have a low probability of occurrence. Twenty times smaller than low probability occurrence patches located within TNWR, all off refuge patches are threatened by land use practices. Water availability will limit future land development and off-refuge elk will likely compete with humans for water. Human-induced climate change is predicted to result in warmer, wetter winters and drier summers. A compression of plant communities may restrict aspen to shrinking riparian areas, and ponderosa pine may become the dominant vegetation on this landscape. By 2030, many parturient elk occurrence patches within TNWR may be unavailable due to water loss and by 2060 through 2090 landscapes may no longer be capable of supporting elk. If elk are a management priority in this area conservation practices, such as establishing more protected areas, utilizing fire management to open additional habitats, protection of water resources, and maintenance of travel corridors is warranted.
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INTRODUCTION

Understanding factors underlying the distribution and abundance of wildlife species remains a central question of wildlife ecology and has become increasingly complex as humans continue to alter landscape conditions. Although certain activities, such as overharvest and habitat loss and degradation have predictably negative impacts on ungulate populations, other activities, such as predator removal, hunting restrictions, and establishment of refuges lead to population increases. The history of elk (*Cervus elaphus*) in North America demonstrates this.

Six sub-species of elk once inhabited most of North America (Bryant and Maser 1982) (Fig. 1). By 1978, unregulated hunting, cattle-grazing, and human development resulted in two extinction events and fragmentation of the remaining sub-species. Washington State is home to two of the remaining subspecies of elk; Roosevelt elk (*Cervus elaphus roosevelti*) west of the Cascade Mountains and Rocky Mountain elk (*Cervus elaphus canadensis*) predominantly in the Blue Mountains. Both were near extinction in the early 1900’s but both populations have increased with human management, including hunting restrictions (Bryant and Maser 1982, Burcham et al. 1999) and re-introductions (Bryant and Maser 1982). These increases also reflect elk dispersal to previously unused habitats (e.g., the expansion into arid regions of southern Washington, including the Channeled Scablands of eastern Washington), expansion of populations on protected lands, and habituation to human use areas (McCorquodale et al. 1986, Burcham et al. 1999, Thompson and Henderson 1998). In 1979, the Washington State Department of Game reported 36,000 Roosevelt elk and 24,000 Rocky Mountain elk in Washington state (Taber et al. 1982). Today, the Washington State Department of
Fish and Wildlife reports there are approximately 30,000-34,000 Roosevelt elk and 26,000-30,000 Rocky Mountain elk in Washington State (Brock Hones, pers comm).

However, with increasing elk populations new management issues arise primarily due to elk over-browsing. For example, human-elk conflicts arise when elk damage crops (USFWS 2007). In refuges and other protected areas over-browse by elk on deciduous trees, especially aspen (*Populus tremuloides*), reduces tree regeneration and has a negative impact on biological diversity (Baker *et al.* 1997, Beschta and Ripple 2008). One management response to human-elk conflicts is modifying hunting regulations in an effort to cull herds and disperse elk out of conflict areas, often into increasingly human-modified landscapes. Land use practices, including housing developments and roads, can disrupt how elk traditionally use landscapes by reducing availability to or fragmenting habitats, which can result in population isolation or increased mortality (Frair *et al.* 2008, Dzialak *et al.* 2011a). In addition to continued human development of landscapes, the habitat condition of these landscapes is predicted to be further modified by human-induced climate change.

The management of elk on and adjacent to Turnbull National Wildlife Refuge (TNWR) in eastern Washington exemplifies these issues. The goals of my study are first, to document elk movement and distribution in and around TNWR in response to hunting pressure, and second, to identify current habitat use by elk and predict how those habitats might be altered by land use practices and anthropogenically-induced climate change. Finally, I offer insight as to how land use practices and anthropogenically-induced climate change might affect elk distribution in this region. Analysis of current elk
response and prediction of future elk response to anthropogenic disruptions can be used to inform future hunting regulations and to highlight areas for conservation.
CHAPTER 1. RESPONSE TO NOVEL HUNTING PROGRAM

The extirpation of large predators and the restrictions on hunting on some public lands, such as national parks and wildlife refuges, has led to increased populations of elk (*Cervus elaphus*) in many western states. High elk density can lead to over-browsing of riparian plant communities, including aspen (*Populus tremuloides*) and willow (*Salix* spp.), resulting in a reduction of riparian structure and function that can negatively impact riparian-dependent species such as resident and migratory birds (Ripple and Beschta 2007, Beschta and Ripple 2008, Hollenbeck 2006). This type of trophic cascade occurs on landscapes lack large predators. Without large predators to regulate elk populations, elk over browse deciduous trees and shrubs, preventing recruitment of new shoots that, in turn, prevents trees from attaining their full height. Stunted trees provide limited over-story and reduced habitat for bird species. Land managers of large public lands removed from urban centers, such as Yellowstone National Park, have used the reintroduction of large predators to reduce elk impacts on the ecosystem (Ripple and Beschta 2007). However, this approach is not feasible for smaller public lands near urban centers. As an alternative to predator reintroduction, managers may respond with controlled hunting. Novel hunting programs disrupt patterns of movement and habitat use by elk unaccustomed to hunting pressure (Thompson and Henderson 1998, Burcham *et al.* 1999, Johnson *et al.* 2005).

Unlike mule deer, which respond to hunting pressure by hiding, elk respond by modifying the time they spent in any one area and altering habitat selection (Johnson *et al.* 2005, Cleveland *et al.* 2012). Movement depends on whether the landscape is open or closed, the mode of hunting, and hunter density. In a closed study area, elk mean daily
speed of movement during archery season was significantly higher than during rifle season, and movements persisted hours longer due to the difference between archers who stalk elk and rifle hunters who sit and wait (Johnson et al. 2005). By contrast, in open landscapes, studies suggest little difference in elk movement rates between archery and non-hunt seasons, but find significant differences between non-hunt and rifle hunting seasons (Cleveland et al. 2012). Although many, usually younger, elk employ a “runner” anti-predator strategy, often darting across open fields, mortality increases at high movement rates. This suggests a threshold at which higher movement rates begin to decrease elk survival. Elk that survive hunting were found to show intermediate movement rates and to avoid open areas (Ciuti et al. 2012).

Hunted elk choose habitats with greater vegetative cover, fewer roads, and lower hunter density (Edge et al. 1985, Burcham et al. 1999, Millspaugh et al. 2000, Proffitt 2010). During archery season, elk will remain in close proximity to hunters if cover is sufficient, and road and hunter densities are low (Millspaugh et al. 2000). During rifle season or if hunter density increases, elk flee to habitats that decrease the risk of discovery. In many cases, elk remain within their home range during escape events (Edge et al. 1985, Conner et al. 2001). This strategy of site fidelity offers the advantage of remaining in areas of known cover and quality forage (Edge et al. 1985, Thompson and Henderson 1998, Hebblewhite and Merrill 2011). This hunting response is often short-lived, and elk return to their pre-hunt habitats when hunting pressure ends (Edge et al. 1985, Conner et al. 2001).

Other elk may be less tolerant of hunters towards the end of hunting season, causing them to flee their home range or move onto non-hunted lands (Millspaugh et al. 2000).
Movement onto private or protected lands is also common on landscapes that lack abundant cover or where hunting pressure is exacerbated by additional disturbances, such as logging (Edge et al. 1985, Burcham et al. 1999, Millspaugh et al. 2000, Vieira et al. 2003). During successive hunting seasons elk will return to protected lands, remaining in undisturbed areas until hunting season terminates. This anti-predator strategy is such that elk may even forego traditional security areas, those with dense forage cover away from open roads, if the new area offers a reduced likelihood of hunter encounters (Millspaugh et al. 2000). With persistent pressure, natural site fidelity develops, causing elk to return to these protected areas during subsequent hunting seasons. Over generations, these movements may overlap with seasonal triggers, such as photoperiod, and they may become environmentally-associated behavior in younger cows (Conner et al. 2001). As those cows assume leadership roles in the herd they pass the new behavior to younger generations. Over time, elk may begin to utilize these new habitats outside of hunting season and relocation may occur (Burcham et al. 1999). Such an associated response develops over many years, and may not be possible to determine from short-term response studies. However, if elk begin to remain longer in new protected areas, a trend towards relocation may be inferred.

Monitoring of the elk population of Turnbull National Wildlife Refuge (TNWR) provides an opportunity to study elk response to novel hunting pressure. Prior to 2010 these elk were exposed to only off-refuge hunting from late October early November but in 2010 these elk were exposed to both on- and off-refuge hunting. Albrecht (2003) radio tracked cow elk collared on and adjacent to TNWR from November 2001 to April 2003 to follow seasonal movements on and off refuge and to determine areas of the refuge with
high versus low elk use and corresponding elk impact on aspen stands. Seasonal elk movements were driven by off-refuge hunting and resource conditions. Elk were mainly found on refuge during late spring through fall when the refuge provided cover and forage for calving and protection from off-refuge hunting but, from November to April, elk were more often found off refuge where they foraged on hay (Albrecht 2003). Elk disproportionately used the southeast and northern portions of the refuge and aspen regeneration in these areas was less than in low-use areas (Albrecht 2003). The negative impacts of elk on aspen regeneration prompted refuge managers to initiate a hunting program in 2010 to reduce the herd and displace elk away from aspen stands and off of the refuge. Preliminary analyses following the first two years of a novel hunting program within TNWR suggest elk exhibit a short-lived flight response. Elk responded to the first year of hunting by dispersing off-refuge during the late hunt and early post hunt periods, and then returning to the refuge within four months following the termination of the hunt (Dwight 2012). During the second year, elk primarily moved into the non-hunt areas of the refuge during the pre-hunt and early hunt, into both non-hunt areas and off refuge by the late hunt, and then dispersed off-refuge by the end of the hunt (Walker 2012). Because it was not the focus of the 2012 study, elk return to TNWR was not documented.

I monitored elk response to refuge hunting during the third and fourth hunting seasons and combined my data with previous data for a comprehensive analysis of elk movement and distribution in response to hunting pressure. I documented elk movement patterns in response to the new hunting program to see whether elk continued to disperse off-refuge during or following the refuge hunt, and whether they returned following the end of the hunt. The two objectives of my study were to 1) determine if hunting pressure
disrupts elk movement in a manner indicative of dispersal, and II) to determine if elk continue to exhibit a temporary flight response, or if they begin to relocate. With respect to the first objective I asked 1) are there breaks in elk movement behavior and if so, how do the timing of the breaks relate to hunting season, and 2) are elk displaying dispersal-type movement behavior (spending less time in a given area while moving in a forward direction) following movement breaks? I expected to find more movement breaks during the hunting season resulting in dispersal-type behavior. With respect to the second objective I asked 1) are there differences in the probability of where elk are located between the first year of hunting and subsequent hunts, and 2) are dispersal events followed by a return after the end of the hunting season and/or before the start of the next hunt? When compared to elk locations during the 2010 hunting season, I expected to find elk would have a progressively higher probability of being off refuge or in refuge non-hunt areas during the 2011 through 2013 hunting seasons, and to have a higher probability of being in the refuge hunting areas outside of hunting season. I also expected to find progressively fewer returns to refuge hunting areas following hunting season or early post hunting season dispersal events. If elk are beginning to relocate, I expected to see elk progressively increasing their use of off-refuge areas during all seasons.
Methods

Study Area

Established in 1937, TNWR encompasses 7,312 hectares of the Channeled Scablands of eastern Washington. At 700 m elevation, this low relief landscape is dominated by ponderosa pine forests, Palouse steppe grasslands interspersed with aspen stands, and hundreds of marshes, deep-water lakes, and wetlands. Average daily winter temperature is between -3.5 °C and -1.0 °C, and most of the 400 mm of annual precipitation falls as snow. Summer daily highs are currently above 26.5 °C (USFWS 2007).

The refuge lies approximately 8 km south of Cheney, Washington (population 11,000) and 35 km southwest of Spokane, Washington (population 200,000), and is divided into two main areas. The 8.9 km² public use area to the east houses the refuge headquarters, bunkhouses, educational centers, wildlife viewing areas, an 8 km auto tour route, and hiking trails. The non-use areas, primarily to the west, contain only service roads. The landscape surrounding the refuge is dominated by low-density rural housing and small tract agriculture north of the refuge. Large tract agriculture dominates the landscape south, east, and west of the refuge. My study area encompasses TNWR and a surrounding area that extends approximately 8 km around the refuge boundary (Fig. 2).

At its inception in 1937, no elk were reported on the refuge (USFWS 2007). Elk first appeared during the 1950’s. Populations increased relatively quickly during the 1980’s and by 2004, between 300 and 400 resident elk utilized the refuge and surrounding areas (USFWS 2007). The three primary natural elk predators, bear, cougar,
and wolves, are either absent from the landscape or appear infrequently in low numbers. Over-browsing of refuge riparian aspen prompted managers to initiate a hunting program in 2010 to cull the herd and to disperse elk out of over-browse areas. Each year, approximately 63 hunting permits are issued, but the number of actual hunters varies. The hunt is divided according to the weapon used and its associated level of disturbance to elk. Generally, the hunt is as follows: early archery, early muzzleloader, modern firearm, late muzzleloader, and then late archery. Elk hunting is allowed in designated locations within the non-use area of the refuge.

Data Collection

In February 2010, 34 cow elk from different locations within TNWR were net-captured and fitted with radio collars (Dwight 2012). Beginning in July 2010, elk were tracked via very high frequency (VHF) radio telemetry using handheld equipment consisting of a standard H-antenna, a receiver unit, and a compass. Bearings were triangulated using Locate III software. With an inherent precision error of 5%, VHF telemetry locations often include error ellipses. Additional error arises when elk move between signal readings, from topological or atmospheric interference, or from an inability to correctly pinpoint the signal direction (in Montgomery et al. 2011). My data included error ellipses for 57.5% of locations, averaging 613.2 m easting and 687.8 m northing. This is roughly 0.8 km error on over half of the elk locations. Final locations were downloaded into ArcGIS, and error ellipses were added.

Tracking began in June 2010 (Dwight 2012). By April 2011, when the first telemetry effort ended, seven collared elk had died. A new effort to locate the remaining
27 elk began in June 2011, and ran until April 2012 (Walker 2012). Walker reported that 21 cow elk remained by April 2012. In July 2012, with 18 collared elk remaining, tracking commenced and has continued ever since. I began tracking elk in August 2012 and continued tracking until December 31, 2013. At that time, 16 collared elk remained. Following Dwight (2012), I tracked a minimum of twice per week, rotating mornings, afternoons, and evenings, including weekends. Telemetry data from 2010 through 2013 were used for the response analyses.

Elk locations were categorized into three broad spatial areas: refuge hunting areas, refuge non-hunt areas, and off refuge areas. Elk locations were also categorized temporally as hunting season (September through December), post-hunt season (January through April), and pre-hunt season (May through August). Year refers to the number of years for which elk have been exposed to hunting pressure. There were differences in telemetry protocol between years. Initially, Dwight (2012) performed 24-hour tracking to determine if elk movements differed between day and night; they did not. To interpret Dwight’s telemetry data, I removed observations to ensure all locations were a minimum of 24 hours apart. This ensured there was no spatial autocorrelation between locations. If there was more than one observation in a 24-hour period, I removed the observation with the greatest telemetry error as determined by the area within the error ellipse.

Response Analyses

Movement Analysis- To document whether hunting disrupts elk movement behavior, I ran individual behavioral change point analyses ("BCPA") on individual elk, limiting my analyses to elk with over 40 observations from 2010-2013. The BCPA is a type of state-
space model that is robust against error-prone telemetry data that includes missing observations (Gurarie et al. 2009). It is useful for relating changes in behavior, such as foraging or loitering and displacement or migration, to associated changes in movement. The analysis converts elk location information into time series data, including time and distance between locations, and turn angles. Time and distance between locations were used to measure changes in both velocity and the variation in velocity over time. Here, velocity refers to broad-scale displacement on the landscape, and not fine-scale speed while moving. Increased displacement occurs when elk spend less time in a given area, and decreased displacement means elk are spending more time in a given area. Turn angles combined with displacement are used to measure the transition between more-directed and less-directed movements, as measured by the time-scale autocorrelation between steps. Time-scale autocorrelation is a measure of the degree to which current movements persist in a given direction (longer time-scales) or reverse direction (longer time-scales), or re-direct in a more perpendicular direction (shorter time-scales).

The BCPA package looks for dates where the movement behavior before a potential break is abruptly different from the movement after a potential break. Each elk observation is a potential break. To determine breaks, a moving window sweeps across the time series and averages the three explanatory variables before and after each step (elk observation). The moving window is a way to analyze smaller groups of locations before and after each step in the time series. Because of the paucity of telemetry data, and because smaller windows can yield spurious results (Gurarie et al. 2009), I selected the largest window possible, which was usually 60 to 80 observations.
The explanatory variables are expected to change gradually on either side of each step. Where they change abruptly, a break is recorded. Using likelihood estimates, the model shows the most likely date of a movement break and provides a mean description of movement (displacement, displacement variation, and time-scale autocorrelation) before and after each break. To best explain the movement behavior, the BCPA package runs a number of linear models that incorporate combinations of the three explanatory variables; displacement, displacement variation, and time-scale autocorrelation, and chooses the model with the best fit, as determined by Bayesian Information Criteria (BIC). Derived from Information Theory, BIC determines model goodness-of-fit and prevents over-fitting by penalizing models with greater complexity, thereby choosing the most parsimonious model (Schwarz 1978). I analyzed the dates of each movement break to see how many breaks occurred during the hunting season, and to determine whether the breaks resulted in increased displacement and/or longer time-scales of movement. All BCPAs were run in R using the “bcpa” package.

**Location Analysis** - To document changes in the probability of elk locations relative to hunting pressure and to determine if elk dispersal was followed by a return, I used a generalized linear mixed effects model (“GLMM”), which is appropriate for modeling nominal, categorical data. While multinomial data are often modeled using a statistical package specific to its error distribution, the “multinom” package in R does not incorporate random effects. My dataset included missing data and repeated measures that I incorporated into the model as random effects. This necessitated my performing three pairwise binomial GLMMs rather than one multinomial GLMM.
I modeled elk locations in three sets of two locations each: 1) refuge hunting areas versus all other areas, 2) refuge non-hunt areas versus the other areas, and 3) off-refuge areas versus on-refuge areas. All GLMMs were run using the “lme4” package in R. The GLMM model output for nominal, categorical data is unlike the output for standard continuous data. This means that the model did not show changes in the number of elk locations relative to a predictor. It yielded the log odds of elk being in one location relative to the baseline (IDRE n.d.). I chose hunting season 2010 as the baseline to determine changes in elk locations relative to the first hunting season.

Results

The telemetry effort from 2010 through 2013 yielded 1,994 elk observations, after adjusting for Dwight’s (2012) 24-hour telemetry. Of these, 17.6% were located within TNWR hunting areas, 45.1% were located in TNWR non-hunting areas, and 37.3% were located off-refuge. The majority (53.3%) of the elk locations were observed during the hunting season, 27.2% were observed during the post-hunting season, and 19.5% were observed during the pre-hunting season (Table 1).

Movement Analysis- The behavior change point analysis identifies the most likely date of each break in movement behavior, and then averages each movement variable (displacement, displacement variability, and time-scale) before and after each break. This information can be used to determine if, following a break, elk spend less time in a given area while moving in a persistent direction (dispersal behavior). I analyzed 35 movement breaks of 20 individual elk from May 2010 through December 2013 for changes in displacement (time spent in a given area) and time-scales of movement (Fig. 3). Ten elk had one movement break, and no elk had more than four breaks. Breaks occurred during
all seasons and during all years, but not during each season of every year. The majority of
the movement breaks (n = 21) occurred during hunting season (Fig. 3). Of those, 16
occurred during 2011. There were no movement breaks prior to the beginning of the
hunting program, nor were there any breaks during hunting season 2013.

From 2010 through 2013, the majority of the breaks (n = 34) were selected due to
changes in level of displacement. The majority (57.1%) resulted in decreased
displacement, meaning elk were spending more time in a given area, while 42.9%
resulted in increased displacement, meaning elk were spending less time in a given area
(Fig. 4). During hunting season and post-hunt, roughly half (10 out of 21) of the
movement breaks resulted in increased displacement while the remaining breaks resulted
in decreased displacement. This variability in displacement suggests that response to
disturbance differs by individual elk. In contrast, during pre-hunt season, most elk
switched their behavior from one of increased displacement to a behavior with decreased
displacement. This suggests that individual elk began to spend more time in a given area.

The one movement break selected due to a change in time-scale of movement
occurred during hunting season 2011 and resulted a longer time-scale of movement,
indicating an increase in dispersal-related behavior. Although only one movement change
was attributed to a change in the time-scale of movement, there were differences in the
level of directed (longer time-scale) versus non-directed (shorter time-scale) movement
following movement breaks (Fig. 5). Out of 20 elk analyzed, 15 elk became more
directed in their movement, and 5 elk became less directed. Of 35 total movement
behavior breaks, 19 resulted in an increase in the time-scale of movement, 15 resulted in
a decrease in the time-scale of movement, and one resulted in no change. During the hunt
and post-hunt seasons, elk more often switched to longer scales of movement. This suggests persistent movement in a given direction, and is more indicative of dispersal behavior than foraging behavior. In contrast, during the pre-hunt season elk switched to a shorter time-scale movements. This indicates less-directed movement, and suggests elk began to make more frequent turns in more perpendicular directions, and is indicative of foraging behavior.

**Location Analysis** - The generalized linear mixed effects model (GLMM) predicts differences between the log odds of elk locations during the baseline time period (hunting season 2010) and the relative log odds of elk location during other time periods. The results of the three pairwise GLMMs showed significant differences in the log odds of elk location between the baseline and four other time periods (Fig. 6-8). The log odds of elk being in the refuge non-hunt area during the pre-hunt 2010 season was 0.344 less than the log odds during the 2010 hunting season, a marginally significant difference ($z = -1.846$, $p = 0.065$) (Fig. 6). This reflects elk movement into the non-hunt area during the first hunting season.

Compared to hunting season 2010 (the baseline), the log odds of elk being in the refuge non-hunt area during the post-hunt 2011 decreased by 0.665 ($z = -1.976$, $p = 0.048$) while the log odds of elk being off refuge increased by 0.760 ($z = 2.225$, $p = 0.026$) (Fig. 6 & 7). There was no significant change in the log odds of finding elk in the hunting area during that time (Fig. 7). This means that elk moved out of the refuge non-hunting area at the end of the first hunting season, but did not move to the refuge hunting area. Elk had the greatest probability of being off refuge.
Compared to the 2010 hunting season, the log odds of elk being in the non-hunt area during pre-hunt 2012 increased by 1.941 \( (z = 3.861, p < 0.001) \) while the log odds of elk being off refuge decreased by 1.992 \( (z = -1.986, p = 0.001) \) (Fig. 6 & 7). The probability of finding elk in the hunting area decreased insignificantly (Fig. 8). This means elk had shifted their location to the refuge non-hunt area, and there was a greater likelihood of finding elk in the refuge non-hunt area during pre-season 2012. In comparison, during pre-hunt 2013, the probability of elk being off refuge increased by 0.675 \( (z = 1.986, p = 0.047) \) while the probability of elk being in the hunting area decreased by 0.926 \( (z = -2.229, p = 0.026) \) (Fig. 6 & 8). There was a very small decrease in the probability of finding elk in the refuge non-hunt areas (Fig. 7). This means that elk had the greatest probability of being found off refuge during pre-hunt 2013. While elk location probabilities showed significant differences between the baseline and a number of other seasons and years, there was also a great deal of variability, as evidenced by the confidence intervals (Fig. 6-8).

By converting the log odds to probabilities, I was able to determine where elk were most likely to be found during each season between 2010 and 2013. From this I determined whether elk had a progressively higher probability of being off refuge or in the refuge non-hunt areas during hunting season, and whether elk had progressively fewer returns to refuge hunting areas during the post-hunt and pre-hunt season. Elk responded differently with repeated hunting pressure. The probability of elk being off refuge during hunting season increased each year from 2010 through 2012, and then decreased in 2013 (Fig. 9). The probabilities of elk being located in the refuge non-hunt area and the refuge hunt area increased one year and decreased the next. This means that,
during the first three years of hunting pressure, elk were trending towards being off refuge during hunting seasons, but the trend was interrupted in the last hunting season. During the last hunting season, elk had the greatest probability of being within the refuge hunting areas.

Across the 2011 through 2013 post-hunt seasons, the probability of elk being off refuge decreased while the probability of elk being in the refuge non-hunt area increased (Fig. 10). The probability of elk being in the refuge hunting area increased in 2012, then decreased in 2013. Because the probability of elk being in the non-hunt continues to increase while the probabilities for elk being in other areas decreases, this suggests a potential trend of elk favoring refuge non-hunt areas during the post-hunt season. During subsequent pre-hunt seasons, from 2010 through 2012, the probability of elk being in refuge non-hunt areas increased while the probability of elk being in refuge hunting areas and off refuge both decreased (Fig. 11). However, during pre-hunt 2013, the probability of elk being in refuge non-hunt areas decreased while being off refuge during the 2013 pre-hunt season increased. The probability of elk being in refuge hunting areas continued to decrease. Elk show increasing preference for the refuge non-hunt area with decreasing preference for refuge hunting areas during subsequent pre-hunt seasons from 2010 through 2012. Elk continued to show decreased preference for hunting areas during the 2013 pre-hunt, but favored off refuge areas to refuge non-hunt areas.

**Discussion**

I first asked whether there were changes in elk movement during the hunting season, with respect to speed and direction of travel. Studies have shown that elk respond to hunting pressure by increasing their speed of movement, a response that increases with
increased hunting pressure (Johnson et al. 2005, Cleveland et al. 2012). I found individual elk changed their movement behavior more often during hunting season. While I expected to find hunted elk display movements consistent with dispersal behavior (greater displacement with longer scales of movement), the data did not fully support this. Of my hunting season movement changes, under half resulted in increased displacement. Only one individual increased its displacement in a persistent direction (timescale of auto-correlation). These findings suggest a mixed response to hunting. Some elk may be moving through the area attempting to flee hunters while other elk move into areas with greater cover density where they may remain over time (Mogantini and Hudson 1979 in Conner et al. 2001, Millspaugh et al. 2000). I also found more movement breaks during muzzleloader and rifle season than during archery season (data not shown). This suggests that movement changes had less to do with persisting hunting pressure and more to do with the mode of hunting.

These movement results must be interpreted with caution. The BCPA package was able to detect, on average, one change in movement behavior for each elk across four years of study. It is unlikely that elk make so few changes in their movement behavior. It is feasible that more frequent elk observations would have made it possible to detect a more representative picture of progressive changes in elk movement patterns. Also, my dataset was fraught with missing data. While the BCPA package is reported to be robust against missing data, there can be no doubt that a dataset with more observations would likely have produced results more representative of fine-scale elk movement patterns. Finally, performing BCPAs includes user defined controls, such as choosing the size of the window and the smoothing parameters. Because of my small dataset, I chose the
largest window and smallest smoothing parameter, which combined adjacent breaks. I chose the largest window because they are robust against sparse data and are less likely to give spurious results (Gurarie et al. 2009). I combined adjacent breaks because the clustered breaks were most likely the product of a sparse dataset. By increasing the smoother, I effectively averaged the behavior across all adjacent breaks. With a more intuitive grasp of the BCPA package and a larger dataset, I may have been able to fine tune the analysis.

The goal of the hunting program was to displace elk out of the high elk-use areas of the refuge that Albrecht (2003) had identified and off of the refuge. My second question considers whether there was a change in the location probability of elk between the first hunting season and subsequent hunting seasons. Location probabilities show a variable response over time. While the change in log odds of elk locations during later hunting seasons are insignificant compared to the first hunting season (the baseline), elk had a greater probability of being in refuge non-hunt areas during the 2011 hunting season, and of being off refuge during the 2012 hunting season. The 2013 probabilities show elk utilizing hunting areas during hunting season. It is possible that elk are habituating to hunter patterns. Millspaugh (1999 in Millspaugh et al. 2000) observed that hunters show a high degree of site fidelity. As elk habituate to hunters and their preferred hunting grounds, remaining within hunting areas while avoiding hunters may be an effective, energy-conserving strategy. Alternatively, the use of refuge hunting areas during hunting season may reflect the government shutdown. Beginning October 1, 2013, the refuge was closed and the hunting program interrupted. During the 2013 hunting season only 9 elk were harvested, compared to the 20-25 elk harvested each of the
previous three hunting seasons. The movement analysis showed no breaks in movement behavior during this time.

Elk display two broad categories of hunting responses: restriction to cover areas within hunting areas or movement to protected areas. Movement away from hunted areas may be followed by a return after the termination of the hunt (Conner et al. 2001) or it may result in relocation (Burcham et al. 1999). Movement away from hunted areas was documented at TNWR by Dwight (2012) and Walker (2012). Elk return following the end of the hunting season was documented by Dwight (2012). While a paucity of data left me unable to model GLMMs for seasons spanning only two-to-three month time increments, my probability analysis mimics Dwight and Walker during the 2010 and 2011 hunting seasons. My results document elk return following the 2011 hunting. Post-hunt 2012, elk had a greater probability of being in refuge hunting areas, and moved into the non-hunt areas by the 2012 pre-hunt season. While elk appear to have fled 2010 and 2011 hunting pressure by moving into refuge non-hunt areas, the probability graphs show that elk fled 2012 hunting by moving off refuge. Many returned to the refuge by the 2013 post-hunting season.

Movement away from an area followed by a return is energy expensive, and the behavior must be cost-effective to the individual. Site fidelity offers elk the advantage of knowing the location of optimal forage, water, and cover. This may explain the return to TNWR following hunting pressure. The timing of the TNWR elk return to the refuge suggests that elk may be returning to the refuge to calf. Calving and parturition are energy expensive and cow elk move to calving and nursery grounds where their forage, water, and cover needs can be met within close proximity (Thomas 1979). While there is
an advantage to fleeing the threat of refuge hunting in the fall, the security of known

calving arenas may be strong enough to encourage the subsequent return.

Some studies have observed that elk respond to persistent hunting by relocating.

Movement into non-hunted areas during hunting season is a common elk response
2003, Johnson et al. 2005). Burcham et al. (1999) found that elk remain longer in these
protected areas over time, even utilizing areas offering fewer security features provided
they offer relief from hunting pressure. The cost-benefit of remaining in a secure area
may out-weigh the return to previously used areas, or elk may prefer the resources of the
new area over previously-used resources.

I found elk had a greater probability of being off-refuge during the 2013 pre-hunt
season, a shift away from probable elk behavior at that time in 2012. A return to refuge
non-hunt areas would have suggested a return to known nursery areas. Instead, the shift
in elk probability of occurrence suggests either a reduction in the number of elk returning
to the refuge following a dispersal event, or a return to resource areas that may have been
discovered during a previous flight or exploratory event. Because TNWR elk were
located on the refuge the previous season, post-hunt 2013, my data suggest elk may be
returning to previously discovered resources. Note that elk had an increasingly higher
probability of being off refuge areas during consecutive hunting seasons. When elk left
the refuge during the late post-hunt or early pre-hunt 2013, they may have been returning
to areas discovered during those hunt season dispersal events. This shift off refuge during
calving season may indicate the beginning of relocation behavior. Continued analysis is
needed to determine whether elk will continue using off refuge resources during the pre-
hunt season, and whether this behavior results in relocation over time.
CHAPTER 2. ANTHROPOGENIC LAND USE AND CLIMATE PROJECTIONS

The habitat requirements of elk include open grasslands and water for forage, forests for thermal and hiding cover, deciduous forests and riparian areas for calving cover, and forest strings and riparian areas for travel corridors (Thomas 1979, McCorquodale et al. 1986, Brook 2010). The juxtaposition of habitats on the landscape and the seasonal dynamics of plant communities determine movement between habitats. For example, elk in much of western North America use higher elevations, often public lands, during the spring and summer for calving, summer foraging, and cover, and move to lower elevations for winter foraging and cover (Thomas 1979, Conner et al. 2001, Anderson et al. 2005, Stubblefield et al. 2006, Webb et al. 2011). These seasonal patterns of habitat use are mediated by environmental cues, particularly photoperiod (Adams 1982, Conner et al. 2001), and reflect elk knowledge of the landscape. This knowledge is passed from dominant cows to calves (Conner et al. 2001).

During the past 50 years, elk in eastern Washington have expanded their year-long ranges into lower elevation areas of the Columbia Plateau, including the Hanford region and Channeled Scablands (McCorquodale et al. 1986, USFWS 2007). Consequently, the home ranges of these non-migratory elk must satisfy the habitat conditions of both the summer and winter ranges of migratory elk (Hebblewhite and Merrill 2011, Nelson et al. 2012). The persistence of these populations is dependent upon core protected areas with surrounding low human density agriculture or rangeland. However, conversion of agriculture and rangeland habitats to other land uses, such as housing and industry, might increasingly restrict these elk populations to core protected areas. This poses two potential problems. First, an overabundance of elk often leads to
damage of protected areas as elk over-browse deciduous and riparian habitats (Zeigenfuss et al. 2002, Ripple and Beschta 2007). Second, as human-induced climate change progresses, the distribution and abundance of forests and other required habitats might shift relative to the protected areas (Johnson and Schmitz 1997, in Burns et al. 2003).

The elk population that inhabits Turnbull National Wildlife Refuge (TNWR) in the Channeled Scablands of eastern Washington provides an opportunity to examine these issues. At its inception in 1937, no elk were reported on the refuge (USFWS 2007). Elk first appeared during the 1950’s. Populations increased during the 1980’s and currently between 300 and 400 resident elk utilize the refuge and surrounding areas. Habitat use is not restricted to TNWR. Collared elk have been recorded as far east as Mica Peak (this study), located south of Spokane, Washington, and elk often forage on private property surrounding the refuge, particularly on hay and winter wheat (USFWS 2007). Previous studies showed that, prior to the refuge hunting program, elk used TNWR disproportionately to the surrounding landscape (Albrecht 2003). Over-browsing of refuge riparian aspen prompted managers to initiate a hunting program in 2010 to cull the herd and to disperse elk off refuge. In the preceding chapter of my thesis, I addressed how the hunt has affected elk movements and concluded that with sustained hunting pressure elk might relocate off refuge. In this chapter I assess current habitat use by these elk and address how land use and human-induced climate change might affect the distribution and abundance of suitable habitat for this elk population.

Increased human development around TNWR could alter landscape complexity by increasing patchiness, creating barriers to and reducing resource availability for the elk. Conversion of low-density, rural areas to residential developments ultimately reduces
the habitat suitability for elk and increases elk-landowner conflicts. Likewise, conversion of these lands to industrial areas (Dzialak 2011a) or roads (Millspaugh et al. 2000, Vieira et al. 2003, Johnson et al. 2005, Frair et al. 2008) reduces usable habitats, decreases the quality of adjacent habitats, and increases elk mortality. Road construction is associated with elk relocation, reduced emigration, and potential population isolation (Frair et al. 2008). If the trend for elk to relocate off refuge continues, the net result is a reduction in elk use of the core protected areas and an inability of the surrounding lands to support elk.

Human-induced climate change is expected to affect elk habitats (Post et al. 2008), but predicting habitat use in response to climate change is difficult. In eastern Washington, broad climate change predictions include warmer winters and drier summers (Littell et al. 2009). These changes have the potential to affect elk two ways. First, changing climate patterns may alter plant phenology via earlier emergence rates, reduced growing seasons, and homogeneity of plant communities (Post et al. 2008). While elk might adjust favorably to earlier emergence rates, a reduced growing season combined with compressed forage plots would limit the spatial and temporal availability of high-quality forage. Elk would be burdened to meet forage demands in a shorter timeframe on a landscape where target forage species are further apart.

Second, climate change may result in a redistribution of plant communities to more northern latitudes. The National Aeronautics and Space Administration’s Jet Propulsion Laboratory projected global response to anthropogenic climate change, predicting overall reductions in forested biomes in temperate North America with potential replacement by grasslands (Bergengren et al. 2011). Although this would
increase elk forage, elk are an ecotone species, selecting the forest- grassland interface (Geist 1982, Thomas 1979) and a northward distribution of forest habitat off TNWR could reduce the future habitat suitability of the refuge.

To examine how the distribution of the TNWR elk population might be impacted by potential habitat alteration due to land use and climate change I identified elk resource use areas on and around TNRW, and investigated how those use areas might be modified by future land use practices and human-induced climate change. My two objectives for this portion of my study were to I) identify the probability of elk occurrence in different habitat patches and II) to explore how the availability of high and low probability patches could be altered by human-induced land use and climate change. With respect to the first objective I ask 1) which landscape-level habitats have the highest probability of elk occurrence, 2) how many high and low probability use patches are located on and around TNWR, and 3) what is the mean size of high and low probability elk occurrence patches? With respect to the second objective I ask 1) which land use changes are expected to occur around TNWR within the next 20 years that might alter the number of high and low probability elk occurrence patches, 2) which high and low probability elk occurrence patches are vulnerable to loss due to land use changes, 3) how might projected climate change alter the distribution of broad habitat types and water availability on and around TNWR, and how would this impact the availability of high and low probability elk occurrence patches between 2010 and 2030, 2060, and 2090?
Methods

Study Area

The study area includes TNWR and extends approximately 8 km into the surrounding area (Fig 12.). A detailed description of TNWR and the surrounding area is given in Chapter 1.

Data Collection

I used the elk locations collected via VHF radio telemetry from 2010-2013, with one exception. Given that parturient elk have specialized habitat needs that might be a limiting factor in overall elk survivorship, I limited my study to parturient elk, restricting the analysis to elk locations collected from May through mid-July. During this time, calves require high quality forage to meet developmental growth demands (Debeffe et al. 2012, Edge et al. 1985, Brook 2010) and parturient females select areas where both forage and hiding resources are in close proximity (Thomas 1979). I chose May through mid-July because pregnant cows separate from their herd before giving birth (early to mid-May), and they remain within their nursery grounds for approximately two months (Taber et al. 1982). A detailed explanation of elk telemetry and data processing is given in Chapter 1.

Response Analyses

The response analyses consisted of four parts. First, I determined late spring/summer environmental variables that predict parturient elk occurrence. Second, I determined areas, or patches, within the study area where parturient elk had a high and low probability of occurrence. Third, I investigated current and future land use practices to determine which elk patches may be vulnerable to loss of use between 2010 and 2030.
Fourth, I used predictions from available climate change models to determine how broad habitat types and water availability might change over time, and I identified which elk patches might be lost because of climate-related impacts.

Elk Occurrence- Using ArcGIS 10.1 software, I separated each individual elk location and converted each location polygon into a unique 30 by 30 meter raster layer. I chose this cell size because it is the standard size of many available habitat raster layers, and is appropriate for investigating landscape-level habitat use. I performed two habitat use analyses, one using only precise elk locations, or those without associated telemetry error (n = 61), and another that included error-bound elk locations (n = 130).

To determine patches within my study area where parturient elk have a high and low probability of occurrence using only precise elk locations, I performed a binomial generalized linear regression (GLM) (Nelder and Wedderburn 1972) in R using environmental covariates shown to influence elk distribution (Table 2). The model predicts the change in log odds as an individual moves from a place lacking a covariate (covariate = 0) to a place containing the covariate (covariate = 1). I selected covariates based on literature review of elk resource use (Table 3). Due to the low-relief topography of my study area, slope and aspect were not considered. Habitat variables were obtained from the National Land Cover Database, available online through the United States Geological Survey. Road layers were obtained from the Spokane County website. Water resources were gathered by the National Wetlands Inventory and obtained through the U.S. Fish and Wildlife Service.

To determine which covariates would produce the most parsimonious resource use model I performed a reverse stepwise binomial GLM against elk presence/absence,
using each raster cell as an observation (Efroymson 1960). After running the full model I performed a series of stepped down models, each one missing one covariate. I chose the model with the lowest QAICc as my next reference model and repeated the next backwards step of removing one covariate. Quasi-AIC (QAIC) model selection is appropriate here because it uses over-dispersion to represent Akaike information, the measure of information lost between the best-fit model and the dataset (Richards 2008). I used the second-order QAIC, QAICc, which is appropriate for small sample sizes. I repeated the process until none of the stepdown models had a QAICc more than 2 points below the reference model. Evaluating model performance usually requires partitioning the dataset (Mark and Goldberg 2001). Because my dataset contained a limited number of observations I assumed that the best model, as chosen by QAICc, was the best possible model given the data constraints. The best model contained ownership (public versus private lands) as a covariate, but land use practices do not impact public lands. To explore land use impacts to habitats used outside of public lands, I re-ran the final model omitting ownership.

Finally, I converted the relative log odds into probabilities, and then scaled the relative probabilities so that the probability of elk occurrence ranged from 0.0 to 1.0 (Manly et al. 2002). Choosing a threshold for high versus low probability in the absence of validation methods is difficult. In other studies, occurrence threshold values vary from 0.25 (plant) to 0.40 (red squirrel) to 0.50 (wolf) (Guisan et al. 1998, Pereira and Itami 1991, Mladenoff et al. 1999, respectively). I considered occurrence patches with scaled probabilities of 0.5 to 1.0 to be “high” occurrence patches, and 0.25-0.5 to be “low” occurrence patches. Probabilities below 0.25 were not considered.
To determine patches within my study area where parturient elk have a high or low probability of occurrence using error-bound elk locations I performed a modified presence/absence GLM. Locate III software, used to triangulate elk locations, provides data on error ellipses, but does not provide data in a geographic information system (GIS) ready format, such as a raster layer. I used ArcGIS to insert error ellipses around elk locations and then separated the locations into individual raster layers. I used the best model, determined by the precise elk locations, as a baseline with which to compare the amount of noise introduced by the error ellipses. In R, I added small groups of error-bound elk locations into the precise dataset, in order from smaller to larger ellipses, and ran 100 Monte Carlo generalized linear regression simulations, averaging the results. During this stage, each model randomly selected one cell within an error ellipse as the “presence” response while every other cell in the raster layer, including those within the error ellipse, were used as absences. After each Monte Carlo round, I qualitatively assessed the level of variance introduced to the coefficients by the error ellipse. I continued adding locations until the level of introduced noise left the regression unable to identify important habitats or predict the probability of elk occurrence. Once I had determined the best model, I averaged the coefficients and converted the log odds to probabilities as with the error-free model.

After obtaining elk occurrence within the study area, I created two final raster layers of elk occurrence probabilities, one using error-free elk locations and one using error-bound elk locations, and loaded them into ArcGIS where I grouped high and low probability occurrence patches by broad spatial location and measured the total area of patches within each group. Because of the similarity of elk occurrence areas between the
precise and error-bound models, I chose to use only the precise model for remainder of the study. I performed the land use analysis on elk occurrence patches (“elk patch”) within private lands, and I performed the climate change analyses on each high and low probability patch.

**Land Use**- I used GIS to identify which elk patches were vulnerable to loss of use by any of these land use elements; current or new zoning designations, current or planned transportation networks, or well and septic potential.

According to the Growth Management Act of 1991, county and local governments must have a written plan outlining their housing and infrastructure provisions to accommodate urban growth for at least 20 years. I obtained growth management plans through 2030 for the City of Cheney and Spokane County online. The City of Cheney does not make planning policy outside of its incorporated and unincorporated areas, and because cities must comply with county planning policies, I focused my investigation on the Spokane County Comprehensive Plan (2012). First, I determined current zoning designations for each elk patch. Zoning designations such as rural conservation or lands with special designations are considered protective of elk patches over time. Special designations include open space corridors, critical areas (priority species habitat, geologic hazards, or critical aquifer recharge areas), or natural resources area. These areas have restrictions that prohibit human development or require special permits or mitigation, making the land less likely to be developed. Zoning designations such as commercial, urban reserve, rural activity center, and also cities and roads make elk patches vulnerable to loss. Next, I determined whether there were any plans to re-designate lands containing elk patches.
I investigated roads within the study area to determine whether current or future roads, or road effects, had the potential to impact elk patches. Road effects have been reported within 700 meters of roads (Frair et al. 2008), so I buffered all major roads with a 700 meter buffer. Major roads were roads classified by Spokane County as interstate, principal or minor arterial, rural major or minor collector, and non-primitive rural local access. I investigated future road development plans for 2011-2035 through the Washington State Department of Transportation’s Metropolitan Transportation Plan for the Spokane region (SRTC 2012). New roads planned in the study area were also buffered by 700 meters. Any portion of an elk patch adjacent to a road or within its buffer may be lost by 2030.

To determine the potential for future, unplanned human development I investigated aquifer recharge potential and water rights issuing to anticipate whether new wells might be drilled, and I investigated soil ratings to determine if soils were limited for septic drain fields. I obtained aquifer recharge potential from Spokane County. I spoke with Gene Drury of Washington State Department of Ecology, Spokane, to discover if water rights were being issued. Last, I obtained soil records, which include soil limit designations for septic drain fields, from the United States Department of Agriculture (USDA), available through the Natural Resources Conservation Service. Areas outside the critical aquifer recharge area, where water rights are allowed, and on soils conducive to septic drain fields have development potential. Elk patches within these areas may be lost by 2030. Elk patches within critical aquifer recharge areas, where water rights are no longer issued, and on soils limited to septic drain fields are less likely to be developed.
**Climate Change** – I examined future climate predictions to determine which elk patches may be lost due to changing vegetation distribution or water resources. Climate models are mathematical representations of the complex interactions between environmental elements such as atmosphere, land, oceans, sea ice, the biosphere, and human activities, and the manner in which energy is transferred between them (GFDL 1999) (Fig. 13). A tutorial on climate models, including inputs and uncertainties is available online (NAS 2012).

I examined three avenues of climate predictions. First, I obtained a general consensus of climate change in this region (eastern Washington and the Columbia Plateau) for elements such as temperature, precipitation, snowmelt and spring runoff, drought, wildfires, and carbon stocks. I included seasonal predictions of temperature and precipitation because elk are affected by seasonal weather. Second, I investigated how changing climate might alter the climate suitability of broad habitat types within my study area. I examined broad redistribution of dominant vegetation types caused by changing climate suitability, and I examined species-specific changes in climate suitability for both ponderosa pine and aspen trees. Last, I examined potential changes in water availability. Due to the lack of predictions concerning water availability, I limited my evaluation to water availability through 2030. I identified elk patches vulnerable to loss by 2030 because of changes in water availability, and I identified elk patches that may be lost due to broad shifts in vegetation by 2030, 2060, and 2090.

Temperature and precipitation predictions came from the Joint Institute for the Study of the Atmosphere and Ocean’s Climate Impacts Group (CIG) at the University of Washington (Mote *et al.* 2005, Mote and Salathe 2010), and seasonal predictions came
from members of the Integrated Scenarios of the Future Northwest Environment (ISFNE) project (Mote et al. 2014). I chose CIG because they average data from a number of global climate models, using the Special Report on Emissions Scenarios (SRES) A2 storyline, which was used for my dominant vegetation and tree species predictions. I chose ISFNE because they model seasonal climate predictions at the eco-region scale (Columbia Plateau). I chose seasonal predictions derived by the U.S.-based Geophysics Fluid Dynamics Laboratory (GFDL), who work in concert with the National Oceanic and Atmospheric Association. I chose their representative concentration pathways (RCP) 8.5 emissions scenario because it most closely aligns with future temperature predicted by Mote et al. (2010) under the A2 storyline. The RCP scenarios replaced the SRES scenarios in the Intergovernmental Panel on Climate Change (IPCC) fifth Climate Assessment Report (Moss et al. 2008). Seasonal predictions using the earlier SRES storylines are not available. Information for the remaining climate elements was derived from the above resources plus many others (Bachelet et al. 2001, Derner et al. 2005, PAWG 2008, Littell et al. 2009, CIG 2009, Mote et al. 2010, Salathe et al. 2010).

I obtained projections for the redistribution of dominant vegetation types, determined by changes in climate suitability, from Dr. Dominique Bachelet, a senior climate scientist with Oregon State University who helped develop the MAPSS-CENTRUY (MC) dynamic vegetation model (Bachelet et al. 2001). She and her team, led by Ron Neilson of the US Forest Service, integrated the biogeography model MAPSS (Neilson 1995) with the biogeochemistry model CENTRUY (Parton et al. 1983) to create MC. Their updated C++ version, MC2, used climate futures projected by the Coupled Global Climate Model, CGCM3, run under the SRES A2 storyline, for my study. A
product of the Canadian Centre for Climate Modeling and Analysis, the CGCM3 model was used for the ICCP’s fourth assessment on climate change. The technical parameters of this model are provided in McFarlane et al. (1992), Flato and Boer (2001), Kim et al. (2002), Kim et al. (2003), and Scinocca et al. (2008). Model developers use historic climate data to validate their models. I chose this model because the CGCM3 model validation runs were only slightly above the observed trend (Fig. 14). The SRES A2 storyline reflects regional self-reliance, steady population growth, and delayed development of renewable energy (IPCC 2000). Economic and technological growth is fragmented by region, resulting in global heterogeneity. This is a high emissions storyline representing a worse-case scenario (Fig. 15).

Dr. Bachelet and her associate, Ken Ferschweiler, created 800 meter resolution future vegetation maps for each year until 2100 and provided dominant vegetation distribution maps for 2005, 2030, 2060, and 2090. Each map comprises the 10-year mode around the target year (for example, 2030 is the mode of 2025-2034).

The MC2 model consists of four modules; two biogeography modules, one biogeochemistry, and one wildfire, each acting as a feedback loop to the other modules (Fig. 16). The biogeochemistry module receives the landscape composition from the biogeography modules. The current landscape in my study area consists of temperate coniferous forests, temperate coniferous woodland, and temperate shrubland. The biogeochemistry module incorporates climate predictions and simulates monthly changes in the carbon, water, and nutrient budget. Carbon and nutrient dynamics alter specific ecosystem processes, such as nutrient and water cycling, above- and below-ground plant production, and organic decomposition. Plants compete for water, nutrients, and light.
Changes in plant biomass plus climate indices are returned to a biogeographic module, where landscape composition is updated. Changes in above-ground biomass are also fed into the fire module where biomass is converted into fuel classes. Different types of vegetation have different fuel loading potential, and the biogeographic module provides the proper, vegetation-specific, conversion equations to convert the type of vegetation into its fuel class. Fire effects are a function of fire intensity and spread, and climate models are used to identify changes in fire regimes. Fires alter vegetation structure via loss of both live and dead biomass and carbon stocks. These changes are fed into the biogeochemistry module where they alter the carbon and nutrient budget. These new values, along with the next time-step of climate data, are used to continue the cycle of carbon and nutrient cycling, above- and below-ground production, and decomposition, all of which may result in a redistribution of vegetation.

There are a number of assumptions with the MC2 model. First, the model predicts potential dominant vegetation, exclusive of human disturbance, and does not identify vegetation to species. There is no cell-to-cell communication on the landscape grid. For example, water does not flow between cells, rather, the updated value of each cell changes based on the data input. This means forces such as gravity and fine scale modifications, such as obstacles to water flow, are not considered. Nitrogen demand is met through nitrogen fixation, and natural fire regimes are suppressed, so only large catastrophic fires occur, those that result from a build-up of fuel loads and drought conditions (Ken Ferschweiler, pers comm).

To relate changes in the distribution of dominant plant species to the availability of elk occurrence patches, I created a pseudo landscape in R where I randomly sampled a
number of cells to match the projected progression of forest increase. I increased the amount of available forests by increments of 10%, while decreasing shrubs until shrubs were deleted. I re-predicted the new area (ha) of high and low probability elk patches at each stage.

To examine species-specific climate suitability shifts, I obtained one kilometer resolution future forest species raster maps from the Moscow Forestry Sciences Laboratory (MFSL). Each cell on the map contains a value, between 0.0 and 1.0, representing the potential for climate to support certain tree species. I obtained climate suitability maps for ponderosa pine and quaking aspen for the years “current,” 2030, 2060, and 2090, and classified climate suitability into tenths to simplify presentation. Each set of maps was created using the CGCM3 climate model, version T63, run using the SRES A2 storyline described above.

The U.S. Forest Service identified climate suitability parameters for a number of tree species, including ponderosa pine and aspen trees (Rehfeldt 2006). Monthly climate data from 1961 to 1990, obtained from weather stations across the western U.S., were fit to and interpolated across a geographic surface using thin plate splines (ANUSPLIN) (Hutchinson and Xu 2013). Tree presence was regressed against the multivariate climate surface, effectively describing plant-climate relationships. To predict future climate suitability the climate surface (splines) was updated using monthly climate data derived from the CGCM3 climate model (see above), and suitability was predicted using the covariates describing plant-climate relationship. A list of files and surfaces used in each prediction, and a more in-depth discussion of the model and processes is available through the MFSL website (Crookston 2014, http://forest.moscowfsl.wsu.edu/climate/).
Meghan Halabisky of the University of Washington is currently investigating climate impacts to Eastern Washington waterbodies. She provided historic data on surface water area for wetlands within TNWR, useful for indicating changes in water levels over time. Wetland locations were derived from the National Wetlands Inventory and then stretched to match wetland boundaries determined through ground-truthing. The change in surface area was derived using spectral mixture analysis, a process that identifies the fractional abundance of water within each pixel on a map using high-resolution aerial imagery and stacked layers of Landsat images (Lawler et al., in submission). Changes in surface area were identified using 331 images of wetlands spanning 1984-2011. Because data are available for TNWR only, I limited my response of water availability to elk patches within TNWR.

Future water availability predictions are unavailable at this time, partly because predicting changes in water availability via traditional climate models is difficult in my study area. Traditional climate models rely on the physics of natural environmental interactions to direct change over time. A number of anthropogenic modifications aggravate traditional climate modeling in this area. First, most of the wetlands in the study area were manually connected by drainage lines in the early 1900s and then drained in an attempt to create farmland (USFWS 2007). Today, many of the refuge ditches have been sealed, dividing the landscape into four, separate drainage networks. Recharge to a specific waterbody is no longer limited by elevation and access to groundwater. Instead, groundwater recharges a connected series of waterbodies. Second, many off-refuge wetlands continue to be drained annually, sending water into the refuge wetland system where the wetlands and lakes remain connected by water control structures. The refuge
receives a large amount of supplemental water from these drainage practices. Historic patterns of water flows are likely to change as water becomes limited if landowners cease drainage practices. Third, the City of Cheney punched through the shallow aquifer and the confinement bed that separates the area’s shallow “recharge” aquifer from the deeper, confined aquifer to create a municipal well. As a consequence, water from the recharge aquifer escapes down into the deep aquifer, further reducing water availability.

In light of these uncertainties, I limited my investigation of water availability to qualitative presumptions from changing water levels. I assumed water bodies that gained water from 1984-2011 would retain water from 2011-2030, and I assumed water bodies that did not gain water 1984-2011 would lose all water by 2030. To relate water availability to elk patches, I determined the mean distance to lakes for parturient elk in high probability and low probability patches and then I buffered water bodies by the mean. I chose mean distance to lakes because distance to lakes was a strong predictor of elk occurrence. Elk patches outside of the buffer to a waterbody that historically gained water may be lost by 2030 due to reduced water availability.

**Results**

A total of 1,997 elk locations from 26 cow elk were collected between 2010 and 2013 using VHF telemetry. Of these, 177 locations from 20 elk were obtained between May and mid-July. To determine which habitat variables predict parturient elk occurrence, I ran a generalized linear regression model (GLM) using 61 error-free elk locations from 15 cow elk. The best fit model included 25 habitat covariates (QAICc = 1225.9, $R^2 = 0.109$). The original probability map including the ownership covariate is given (Appendix). Afterwards, I ran the regression with the ownership covariate
removed. I also performed GLM Monte Carlo simulations using new datasets to which error-bound elk locations were added. A table of the averaged change in log odds, standard error, and p-values for each new dataset is given (Appendix). In the largest dataset (n = 130 elk locations), error ellipses were 54 ha or less in size. I converted the log odds into probabilities, and then scaled them from 0.0-1.0. A final map showing the high and low probability elk occurrence areas, derived using error-bound elk locations, is given (Appendix).

There was a significant change in the log odds predicting elk occurrence for four habitat covariates, and marginal significance for two additional covariates (Table 4). The relative log odds of elk presence increased significantly in recent burns (2010-2013), coniferous forests, and woody wetlands, with decreasing distance to lakes and increasing distance to edge, and decreased significantly in seed and grain cropland. To determine where elk had the highest probability of occurrence, I converted the log odds to probabilities and scaled them from 0.0-1.0. Between May and mid-July, when parturient elk have specialized habitat needs, elk had the highest probability of occurrence (> 0.70) where housing density was low, on recent (2010-2013) burns, and in woody wetlands and coniferous forest (Fig. 17). Elk had the lowest probability of occurrence (< 0.20) on croplands such as nursery/orchard, vegetable/turfgrass, seed/grain, and pasture/hay, on burns 2005-2009, and in forests with high canopy cover (> 61%). All high probability elk occurrence patches (values > 0.5) and 95% of low probability elk patches (0.25 ≤ values < 0.5) were located within TNWR (Fig. 18). The mean probability of occurrence in high probability patches was 0.63. The mean probability of occurrence in low probability
patches within TNWR was 0.31. Outside of TNWR, the mean probability of elk occurrence in low probability patches was 0.27.

Elk occurrence patches (“elk patches”) totaled 323.73 ha (Table 5). Outside of TNWR, low probability elk patches totaled 14.22 ha, and were numbered P1 through P4 (Fig. 18). P1 was located along both shores of central Silver Lake. P2 was located near the southwest corner of the James T. Slavin Conservation Area. P3 was located on the north tip of Chapman Lake. The largest elk patch, P4, was located along both shores of central Badger Lake. Within TNWR, high probability elk patches totaled 38.88 ha and low probability elk patches totaled 270.63 ha (Table 5). Elk patches were grouped by broad refuge location. High probability elk patches were located in four of eleven refuge sections (Fig. 18). Eastern Slough contained the greatest overall area of high probability patches, and Long Lake contained the largest contiguous high probability patch. Low probability elk patches were located in eight of eleven refuge sections (Fig 18). Eastern Slough held the greatest total area of low probability elk patches, and Southwest contained the largest contiguous low probability patch (Table 5). There were no elk occurrence patches in Findley Lake (FL), Auto Route (AR), or Stubblefield (SF) sections.

**Land use** - I analyzed current and potential future land use activities to determine which land use practices may limit elk use of low probability patches. My analysis was limited to elk patches located outside of the refuge. Zoning designations such as commercial, urban reserve, rural activity center, and cities and roads reduce the usefulness of elk patches. Zoning designations such as rural conservation or lands with special designations are considered protective of elk patches. Currently, all elk patches are found within rural conservation or special designations; priority species habitat or open space
corridor (Table 6, Fig. 19). A portion of one elk patch, P4, is located within a rural traditional zoning designation, suggesting it is vulnerable to loss of use over time. There are no plans to re-designate lands containing elk patches.

I examined current and planned roads to determine if roads or road effects make elk patches vulnerable to loss of use. Although no elk patches lie adjacent to roads, if the 700 meter road effects buffer is considered, then P1 and P4 may be vulnerable to loss of use (Fig 19). Two transportation projects planned for 2011-2035 are not located near elk patches.

To determine if elk patches were located on lands with future development potential, I examined elk patch location in relation to new well and septic drain field potential. Development potential is highest outside of critical aquifer recharge areas where water rights are being granted, and where soils are not limited for drain fields. Development potential is lowest within critical aquifer recharge areas where water rights are no longer being issued, and where soils are limited for septic drain fields. A portion of P1 falls within the critical aquifer recharge area where water rights are no longer being issued. This patch is protected from potential future development. The remaining patches are within moderate aquifer recharge areas. No new water rights are being granted within the study area. The majority of the study area, including all elk patches, contains soils limited for septic drain fields. While this suggests limited development potential, there are many houses with septic fields within the study area. Because people are currently installing septic drain fields on soils with limited support capability, elk patches P2 - P4 have an equal likelihood of being developed in the future.
Climate Change- To determine how anthropogenic climate change might affect elk patches, I collected climate change predictions for eastern Washington, examined predicted shifts in dominant vegetation, examined changes in climate suitability for two tree species, ponderosa pine and quaking aspen, and reviewed recent historical changes in water levels on TNWR to predict near term changes in water availability. I identified which elk patches might be lost by 2030, 2060, and 2090 based on changes in vegetation distribution, climate suitability, and water availability.

Mean average temperature in the Pacific Northwest (PNW), which includes Washington, Oregon, Idaho, and western Montana, is expected to rise during the 21st century. The average of ten climate models, run under the SRES A2 storyline, predicts increases of roughly 1.1 - 1.3°C by 2020s, 1.6 - 2.2°C by 2040s, and 3.1 - 4.6°C by 2080s, compared to 1970-2000 (Fig. 20). Temperature increases are expected to be largest in summer. Annual precipitation for the PNW is predicted to rise roughly 2.0% by 2020s, 2.0% by 2040s, and 5.0% by 2080s (Fig. 21), compared to 2000 precipitation. Most models predict precipitation will decrease during summer months (June through August), and increase during the winter (December through February). Smaller precipitation increases are expected during fall and spring.

Down-scaled climate predictions for the Columbia Plateau ecoregion show similar increases in mean annual temperature with moderate increases during the first half of the century and more intense increases in the latter half of the century. Seasonally, summer versus winter temperatures appear to become more distinct, while fall and winter appear to become less distinct (Fig. 22) due to rising winter temperatures. Given the predicted change in winter temperature, an increasing portion of precipitation will fall as
rain rather than snow, especially at lower elevations, resulting in an earlier spring run-off. April 1 snowpack for the PNW is expected to drop by 26.0% by 2020s, 35.0% by 2040s, and 59.0% by 2080s. Climate scientists agree that drought will increase with a loss of soil moisture, particularly in the summer. As fuel loads grow in response to drought, many predict doubling or tripling of burn areas unless fires are suppressed.

Over the entire PNW region, moderate temperature increases during the early 2100s may cause carbon stocks to increase, which may result in an increase in vegetation density and biomass. Broad plant communities may shift, and both evergreen and deciduous forests might expand, depending on the migration rate of the tree species. During the second half of the 21st century, as temperatures escalate, carbon may be lost to increasing fires at a cost to vegetation density and biomass. Without fire suppression, forests are expected to retreat with replacement by grasslands. Forests that remain may experience decreased vigor and productivity.

Within the study area, there are currently three dominant vegetation types: temperate coniferous forest (46.94 % of the landscape), temperate coniferous woodland (32.02 %), and temperate shrubland (21.05 %). Changing climate suitability is expected to change the distribution of these habitats (Fig. 23) Coniferous forest is predicted the dominant vegetation across 80.1 % of the landscape by 2030, 97.1 % of the landscape by 2060, and 99.7 % of the landscape by 2090 (Fig. 24). By 2060, the landscape will no longer be suited for temperate shrubland. However, 0.6% of the study area may be suited to subtropical shrubland. By 2090, only 0.3% of the landscape will be best suited for temperate coniferous woodland, and the remaining landscape will be best-suited for temperate coniferous forest.
Here, temperate coniferous forests are comprised of ponderosa pine. A table demonstrating changes in the climate suitability for ponderosa pine between current, 2030, 2060, and 2090 is given (Table 7). Ponderosa pine suitability for all elk patches follows the same basic trend of improving by 2030, declining to near or slightly below current suitability by 2060, and increasing slightly by 2090 (Fig. 25). The eastern portion of the study area, which includes P2, is and will remain highly suited to ponderosa pine through 2030 (Fig. 26). Forests may expand in these areas. During the last half of the century climate suitability will once again be near the lower range of current suitability values. This suggests ponderosa pine will persevere over time. Given this, elk patches may be not be adversely affected by the changing suitability of ponderosa pine. As the availability of ponderosa pine increases, the amount of high and low probability elk patches may increase. By 2030, MC2 predicts coniferous forests will increase by 72%, and by 2060 coniferous forest will have doubled relative to 2000.

I predicted the change in the overall area (ha) of both high and low probability elk patches should ponderosa pine replace shrublands as the dominant vegetation model suggest. If shrublands were lost, ponderosa pine forests would double in size. High probability patches would increase 13.07%, and low probability patches would increase 39.01%. A chart showing predicted increases in high and low probability elk patches, as ponderosa pine replaces shrubland, is given (Fig. 27).

Woody wetlands, a high predictor of elk occurrence in this area, are comprised primarily of quaking aspen. A table demonstrating changes in the climate suitability for quaking aspen between current, 2030, 2060, and 2090 is given (Table 7). Currently, quaking aspen shows a low degree of climate suitability across the entire study area with
the highest suitability in the west (Fig. 18). By 2030, climate suitability will decrease in
the west such that the entire landscape will have a reduced, but similar, degree of
suitability. Aspen should function at the lower range of current levels during this time.
During the second half of the century climate suitability will drop to near zero,
suggesting aspen may be lost in much of its current extent by 2060 (Fig. 29). Given this,
portions of elk patches may be lost to changing aspen suitability beginning mid-century.

I compared changes in water availability from 1984–2011, as measured by
changes in the surface area of water bodies, to predicted how climate change may affect
water availability. Historic water data are only available for TNWR water bodies so
predictions and potential impacts to elk patches are limited to the refuge. Of 428 water
bodies studied, 81.5% lost water and 12.6% gained water. Changing surface water area
ranged from -0.5652 ha to 1.3524 ha, with a mean change of -0.0164 ha. The majority of
increasing water bodies gained between 0.0002 and 0.57 ha of surface area. Only two
locations showed a surface gain greater than 0.57 ha. These were located in Mullinix and
Long Lake sections (Fig. 30). I assumed water bodies that gained water during the 1984-
2011 should retain water until 2030.

A strong predictor of elk occurrence, the mean distance to lakes was 604 meters
for elk in high probability elk patches, and 491 meters for elk in low probability elk
patches. Out of 38.88 ha of high probability elk patches, 20.88 ha were within 604 meters
of a water body that has gained water from 1984-2011, and 18 ha are more than 604
meters away. Portions of elk patches in Long Lake and Eastern Slough will be lost by
2030 to decreasing water availability (Fig. 31). Of 270.63 ha of low probability elk
patches, 104.85 ha are within the 491 meters of a water body that has gained water from
1984-2011, and 169.69 ha are beyond 491 meters. All low probability elk patches will lose some area by 2030 due to reduced water availability (Fig. 31).

**Discussion**

Relatively recently, Rocky Mountain elk have expanded their range into the Channeled Scablands of eastern Washington. The persistence of this non-migratory population is tied to their use of the core protected habitats of Turnbull National Wildlife Refuge and adjacent private agriculture and range lands. Given the refuge proximity to Spokane, the adjacent areas increasingly face development pressures. Human-induced climate change presents potential habitat changes irrespective of land ownership. The goals of my study were to identify which habitats elk in the Channeled Scablands are currently using, and then to examine how these habitats might be affected by land use and human-induced climate change. Given the specific habitat requirements of parturient females and the importance of calf survival for population persistence (Garrott *et al.* 2003), I limited my investigation to radio-collared cows located during May to mid-July. In the following I comment on how the distribution of habitats currently used by elk might be expected to change due to land use activities and climate change, and I speculate on how this might impact elk persistence in this region. In general, I find that the combined effects of land use adjacent to the refuge and the broader effects of climate change suggest the long term persistence of elk in this region is uncertain.

I first asked which habitats have the highest probability of parturient elk occurrence. Parturient elk have higher energy demands due to birth recovery and lactation (Geist 1982, Barbkneckt *et al.* 2011, Dzialak *et al.* 2011b). Their movements are
restricted by their need to remain near hiding calves so they may return to suckle and nurture, and by the limited mobility of older calves (Barbkneckt et al. 2011). Studies show that parturient elk move roughly half the average daily distance of non-parturient elk (Barbkneckt et al 2011). Because of this, parturient cows must meet all of their physiological demands within close proximity. Previous studies suggest these elk primarily select riparian areas (McCorquodale et al. 1986), deciduous forests (Brook 2010, Barbkneckt et al. 2011), and shrubs (Thomas 1979). My data support this. I found that parturient cows had the highest probability of occurrence in woody wetlands, both herbaceous wetlands and grasslands, and shrub-steppe. Woody wetlands in my study area are primarily aspen that provide both cover and high quality shoots during their green up period, and while elk may seek out grasslands for a more sustainable source of fibrous forage, they have a higher probability of occurrence near the higher quality forage of herbaceous wetlands (Geist 1982). I also found that elk have a higher probability of occurrence on recent (2010-2013) burns, which offer higher quality forage than older or unburned forests (Long et al. 2009). Combined, these findings highlight the importance of forage habitats for parturient elk (Brook 2010).

Parturient elk were also predicted to occur in coniferous forests. Coniferous forests provide both thermal and hiding cover. Elk selected forests with 41-60% canopy cover over forests with less or more canopy cover. Optimal canopy cover for elk was once defined as forests at least 12 meters tall with an average of 70% cover (Thomas 1979). It has been argued that ponderosa pine forests with such high canopy cover are not sustainable, and 50% cover has been identified as an alternative elk standard (Powell 2012). It has also been argued that thermal cover is not critical to elk survival,
particularly in the summer (in Sawyer et al. 1997), and some suggest hiding cover may be a greater driver of forest use.

My findings show that parturient elk occurrence was predicted by lands with some degree of development. Developed lands may offer higher quality forage, or they are used as an anti-predator strategy where elk move closer to humans to take advantage of human tendency to drive away large predators. However, elk productivity has an inverse relationship to human disturbance (Shively et al. 2005) and elk have been shown to avoid humans during the calving season (Barbkneckt et al. 2011, Dzialak et al. 2011b). This disparity may be an artifact of the modelling process. Development at varying intensities were not important predictors of elk occurrence during earlier model runs, so classes were grouped in the final selection processes. The final grouping resulted in developed lands being categorized as “0” for barren land, and “1” for lands with any amount of development from a plot without buildings to a plot with more than one building. Because of this, almost the entire study area was categorized as “1.” It is possible that developed lands were included in the model simply because they represent a majority of the study area.

Parturient elk occurrence was not predicted by most cropland types. Only croplands devoted to seeds, grain, and oilseed showed a low probability of occurrence. Brooks (2010) showed that, on a landscape of farmland versus deciduous forests in protected lands, 73% of parturient elk had their entire home range within the protected lands and 21% had portions in both areas. Elk may avoid these areas because crops had not grown sufficiently to offer adequate forage, and the energetic trade-off of this forage resource may not be enough enticement, or it may be that farmlands, particularly early in
the growing season, may be too exposed. Pastures and hayfields showed zero probability of occurrence. This may be because cattle have been shown to displace elk (Stewart et al. 2002), or it may be that these areas offer insufficient cover at a critical time in parturient cow elk life history.

There are two caveats to consider in interpreting these habitat results. First, due to the telemetry error associated with elk locations, habitat selection was computed against 61 total elk locations collected between May and mid-July over four years. Telemetry error results when elk move between signal readings, from topological or atmospheric interference, or from an inability to correctly pinpoint the signal direction (in Montgomery et al. 2011). It is likely that all three of these conditions occurred during telemetry events, making accurate readings difficult. In addition, the GLM produced a very low $R^2$ value of 0.109, meaning that only 10.9% of the variance in the data was explained by the covariates. While a larger dataset that includes a greater number of error-free elk locations might produce different results, the results of my study agree with studies in other areas.

I asked if elk use areas were vulnerable to loss due to current or future land use practices. The majority of habitats predicting parturient elk occurrence areas were located within TNWR. I found occurrence areas in four general locations outside of the refuge, most of those within the riparian area of lake shores, and within eight of eleven sections within the refuge. Because the majority of elk telemetry was performed within the refuge, habitats predicting elk occurrence approximate refuge habitats. This suggests that off refuge landscapes with similarity to refuge habitats are very limited. This is evident in the mean size of occurrence areas. There are no high probability habitats on lands adjacent to
the refuge and the area of low probability patches off refuge is over twenty times smaller than habitats within the refuge. While a larger dataset may predict somewhat different habitat use results, parturient elk habitats surrounding TNWR are likely dissimilar to those within the refuge because of a lack of human modification on public lands.

Human encroachment into wildlife areas has been shown to negatively impact elk, altering their habitats and disrupting their behavior (Theobald et al. 1997, Frair et al. 2008, Dzialak et al. 2011a, Webb et al. 2001). Conversion of lands for energy (in Webb et al. 2011) or industrial (Dzialak et al. 2011a) use increases elk mortality and logging disturbances can disrupt elk use patterns (Edge and Marcum 1985). Roads bring increased mortality due to collisions and by opening travel lanes to predators, including hunters, and road effects include loss and fragmentation of habitat and loss of adjacent habitats (Theobald et al. 1997, Millspaugh et al. 2000, Veiera et al. 2003, Johnson et al. 2005, Frair et al. 2008). I found two of four off-refuge elk patches located almost entirely within the buffer of road effects, reducing the size and availability of off-refuge useful habitats.

A portion of one off-refuge elk patch was located on land designated rural traditional. Approximately 26% of the landscape is designated rural traditional, which allows for ranching, farming, mining, and forestry operations, and where housing density is limited to one unit per 4.05 hectares. In spite of their being less disruptive than urban or commercially zoned lands, elk may be compelled to leave rural traditional lands where development occurs. Housing and other buildings introduce “building effects” where the loss or fragmentation of habitat is compounded by the thinning of proximal trees, removal of native vegetation, introduction of pets, and increased human presence
Elk have been shown to avoid human presence (Shively et al. 2005, Barbkneckt et al. 2011), and even less invasive activities, such as hiking, can disrupt elk though flushing. Flushing effects have been reported at distances of 50-500 meters for elk (Theobald et al. 1997), and are exacerbated when pets are present (Hansen et al. 2005).

Three elk occurrence patches and a portion of a fourth are located on lands designated rural conservation. Rural conservation zoning is applied to environmentally sensitive areas, and housing density is limited to one unit, or two clustered units, per 4.05 hectares. Future development in the area is not restricted, and future zoning re-designations may occur, but zoning for large-scale development is unlikely because there are no new water rights being issued at this time, nor in the foreseeable future. Water resources are low across the study area, and water may be declining in some areas. The Wilson Creek community has already declared itself closed to new wells or water uses (DOE 2015), although this is not legally defensible. As temperatures continue to rise, other communities may adopt this strategy. Considering that water may be the largest driver of development potential, lakes and their surrounding areas may be the most suited for future development. For elk, the majority of off-refuge occurrence areas are located along lakeshores. As development concentrates where water remains available, elk would be left to persist on landscapes where water is at a minimum and potentially in decline. Spokane County (2012) policy is clear that the preservation of wildlife habitats will not occur at the expense of human expansion. Any future development will likely reduce the potential for elk survival outside of the refuge. The net result is elk may become even more dependent on refuge habitats.
In interpreting land use impacts to habitat use by parturient elk, it is important to realize that the majority of the telemetry effort was conducted within TNWR outside of the hunting season where there is little anthropogenic disturbance. This is particularly true in the western half of the refuge. Because telemetry events occurred on relatively undisturbed lands, I did not include human recreational areas as a covariate in the habitat regression. Off-refuge elk occurrence areas in this study are located adjacent to lakes where there is likely some degree of human activity. These areas may not be used by elk due to proximity to human disturbance. To account for this, future studies should focus telemetry across the entire study area, including human use areas, and regressions should include anthropogenic covariates such as fishing, camping, hiking, and other recreational areas as covariates.

I asked how climate may be expected to change during the 21st century and the potential consequences for elk. I found predicted increases in annual temperature and precipitation. Seasonally, winters are expected to become warmer and wetter, while summers are expected to become hotter and drier. Indirect effects include reduced snowpack, earlier spring run-off, drier soils resulting from reduced snowpack and increased evaporative demand, and increased drought. Changes in temperature and precipitation have implications for elk habitat and elk demographics.

I found parturient elk had the highest probability of being found in coniferous forests and woody wetlands, which are primarily composed of ponderosa pine and quaking aspen, respectively, in this study area. The dominant vegetation map shows that climate may reduce species richness, leaving the landscape increasingly more suited to ponderosa pine forest while the species-specific map predicts decreased suitability for
ponderosa pine. This may appear contradictory, but these findings suggest that, as the landscape will become less suited to current dominant species, only those species best suited to warmer, drier climates would remain. Perhaps the only dominant species on this landscape highly suited to warmer, drier climates is ponderosa pine.

Ponderosa pine is extremely well-adapted for higher temperature and drought, and the bark offers protection from fire (Oliver and Ryker 1990). Growth is ultimately limited by soil moisture availability but their root depth, greater than that of other tree species, gives them greater access to deep water tables. Increased carbon stocks are expected to increase the water use efficiency in plants at moderate temperature increases (Derner et al. 2005, Rogers et al. 2011). This is reflected in the increased suitability for ponderosa pine by 2030. Any benefit, however, will depend on nitrogen availability (Rogers et al. 2011). Ponderosa pine have lower nitrogen and phosphorus demands than other tree species, making them better able to take advantage of increased carbon stocks, and their root depth gives them greater access to nutrients. By 2060, when climate suitability for ponderosa pine is at its lowest, overall climate suitability will not have dropped much below its current suitability, and by 2090, suitability will improve in many area and decrease only near the outer edges of the study area. While some areas may function below current levels, these reductions should not hinder the ability of ponderosa pine to function as thermoregulation or hiding cover for elk.

Quaking aspen in the study area survive currently at relatively low climate suitability, which is expected to diminish considerably over the century. Although aspen survive in other geographic locations with temperatures near 23°C, they only occur where annual precipitation exceeds evapotranspiration (Perala 1990). This, along with high
growth and nutrient demands, may explain the loss in climate suitability in the study area. Aspen rely on soil moisture, which is expected to decrease earlier in the year with increased temperatures, lack of snow melt, and earlier spring run-off. Aspen areas important to elk already occur in wetlands and near lakes, where soil moisture is retained longer than in open fields. This suggests that aspen may survive at reduced climate suitability where wetlands are best able to retain water or those with greatest access to groundwater. For elk on TNWR, the most important high and low probability patches are those near the most secure water resources. They may come to rely more on these area not only for their water resource, but for their ability to provide the aspen that elk rely on for forage and hiding cover. But, under stress, stands may show a decreased rate of growth and may not reach their full height, reducing their overall usefulness for elk.

Caution must be applied to interpreting the effects of climate models because they do not take into account human behavior or developments. The “current” dominant vegetation model includes only three dominant vegetation types, ponderosa pine forest, ponderosa woodland, and shrub-steppe. This is because the vegetation module defines vegetation at a large spatial scale and by climate suitability, not by species. A large portion of the actual landscape (24%) is devoted to agriculture and pastureland. These areas, designated natural resource areas, are discouraged for development because they cannot be reclaimed once developed (Spokane County 2012). It is unlikely that ponderosa pine forest would replace agricultural fields or that shrubs or grassland would disappear entirely. If coniferous forest were to replace shrublands, doubling the size of coniferous forest, the predicted effect would be a combined 36% increase in high and low probability elk occurrence areas. This assumes that parturient elk would still have access
to other important areas such as wetlands and grasslands. Replacing grasslands with coniferous forest, which would increase coniferous forest by 50%, would increase total elk occurrence areas less than 8% (data not shown). While coniferous forest may not replace all other land types, landscapes may become more homogenous. With decreased habitat patchiness elk, an ecotone species that prefer forest/grassland edge, may find a reduction in total edge, further reducing the size and availability of useful habitats.

Because climate models are run at low resolution, they are unable to predict small-scale changes, including changes in smaller vegetation communities, which often exist in mosaics, or interspersed patches. Elk reproduction is tied to the onset and progression of plant cycles so that calves are born at the beginning of spring at the onset of plant growth (Taber et al. 1982, Post et al. 2008). Elk selectively forage the highest quality plant material, which is often the newest. Because the date of initial green up differs by plant species, elk are able to consume the newest forage over a long time period by selecting species at the onset of green up. Successful reproduction in the face of changing climates depends on elk ability to adjust to seasonal impacts to plant communities.

In the springtime, elk will have to respond to the earlier emergence of plants, which will favor poorer quality non-native species. Some climate studies suggest shifting plant communities and reduced community heterogeneity (Post et al. 2008), meaning elk may have to travel further between patches of high quality forage. For parturient elk that rely on resources within close proximity to their calves, this will increase their already-increased energetic demand. With predictions of reduced snowpack and earlier spring run-off, the availability of high quality forage near adequate water may become
increasingly limited. And while precipitation is expected to increase, the benefits may be negligible. Many predict plants will have increased water use efficiency as a result of increased carbon stocks, but this supposes that nutrient demands are met. It is unlikely that nitrogen demands will be met in a manner benefiting elk. The increase in plant biomass will be met at the expense of quality as plants increase fiber content to support their growth (Derner et al. 2005). By the latter half of the century, anticipated increases in precipitation may be offset by an increase in evapotranspiration demand.

Johnston and Schmitz (1997) found elk physiologically capable of handling the summer temperature increases predicted by climate models. However, predicted increase in summer temperatures and drought conditions will result in shorter plant growing seasons, reduced summer forage quality, and increased physiological stress if the cow cannot find adequate water supply. Cow elk rely on adequate summer vegetation and water to recover from parturition, meet lactation demands, and fatten up before the fall rut (Taber et al. 1982). Fertilization is less likely in unhealthy cows, and may be unsuccessful during the first estrus cycle. Cows that impregnate during the second or third estrus cycle experience late births, which occur after the onset of green up, delaying access to the highest quality forage for both the cow and the calf. Calves also must select the highest quality forage if they are to store enough fat to survive the winter. A calf unable to feed adequately in the summer and fall will starve on the low-quality forage of winter (Garrott et al. 2003).

Even if elk are capable of adapting to changing temperatures, at the population level the mechanism regulating productivity may change. Historically, cold winters regulate population sizes primarily by restricting juvenile recruitment (Garrott et al. 2003).
2003) and also through expiration of senescent adults (Wang et al. 2002, Creel and Creel 2009). Under an altered climate regime, summer conditions may become the dominant driver of herd size by regulating cow reproduction and limiting calf survivorship. The timing of elk reproduction should shift to accommodate earlier plant emergence, as elk have been shown to alter their estrus cycle when introduced to areas with earlier green up (Taber et al. 1982). Shorter growing seasons, limited quality forage, and a declining water supply may ultimately drive elk survival.

Elk in this region are dependent on habitats within core protected areas and surrounding landscapes with low human density. The landscape surrounding TNWR is unlikely to become developed in the near future, but private lands are rarely managed for wildlife. Without human intervention, the future landscape will tend towards more homogeneous habitats with reduced water supply. This highlights the need for landscape management; fire management to open landscapes for deciduous tree and grassland growth and to provide areas of higher quality forage, protection of water resources, especially near recharge aquifers, and protection of connectivity corridors.
**Conclusion**

Understanding the factors underlying the distribution and abundance of wildlife remains a central question in wildlife ecology. Elk, once near extinction in the early 1900’s, have recovered and have relatively recently expanded their range into previously unused habitats, including the Channeled Scablands of eastern Washington. A non-migratory herd, these elk rely primarily on core protected lands found within Turnbull National Wildlife Refuge (TNWR) and the low density agriculture and range lands surrounding the refuge. Elk use the refuge disproportionately to the surrounding areas, and elk overbrowsing of riparian aspen prompted managers to initiate a hunt to cull the herd and disperse elk out of the refuge. In the first chapter of this thesis, I examined elk response to the hunting program and found that elk are displaced most often during the hunting season. Elk had the greatest probability of being within the refuge during the first three pre-hunting seasons, but had the greatest probability of being off refuge during the fourth pre-hunting season. This may be an indication that elk are beginning to relocate off refuge.

With more frequent use of off-refuge habitats, elk may encounter increasingly fragmented landscapes due to human land use practices. Irrespective of land use activities, elk may also encounter shifting habitat composition in response to anthropogenic climate change. In the second chapter of my thesis, I determined in which habitats elk had the greatest likelihood of occurrence and then explored how those habitats may be impacted by land use activities and anthropogenic climate change. Because parturient elk have specialized habitat needs, and in light of the role that calf
survivorship plays in population persistence, I chose to focus my analysis on habitats important to parturient elk.

I found that habitat selection by parturient elk is primarily focused on forage resources, but also for cover and distance to water. In addition, habitats surrounding the refuge are largely dissimilar to the TNWR habitats that elk seem to prefer. These off-refuge elk habitats are threatened by road effects and some zoning designations, and I speculate that future development may lead to increased elk-landowner conflict as humans and elk compete for water on a landscape where water availability may be in decline. Climate change is expected to result in increased temperatures and precipitation with shifts in the seasonal dynamics of temperature and water availability. Shifting plant phenology may favor invasive plant species and natives may become more isolated on the landscape, forcing elk to travel further in search of target high quality forage. By the latter half of the century, evaporative demand may overcome the near-term benefits of increased precipitation. A lack of water will affect elk habitats as climate suitability drops for aspen and the landscape becomes most suited to drought-tolerant ponderosa pine. Elk occurrence areas within the protection of TNWR will become less favorable to parturient elk due to their distance from water. Elk demographics, once regulated by juvenile recruitment during cold winters, may become dependent of calf survivorship amidst rising summer heat and an associated decrease in forage quality.

Elk persistence on this landscape is dependent on human intervention, and this study emphasizes the need to provide suitable habitats for elk where forage, cover, and water demands can be met. This is possible by establishing conservation areas, public lands purchases, conservation easements and other land use agreements, and habitat
management that includes planting native grasses and trees while controlling for invasive species, fire management, and water control. As time progresses, however, water will likely become the limiting factor.
References


Table 1. Total number of elk locations found on or around Turnbull National Wildlife Refuge, grouped by season per year, 2010-2013. Elk were located using radio telemetry (n = number of elk).

<table>
<thead>
<tr>
<th>Year</th>
<th>Season</th>
<th>Hunting areas</th>
<th>Non-Hunt areas</th>
<th>Off Refuge</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Pre-Hunt Hunt</td>
<td>37 (n=15)</td>
<td>76 (n=20)</td>
<td>73 (n=24)</td>
<td>186</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65 (n=19)</td>
<td>191 (n=25)</td>
<td>138 (n=26)</td>
<td>394</td>
</tr>
<tr>
<td>2011</td>
<td>Post-Hunt</td>
<td>79 (n=24)</td>
<td>121 (n=22)</td>
<td>159 (n=24)</td>
<td>359</td>
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<tr>
<td></td>
<td>Pre-Hunt</td>
<td>7 (n=5)</td>
<td>34 (n=14)</td>
<td>20 (n=13)</td>
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<td></td>
<td>Hunt</td>
<td>59 (n=18)</td>
<td>209 (n=23)</td>
<td>118 (n=22)</td>
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<tr>
<td>2012</td>
<td>Post-Hunt</td>
<td>21 (n=13)</td>
<td>49 (n=17)</td>
<td>61 (n=20)</td>
<td>131</td>
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<tr>
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<td>Pre-Hunt</td>
<td>4 (n=3)</td>
<td>29 (n=10)</td>
<td>4 (n=3)</td>
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<td>Hunt</td>
<td>13 (n=10)</td>
<td>36 (n=14)</td>
<td>35 (n=14)</td>
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<tr>
<td>2013</td>
<td>Post-Hunt</td>
<td>11 (n=8)</td>
<td>17 (n=9)</td>
<td>26 (n=11)</td>
<td>54</td>
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<td></td>
<td>Pre-Hunt</td>
<td>13 (n=6)</td>
<td>42 (n=8)</td>
<td>50 (n=11)</td>
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<tr>
<td></td>
<td>Hunt</td>
<td>43 (n=14)</td>
<td>93 (n=15)</td>
<td>61 (n=15)</td>
<td>197</td>
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<tr>
<td><strong>Grand Total</strong></td>
<td></td>
<td>352</td>
<td>897</td>
<td>745</td>
<td>1994</td>
</tr>
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</table>

Table 2. Landscape variables used to predict parturient elk habitat use. Criteria were taken from scientific literature (Table 2). Data were obtained from the National Land Cover Database, Spokane County, U.S. Fish and Wildlife Service, and Turnbull National Wildlife Refuge.

<table>
<thead>
<tr>
<th>Categorical variables:</th>
<th>Distance variables:</th>
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<tbody>
<tr>
<td>Landtype:</td>
<td>Distance to open water (m)</td>
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<tr>
<td>Coniferous forest</td>
<td>Distance to lakes (m)</td>
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<td>Deciduous forest</td>
<td>Distance to ponds (m)</td>
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<td>Mixed forest</td>
<td>Distance to all roads (m)</td>
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<td>Scrub shrub</td>
<td>Distance to primary roads (m)</td>
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<tr>
<td>Grasslands</td>
<td>Distance to secondary roads (m)</td>
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<td>Developed/Barren</td>
<td>Distance to forest/grassland edge (m)</td>
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<tr>
<td>Woody wetland</td>
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<td>Herbaceous wetland</td>
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<td>Cropland (nursery/orchard, vegetable/grass, seed/grain, pasture/hay)</td>
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<tr>
<td>Forest canopy cover (&lt; 20%, 21-40%, 41-60%, &gt; 61%)</td>
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<tr>
<td>Ownership (public vs. private)</td>
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<tr>
<td>Housing density (1 unit per 4.05, 8.10, 16.20, or 32.40 acres)</td>
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</table>
Table 3. Literature sources for landscape covariates shown to influence elk movement or distribution.

<table>
<thead>
<tr>
<th>Reference:</th>
<th>Forage</th>
<th>Forest or Thermal Cover</th>
<th>Shrubs or Hiding Cover</th>
<th>Developed Land</th>
<th>Cultivated land</th>
<th>Habitat Type</th>
<th>Burn Areas</th>
<th>Human Disturbance</th>
<th>Canopy Cover</th>
<th>Distance To Water</th>
<th>Distance to Edge</th>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

*() = "Reviewed in"

Other = (slope, aspect, riparian, meadow, clear-cut, etc)
Table 4. Habitat coefficients, standard error, and p-values predicting parturient elk occurrence within and around Turnbull National Wildlife Refuge. Model covariates were chosen using backwards stepwise multiple regression analysis. The coefficient for categorical covariates refers to the change in the log odds of an individual moving into the habitat from outside of the habitat, while the coefficient for distance covariates refers to the change in log odds with distance. Significance codes are listed below the table.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>z-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn before 2005</td>
<td>0.560800</td>
<td>0.352600</td>
<td>1.590</td>
<td>0.11174</td>
</tr>
<tr>
<td>Burns 2005-2007</td>
<td>-17.350000</td>
<td>5462.000000</td>
<td>-0.003</td>
<td>0.99747</td>
</tr>
<tr>
<td>Burns 2008-2009</td>
<td>-17.510000</td>
<td>5985.000000</td>
<td>-0.003</td>
<td>0.99767</td>
</tr>
<tr>
<td>Burns 2010-2013</td>
<td>1.791000</td>
<td>0.644200</td>
<td>2.779</td>
<td>0.00545  **</td>
</tr>
<tr>
<td>Canopy Cover &lt; 20%</td>
<td>-0.611100</td>
<td>0.371600</td>
<td>-1.644</td>
<td>0.10008</td>
</tr>
<tr>
<td>Canopy Cover 21-40%</td>
<td>-0.220500</td>
<td>0.358700</td>
<td>-0.615</td>
<td>0.53884</td>
</tr>
<tr>
<td>Canopy Cover 41-60%</td>
<td>-0.065630</td>
<td>0.436400</td>
<td>-0.150</td>
<td>0.88045</td>
</tr>
<tr>
<td>Canopy Cover &gt; 60%</td>
<td>-16.660000</td>
<td>3434.000000</td>
<td>-0.005</td>
<td>0.99613</td>
</tr>
<tr>
<td>Nursery/Orchards</td>
<td>-15.050000</td>
<td>806.300000</td>
<td>-0.019</td>
<td>0.98511</td>
</tr>
<tr>
<td>Vegetables/Turf Grass</td>
<td>-14.690000</td>
<td>1039.000000</td>
<td>-0.014</td>
<td>0.98872</td>
</tr>
<tr>
<td>Seed and Grain Crops</td>
<td>-1.445000</td>
<td>0.594400</td>
<td>-2.431</td>
<td>0.01506  *</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>-14.220000</td>
<td>3260.000000</td>
<td>-0.004</td>
<td>0.99652</td>
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<tr>
<td>Coniferous Forest</td>
<td>1.691000</td>
<td>0.646800</td>
<td>2.614</td>
<td>0.00895  **</td>
</tr>
<tr>
<td>Shrub-Steppe</td>
<td>0.732900</td>
<td>0.634900</td>
<td>1.154</td>
<td>0.24837</td>
</tr>
<tr>
<td>Grassland</td>
<td>1.054000</td>
<td>0.669700</td>
<td>1.573</td>
<td>0.11565</td>
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<tr>
<td>Woody Wetland</td>
<td>1.794000</td>
<td>1.085000</td>
<td>1.653</td>
<td>0.09827  .</td>
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<tr>
<td>Herbaceous Wetland</td>
<td>1.084000</td>
<td>0.785100</td>
<td>1.380</td>
<td>0.16755</td>
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<tr>
<td>Developed Lands</td>
<td>0.993600</td>
<td>1.031000</td>
<td>0.964</td>
<td>0.33516</td>
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<tr>
<td>&gt; 80 acres/dwelling</td>
<td>14.040000</td>
<td>756.200000</td>
<td>0.021</td>
<td>0.98519</td>
</tr>
<tr>
<td>40-80 acres/dwelling</td>
<td>14.940000</td>
<td>756.200000</td>
<td>0.020</td>
<td>0.98424</td>
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<tr>
<td>20-40 acres/dwelling</td>
<td>16.180000</td>
<td>756.200000</td>
<td>0.019</td>
<td>0.98293</td>
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<tr>
<td>Distance to Lakes</td>
<td>-0.000574</td>
<td>0.000117</td>
<td>-4.895</td>
<td>9.82E-07 ***</td>
</tr>
<tr>
<td>Distance to Ponds</td>
<td>0.000119</td>
<td>0.000287</td>
<td>0.416</td>
<td>0.67734</td>
</tr>
<tr>
<td>Distance to Roads</td>
<td>0.000100</td>
<td>0.000147</td>
<td>0.678</td>
<td>0.49807</td>
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<tr>
<td>Distance to Edge</td>
<td>0.000603</td>
<td>0.000326</td>
<td>1.850</td>
<td>0.06425  .</td>
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</tbody>
</table>

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Table 5. Area (ha) of parturient elk occurrence patches. Patches are grouped according to spatial location on the landscape.

<table>
<thead>
<tr>
<th>Patches</th>
<th>Name</th>
<th>Area (ha)</th>
<th>Probability</th>
<th>Section</th>
<th>Area (ha)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Silver lake</td>
<td>0.63</td>
<td>Low</td>
<td>Campbell Lake (CL)</td>
<td>0.00</td>
<td>10.08</td>
</tr>
<tr>
<td>P2</td>
<td>JTS Conservation Area</td>
<td>0.63</td>
<td>Low</td>
<td>Eastern Slough (ES)</td>
<td>18.54</td>
<td>74.34</td>
</tr>
<tr>
<td>P3</td>
<td>Chapman Lake</td>
<td>0.09</td>
<td>Low</td>
<td>Kepple Lake (KL)</td>
<td>0.00</td>
<td>36.09</td>
</tr>
<tr>
<td>P4</td>
<td>Badger Lake</td>
<td>12.87</td>
<td>Low</td>
<td>Long Lake (LL)</td>
<td>18.09</td>
<td>52.83</td>
</tr>
<tr>
<td></td>
<td><strong>Total Area (ha)</strong></td>
<td><strong>14.22</strong></td>
<td></td>
<td>Mullinix (MX)</td>
<td>1.62</td>
<td>14.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pine Creek (PC)</td>
<td>0.00</td>
<td>8.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Southwest (SW)</td>
<td>0.63</td>
<td>25.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Western Slough (WS)</td>
<td>0.00</td>
<td>49.14</td>
</tr>
<tr>
<td></td>
<td><strong>Total Area (ha)</strong></td>
<td><strong>38.88</strong></td>
<td></td>
<td></td>
<td><strong>270.63</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Parturient elk occurrence patches (P1 – P4) in relation to zoning designations and roads. Pink shading indicates a harmful designation, while green indicates a protective designation. Patches in harmful zones may be lost over time.

<table>
<thead>
<tr>
<th>Land Use Component</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cities and Roads</td>
<td></td>
<td></td>
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<tr>
<td>Commercial</td>
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<tr>
<td>Urban Reserve</td>
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<td></td>
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<tr>
<td>Rural Activity Center</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rural Traditional</td>
<td></td>
<td></td>
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<td>X</td>
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<tr>
<td>Roads</td>
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<td></td>
<td>X</td>
<td>X</td>
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<tr>
<td>Critical Aquifer Recharge Area</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geologic Hazards</td>
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<tr>
<td>Open Space Corridor</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Priority Species Habitat</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural Conservation</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Natural Resource Land</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7. Minimum, maximum, and mean climate suitability of ponderosa pine (*Pinus ponderosa*) and quaking aspen (*Populus tremuloides*) across the entire study area during the 21st century. “Current” values are the mean annual values for 1961-1990. The remaining values represent the mean annual values averaged across 10 years around the stated year, so 2030 represents the average annual suitability for 2025-2034.

<table>
<thead>
<tr>
<th></th>
<th>Ponderosa Pine</th>
<th>Quaking Aspen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>current</td>
<td>2030</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.3608</td>
<td>0.5333</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.5333</td>
<td>0.7529</td>
</tr>
<tr>
<td>Mean</td>
<td>0.3968</td>
<td>0.5698</td>
</tr>
</tbody>
</table>
Figure 1. Historic (pre-European settlement) versus current distribution of elk in North America (RMEF no date).
Figure 2. Turnbull National Wildlife Refuge and surrounding area. Data sources are listed in the legend.
Figure 3. Number of breaks in elk movement behavior, for 20 elk located on or around Turnbull National Wildlife Refuge, by season and year, as determined by the Behavior Change Point Analysis (see text).

Figure 4. Seasonal changes in the level of elk displacement following a break in movement behavior, from 2010 through 2014, for 20 elk on or around Turnbull National Wildlife Refuge. Increased displacement means elk are spending less time in a given area, indicating dispersal-related behavior. Decreased displacement means elk are spending more time in a given area, indicating foraging-related behavior.
Figure 5. The number of movement breaks between 2010 and 2014 that resulted in an increase, decrease, or no change in the time-scale of elk movement for 20 elk on or around Turnbull National Wildlife Refuge. An increase in time-scale means movement persists in a given direction, indicative of dispersal behavior. A decrease means shorter time-scales of movement, indicative of foraging behavior.

Figure 6. Changes in the log odds of refuge non-hunt area elk locations versus hunting area and off refuge locations, relative to the baseline of hunting season 2010 (red box), for 26 elk located on or around Turnbull National Wildlife Refuge. Asterisks denote significance at 0.05 and plus sign denotes partial significance at 0.10. Error bars with whiskers represent 95% confidence intervals. Pairwise analyses were performed using generalized linear mixed effects models.
Figure 7. Changes in the log odds of off refuge elk locations versus on refuge elk locations, relative to the baseline of hunting season 2010 (red box), for 26 elk located on or around Turnbull National Wildlife Refuge. Asterisk denotes significance at 0.05 and error bars with whiskers represent 95% confidence intervals. Pairwise analyses were performed using generalized linear mixed effects models.

Figure 8. Changes in the log odds of refuge hunting area locations versus refuge non-hunt and off refuge locations, relative to the baseline of hunting season 2010 (red box), for 26 elk located on or around Turnbull National Wildlife Refuge. Asterisk denotes significance at 0.05 and error bars with whiskers represent 95% confidence intervals. Pairwise analyses were performed using generalized linear mixed effects models.
Figure 9. Comparison of elk location probabilities during hunting season 2010 – 2013 for 26 elk found on or around Turnbull National Wildlife Refuge. Error bars with whiskers represent 95% confidence intervals.

Figure 10. Comparison of the elk location probabilities during post-hunt seasons, 2011-2013 for 26 elk found on or around Turnbull National Wildlife Refuge. Error bars with whiskers represent 95% confidence intervals.
Figure 11. Comparison of the probabilities of elk locations during the pre-hunt seasons 2010 - 2013 for 26 elk found on or around Turnbull National Wildlife Refuge. Error bars with whiskers represent 95% confidence intervals. Pre-hunt 2010 reflects elk location probabilities prior to any refuge hunting pressure.
Figure 12. Turnbull National Wildlife Refuge is at the center of the study area. Land types are a product of the National Land Cover Database, and were obtained from the USGS Multi-Resolution Land Characteristics Consortium, 2011 (Jin et. al. 2013).
Figure 13. Depiction of the natural and anthropogenic forces that affect climate systems. Online from http://www.gfdl.noaa.gov/earth-system-model.

Figure 14. Trend in mean temperature for the Pacific Northwest during the 20th century (black bar) and predicted trends in mean temperature derived from a number of climate models. This type of graph is used to validate the ability of a climate model to predict changes in climate by comparing model predictions to observed phenomena (Mote 2011, GFDL 1999). Note CGCM3.1_t63 to the right of observed (black bar).
Figure 15. Emissions assumptions created by the Intergovernmental Panel on Climate Change (2000). Charts represent changes in, clockwise from top left, carbon dioxide, nitrous oxide, methane, and sulfur dioxide. Emissions assumptions are used to drive changes in climate models. The A2 storyline was used to model changes in dominant vegetation types as well as changes in climate suitability for ponderosa pine and aspen trees.

Figure 16. Schematic of the interacting modules of the MC2 dynamic vegetation model that incorporates climate change predictions to model changes in ecosystem structure and function, which is then used to predict landscape-level changes in vegetation distribution. Slide from Kim et al. (2012).
Figure 17. Probability of parturient elk occurrence in relation to landscape covariates. Data was obtained via generalized linear models using R software. Covariates were obtained through backwards pairwise selection.

Figure 18. Map of study area depicting high (>0.5) and low (2.5-4.9) probability parturient elk occurrence patches. Note all high probability patches are within Turnbull National Wildlife Refuge (TNWR) boundary and four low probability patches (P1 - P4) are located outside of the refuge. See Table 4 and the reading for TNWR section abbreviations.
Figure 19. Parturient elk occurrence patches in relation to land use practices. Red areas indicate land use practices that reduce the usefulness of an elk patch (see pink, Table 4), and gray indicates protective land uses (see green Table 4). P1 lies within the 700-meter road effects buffer, as does a portion of P4. Rural traditional also spans a portion of P4. Blowouts show elk occurrence patches (yellow) in relation to zoning (brown) and road effects (red). Patches within red or brown may be lost over time to land use practices.
Figure 20. Predicted change in temperature. Smooth lines represent different models running under the A2 scenario. Dashed lines are models running the B2 scenario. Reported temperature values are subtracted from the mean temperature for the 1990s (black dots with lines) to get change in temperature over time. Source (Mote and Salathe 2010).

Figure 21. Predicted change in precipitation. Smooth lines represent different climate models running under the A2 storyline and B1 storyline, dashed lines. Model abbreviations are listed by color. Source (Mote and Salathe 2010).
Figure 22. Climate change for the Columbia Plateau Ecoregion determined by the Geophysical Fluid Dynamics Laboratory model GFDL_ESM2M run under representative concentration pathway RCP 8.5, a scenario of higher emissions. Note the increase in summer temperature (red, upper graphs) and decrease in summer precipitation (red, lower graphs). Created by the Conservation Biology Institute.
Figure 23. Climate suitability of dominant vegetation types for current (A), 2030 (B), 2060 (C), and 2090 (D). Suitability reflects 10-year modes. For instance, 2030 is the yearly mode of 2025-2034. Subtropical shrubland is found during the 2060 period only. Vegetation shifts are inferred as a result of changing climate envelopes and do not take into account human disturbance. Maps were created using the MC2 dynamic vegetation model using climate change predicted by the Canadian Global Climate Model CGCM3 run under the Special Report on Emissions Scenarios storyline A2, a worst-case scenario that predicts high population growth, high emissions, and slow technological advances (IPCC 2000).
Figure 24. Shifts in dominant vegetation across the study area resulting from changing climate suitability. Modeling was done with the MC2 dynamic vegetation model using the Canadian Global Climate Model CGCM3, run under the Special Report on Emissions Scenarios scenario A2 (IPCC 2000). The proportion of subtropical shrubland is at the top of 2060.
Figure 25. Changing climate suitability for ponderosa pine (*Pinus ponderosa*) for A) low probability elk occurrence patches (P1-P4) located outside of Turnbull National Wildlife Refuge (TNWR), B) low probability elk patch within TNWR, and C) high probability elk patches, all of which are within TNWR. The legend of TNWR sections between the two lower charts serves both charts. (See Figure 10 for patch locations).
Figure 26. Maps depicting shifting suitability for Ponderosa pine tree species (PIPO). Maps show the 10-year mode around the target year. For example, 2030 is the mode of 2025-2034. Maps were generated by replacing current tree suitability splines with splines updated to reflect climate change predicted by the Canadian Global Climate Model CGCM3, run using the Special Report on Emissions Scenarios scenario A2, a worst-case scenario that predicts high population growth, high emissions, and slow technological advances.
Figure 27. Changes in the total area (ha) of high probability (A) and low probability (B) parturient elk patches following a predicted increase in coniferous forest at the expense of shrub-steppe.

Figure 28. Climate suitability for quaking aspen (*Populus tremuloides*) between 2000 (left) and 2030 (right). Maps show a 10-year mode around the target year. For example, 2030 is the mode of 2025-2034. From 2060 - 2090, the entire landscape is brown (not shown), reflecting a suitability of 0.000-0.100. Maps were generated by replacing current tree suitability splines with splines updated to reflect climate change predicted by the Canadian Global Climate Model CGCM3, run using Special Report on Emissions Scenarios A2, a worst-case storyline that predicts high population growth, high emissions, and slow technological advances.
Figure 29. Changing climate suitability for quaking aspen (*Populus tremuloides*) for A) low probability elk occurrence patches (P1-P4) located outside of Turnbull National Wildlife Refuge (TNWR), B) low probability elk patch within TNWR, and C) high probability elk patches, all of which are within TNWR. The legend of TNWR sections between the two lower charts serves both charts. (See Figure 10 for patch locations).
Figure 30. Changes in the surface area (ha) of waterbodies within and near Turnbull National Wildlife Refuge in relation to the location of parturient elk occurrence patches. Surface area was digitized from imagery layers. Values represent mean changes between 1984 and 2011.
Figure 31. High (red) and low (purple) probability parturient elk patches lost due to climate-driven water loss. Mean distance to lakes, a significant predictor of parturient elk occurrence, was 604 meters for high probability elk patches and 491 meters for low probability patches. Elk patches within the respective distances to water bodies that gained water from 1984-2011 were retained in this 2030 map.
### Appendix

#### TABLES

Table 1. Averaged change in log odds, standard error (St. Error), and p-value for 100 Monte Carlo simulated binomial generalized linear regression for predicting parturient elk presence/absence. The precise dataset, used in the analyses, is given for reference.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>No Error</th>
<th>Error Ellipse = 2 cells</th>
<th>Error Ellipse = 5 cells</th>
<th>Error Ellipse = 60 cells</th>
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<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Std. Error</td>
<td>p-value</td>
<td>Estimate</td>
</tr>
<tr>
<td>Intercept</td>
<td>-23.4000</td>
<td>472.0000</td>
<td>0.960450</td>
<td>-22.3891</td>
</tr>
<tr>
<td>Burned before 2005</td>
<td>-0.0934</td>
<td>0.3630</td>
<td>0.796720</td>
<td>0.0198</td>
</tr>
<tr>
<td>Burned 2005-2007</td>
<td>-17.0200</td>
<td>3360.0000</td>
<td>0.995960</td>
<td>-17.2725</td>
</tr>
<tr>
<td>Burned 2008-2009</td>
<td>-17.1600</td>
<td>3680.0000</td>
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<td>0.3679</td>
</tr>
<tr>
<td>Burned 2010-2013</td>
<td>1.0760</td>
<td>0.6580</td>
<td>0.102070</td>
<td>-0.8616</td>
</tr>
<tr>
<td>Canopy Cover &lt;20%</td>
<td>-0.7437</td>
<td>0.3760</td>
<td>0.047930</td>
<td>-0.5309</td>
</tr>
<tr>
<td>Canopy Cover 20-40%</td>
<td>-0.4435</td>
<td>0.3650</td>
<td>0.224440</td>
<td>-0.2635</td>
</tr>
<tr>
<td>Canopy Cover 40-60%</td>
<td>-0.4576</td>
<td>0.4460</td>
<td>0.326030</td>
<td>-0.4849</td>
</tr>
<tr>
<td>Canopy Cover &gt;60%</td>
<td>-16.0600</td>
<td>2100.0000</td>
<td>0.993890</td>
<td>-16.1322</td>
</tr>
<tr>
<td>Nursery/Orchard</td>
<td>-13.9200</td>
<td>505.0000</td>
<td>0.977990</td>
<td>-14.1537</td>
</tr>
<tr>
<td>Vegetables/Turf-grass</td>
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<td>628.0000</td>
<td>0.982270</td>
<td>-14.0038</td>
</tr>
<tr>
<td>Seeds/Grains</td>
<td>-1.1410</td>
<td>0.6220</td>
<td>0.066700</td>
<td>-0.9366</td>
</tr>
<tr>
<td>Distance to Roads</td>
<td>0.0000</td>
<td>0.0002</td>
<td>0.774390</td>
<td>0.0000</td>
</tr>
<tr>
<td>Developed Lands</td>
<td>1.1040</td>
<td>1.0400</td>
<td>0.288670</td>
<td>0.1812</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>1.7620</td>
<td>0.6550</td>
<td>0.007130</td>
<td>0.8473</td>
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<tr>
<td>Shrub Steppe</td>
<td>0.8387</td>
<td>0.6430</td>
<td>0.191880</td>
<td>0.1577</td>
</tr>
<tr>
<td>Grasslands</td>
<td>1.1330</td>
<td>0.6770</td>
<td>0.094190</td>
<td>0.7327</td>
</tr>
<tr>
<td>Woody Wetland</td>
<td>1.7270</td>
<td>1.1000</td>
<td>0.115450</td>
<td>0.6359</td>
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<tr>
<td>Herbaceous Wetland</td>
<td>1.0890</td>
<td>0.7970</td>
<td>0.171460</td>
<td>0.1513</td>
</tr>
<tr>
<td>Distance to lakes</td>
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<td>0.0001</td>
<td>0.000162</td>
<td>-0.0004</td>
</tr>
<tr>
<td>Distance to Ponds</td>
<td>0.0002</td>
<td>0.0003</td>
<td>0.410190</td>
<td>0.0000</td>
</tr>
<tr>
<td>&gt; 80 acres/Unit</td>
<td>14.6800</td>
<td>472.0000</td>
<td>0.975180</td>
<td>14.8569</td>
</tr>
<tr>
<td>40-40 acres/Unit</td>
<td>13.9600</td>
<td>472.0000</td>
<td>0.976400</td>
<td>14.2160</td>
</tr>
<tr>
<td>20-40 acres/Unit</td>
<td>13.1600</td>
<td>472.0000</td>
<td>0.977760</td>
<td>14.0437</td>
</tr>
<tr>
<td>Distance to Edge</td>
<td>0.0004</td>
<td>0.0003</td>
<td>0.231250</td>
<td>0.0003</td>
</tr>
<tr>
<td>Private Ownership</td>
<td>-1.5020</td>
<td>0.2920</td>
<td>0.000000</td>
<td>-1.5974</td>
</tr>
</tbody>
</table>
Figure 1. Parturient elk occurrence patches when elk presence/absence was regressed against covariates including land ownership. Private land ownership was the strongest predictor of elk occurrence ($\beta = -1.6192$, $p = 1.69 \times 10^{-14}$). Note: nearly all occurrence patches lie within public, federally-owned lands (green).
Figure 2. High and low probability parturient elk occurrence patches. Note that the occurrence patches are in the same general location as the precise location, even with this added variability introduced by the error ellipses. There are no high-probability patches outside of Turnbull National Wildlife Refuge.
VITA

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