IDENTIFYING HOME RANGE, RELEASE SITE FIDELITY, AND RESOURCE SELECTION PATTERNS OF A REINTRODUCED ELK (*CERVUS CANADENSIS*) HERD: JACKSON COUNTY, WISCONSIN

By

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PREFACE

The chapters of this thesis were written and designed following the submission guidelines of the Journal of Wildlife Management, and therefore, strict adherence to the thesis submission guidelines was not followed and the duplication material and citations within each chapter was intentional.

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I would like to give thanks to all of the individuals and organizations that provided support and funding throughout the duration of this project. Without their time and dedication, this project would not have been possible. I want to personally thank my committee members for their time and all of the knowledge they passed on to me. Throughout this project, my graduate advisor, Dr. Tim Ginnett, provided an immense amount of support and guidance while helping me keep my expectations in line. Dr. Scott Hygnstrom provided support throughout this project, and the conversations we had forced me to be more critical of the reasoning behind the methodology's that I employed. Dr. Jason Riddle's knowledge of statistics and his ability to explain statistical concepts in a way that they are easily understood helped immensely. Dan Storm of the Wisconsin Department of Natural Resources aided in all aspect of this research, and his input on elk resource selection was particularly helpful.

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A BRIEF HISTORY OF ELK IN WISCONSIN

Prior to European colonization of North America, approximately 10 million elk (*Cervis canadensis*) ranged throughout significant portions of North America (Popp et al. 2014). One of six subspecies, the eastern elk (*C. c. canadensis*) once inhabited substantial portions of Appalachia and the Midwest and ranged throughout the majority of Wisconsin (Schorger 1954). As European settlement expanded west, unregulated hunting and conversion of suitable elk habitat for agricultural purposes quickly reduced, and ultimately extirpated local elk populations. Eastern elk populations were eliminated from the landscape by the 1920s, and overall elk populations in North America had dwindled to approximately 50 – 90 thousand animals in small herds scattered among the Rocky Mountain and Pacific Coast regions of the United States and Canada (Bryant and Maser 1982, O'Gara and Dundas 2002).

Historic records indicate that elk were present in 50 of 72 counties in Wisconsin (Schorger 1954). They likely were found throughout the state where suitable habitat was located, but were most abundant in the southern and western two-thirds of the state (O'Gara and Dundas 2002). The last recorded harvest of an elk in Wisconsin occurred in 1868, and they had likely been extirpated throughout Appalachia and the Midwest by the late 1800s (Schorger 1954, O'Gara and Dundas 2002).

The reintroduction of elk has been an important, popular, and successful management practice when restoring extirpated populations to their historical range (Roepke 2012). Attempts to reintroduce elk to the eastern United States began almost immediately following their extirpation. The first known reintroduction took place when 332 elk were released in the Adirondack Mountains of New York between 1893 and 1906, and reintroductions have been attempted in 16 states and the Canadian province of Ontario (O'Gara and Dundas 2002). Early reintroduction efforts often failed after only brief periods of time. Lack of planning, monitoring, and resources were often the root causes for failed reintroductions. Popp et al. (2014) notes that approximately 40% of recorded elk reintroduction attempts in eastern North America resulted in failure, with the majority of these having occurred in the first half of the 20th century.

Attempts to reintroduce elk in Wisconsin began in 1913 when an unknown number of elk from Yellowstone National Park were transported to an enclosure in the Trout Lake region of Wisconsin, and when 32 more elk were brought to the enclosure in 1917 (Schorger 1954). In 1932, the 15 elk remaining in the enclosure were released. The herd did not persist beyond the mid-1950s (Schorger 1954).

In 1989, the Wisconsin Department of Natural Resources (WDNR) began assessing the feasibility of reintroducing elk, moose (*Alces alces*), and caribou (*Rangifer tarandus*) to Wisconsin. It was determined that elk were the only viable species for reintroduction, however, in 1991 WDNR chose not to pursue a reintroduction due to insufficient acreage, lack of funding, and public opposition (Parker 1990, Roepke 2012).

In response, to continue exploring the feasibility of restoring elk to Wisconsin, a citizen-based group formed the Wisconsin Elk Study Committee (WESCO) who identified the Great Divide District (GDD) of the Chequamegon-Nicolet National Forest (CNNF) as a potential release site (Roepke 2012). This site was chosen because it contained adequate habitat for elk, and a lack of agricultural practices in the area. In collaboration with WESCO, the University of Wisconsin – Stevens Point (UWSP) was given permission by CNNF, in 1994, to proceed with a study determining the feasibility of reintroducing elk to Wisconsin (Roepke 2012).

In 1995, 25 elk from the Pigeon River State Forest in northern Michigan were acquired to initiate the reintroduction of elk to Wisconsin. The animals spent two weeks in an acclimatization pen and were released in the CNNF near Clam Lake, WI. In May 1999, the reintroduction study was considered a success, and the responsibility of managing the herd was transferred to WDNR. By May 2011, the estimated population of the Clam Lake elk herd (CLEH) was 151, representing an average annual growth rate of 12.5% (Roepke 2012).

Following the reintroduction of the CLEH, a group of local Jackson County enthusiasts garnered community interest in restoring another elk herd. Three public forums were held to see if support existed within the region, and from these forums, the predominant public feelings were positive (WDNR 2001). In December of 2001, the WDNR Natural Resources Board (NRB) approved the Black River Elk Herd (BREH) Management Plan (WDNR 2015). The WDNR designated range for the BREH encompasses approximately 320 mi^2. Located in the Central Forest region of eastern Jackson County, the BREH range is almost entirely publicly owned, consisting primarily of land managed by Black River State Forest (BRSF) and Jackson County Department of Forest & Parks (JCDFP). Gilbert et al. (2010) developed a GIS-based elk habitat suitability model for the state of Wisconsin with the goal of identifying areas potentially suitable for elk reintroduction. Suitable habitat was classified as having sufficient forest cover (both deciduous and coniferous) with little to no agriculture, low road density, and large tracts of public land. One of the locations identified by the model was eastern Jackson county. This provided further support for establishing the BREH.

In December 2014, WDNR and the Kentucky Department of Fish & Wildlife Resources (KDFWR) finalized a 5-year agreement that will potentially provide Wisconsin with 150 wild elk. The agreement allows for the implementation of the BREH, and supplementation to the CLEH. In January 2015, elk were captured in eastern Kentucky for the BREH reintroduction. Following a quarantine period in Kentucky, 26 elk were transported to a holding facility in BRSF in eastern Jackson county. A second quarantine period was enacted. During that time, 5 elk succumbed to a tick born parasite, babesiosis (*Babesia spp.*), one from complications associated with birthing, and one that initially tested positive for tuberculosis had to be euthanized for additional health testing. Four calves were born in the holding facility and 23 elk (9 bulls, 10 cows, and 4 calves) were released into BRSF on August 20, 2015. Following the same capture and quarantine procedures, 39 elk were transported to BRSF in early spring 2017. Eleven calves were born in the holding facility during the second quarantine period. Subsequently, 50 elk (8 bulls, 31 cows, and 11 calves) were released into BRSF on July 11, 2016. In early 2017, 28 Kentucky elk were captured to supplement the Clam lake herd. They were transported to a holding facility in the Flambeau River State Forest in Sawyer County, Wisconsin.

Adult elk have been fitted with GPS collars that possess satellite uplink capabilities, as well as a very high frequency (VHF) radio transmitter. This gives WDNR and UWSP researchers the ability to remotely monitor the elk and download spatial data, as well as terrestrially monitor animals with standard radio telemetry methods. This is critical when it comes to identifying cause specific mortality of individuals, and to mitigate issues that may arise if elk begin to cause conflict with human interests.

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IDENTIFYING HOME RANGE AND RELEASE SITE FIDELITY PATTERNS OF A REINTRODUCED ELK HERD: JACKSON COUNTY, WISCONSIN

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ABSTRACT

One of 6 subspecies of elk (*Cervus canadensis*), the eastern elk (*C. c. canadensis*), once ranged throughout the majority of Wisconsin, but local elk populations were extirpated by the late 1800s. The reintroduction of elk has been an important tool in restoring extirpated populations to their historical range, and we studied the post-release movements of elk reintroduced to Wisconsin from 2015-2017. Elk were captured near Stoney Fork, Kentucky and transported to Jackson County, Wisconsin. Adult elk were fitted with GPS collars to collect spatial data. Our objective was to identify elk resource home range and release site fidelity patterns for one year post-release. Twenty-three elk were released on August 20, 2015, and 50 elk were released on July 11, 2016. To assess release site fidelity, maximum distances traveled were determined for multiple time periods post-release, and data analysis regarding home range size was conducted using time scaled local convex hull. Maximum distance traveled from the release site was stable between days 1 – 90 post-release but increased substantially between days 91 -365. Adult elk traveled further distances from the release site than yearlings, and maternal females remained closer to the release site compared to males and females without calves. Home range sizes decreased days 1 – 90 post-release but increased between days 91 -365. The effect of age on elk home range sizes was minimal between adults and yearlings. Maternal females and

females without offspring had similar range sizes, whereas male home range size was larger than females. Elk initially departed the release site making exploratory movements, and then established home ranges while including previously used habitat. For ungulate reintroductions to be successful, release site fidelity is critical for maintaining initial herd growth, continued reproductive success, and mitigating human-wildlife conflict. Future reintroduction efforts should encourage elk to remain near the release site.

INTRODUCTION

Prior to European colonization of North America, approximately 10 million elk (*Cervis canadensis*) ranged throughout significant portions of North America (Popp et al. 2014). One of six subspecies, the eastern elk (*C. c. canadensis*) once inhabited substantial portions of Appalachia and the Midwest and ranged throughout the majority of Wisconsin (Schorger 1954). As European settlement expanded into Wisconsin, unregulated hunting and conversion of suitable elk habitat to agricultural purposes quickly reduced and extirpated local elk populations. Historic records indicate that elk were present in 50 of 72 counties in Wisconsin (Schorger 1954). The last recorded harvest of an elk in Wisconsin occurred in 1868, and they had likely been extirpated throughout Appalachia and the Midwest by the late 1800s (Schorger 1954; O'Gara and Dundas 2002).

The reintroduction of elk has been an important, popular, and successful management practice, restoring extirpated populations to their historical range (Roepke 2012). Although animal reintroductions have been commonplace in the United States since the turn of the 20th century, early reintroduction projects often failed (O'Gara and Dundas 2002; Bleisch et al. 2017). Lack of planning, little or no monitoring, poaching, small founding populations, and lack of resources were common reasons for failed reintroductions, and approximately 40% of recorded elk reintroduction attempts in eastern North America resulted in failure Popp et al. (2014).

As elk reintroductions to eastern North America become more prevalent, site-specific studies regarding initial movements are needed to maximize success (Bleisch et al. 2017). Elk reintroduction programs have seen renewed interest since the early 1990's, and 19 eastern states and the province of Ontario, Canada have implemented elk restoration efforts (O'Gara and Dundas 2002, Bleisch et al. 2017). Of those 20, 7 have released elk in the past 20 years; Kentucky, Missouri, North Carolina, Ontario, Tennessee, Virginia, and Wisconsin (Bleisch et al. 2017).

When reintroducing or trans-locating any ungulate species, many variables influence the success of an effort. Adverse effects of capture and transportation related stress must be considered during any reintroduction (Teixeira et al. 2007), and translocation-induced chronic stress increases the overall vulnerability of individuals (Dickens et al. 2010). Post-release challenges include conflicts with humans, risk of predation, inclement weather conditions, habitat and food shortages, disease, and parasitic infections (Samuel et al. 1992; Frair et al. 2007; Seddon et al. 2007; Bleisch et al. 2017), all of which can influence habitat use, dispersal, and reproductive success. These challenges, potential lack of available animals, and the high cost of reintroduction programs calls for a complete understanding of factors contributing to restoration success (Bleisch et al. 2017).

Understanding post-release movements of elk is crucial in enabling resource managers to optimize protocols for initial population growth, delineate areas with appropriate habitat requirements, mitigate human disturbance, and to reduce elk-human conflict (Larkin et al. 2004; Rosatte et al. 2007; Ryckman et al. 2010; Bleisch et al. 2017). Elk and other large mammals often leave release sites quickly and can make extensive movements *(*Armstrong & Seddon 2008; Yott et al., 2011; Ewen 2012; Le Gouar et al. 2012; Bleisch et al. 2017). Animals that disperse long distances often experience high mortality rates, higher risk of predation and lower reproductive success (Le Gouar et al. 2012; Scillitani et al., 2013; McIntosh et al. 2014). Reintroduced populations also must maintain densities that minimize inbreeding, maintain resiliency against stochastic events, and prevent temporary Allee effects (Larkin et al., 2002; Armstrong & Seddon 2008; Groombridge et al. 2012; Popp et al. 2014; Bleisch et al. 2017). Adult survival is crucial to the long-term population growth, and large mammal restorations should be developed to encourage animals to remain near the release site (Bleisch et al. 2017).

Age, sex, and reproductive status can all affect post-release movements. Sex and age bias tend to influence range and dispersal distances in mammalian reintroductions, with males usually dispersing farther than females (Ryckman et al. 2010; Bleisch et al. 2017), and older individuals typically dispersing farther than younger animals (Larkin et al. 2004; Ryckman et al. 2010; Le Gouar et al. 2012). Females with offspring may further restrict movements compared to those without, which may be especially true for elk post-parturition as they conceal their young (Bleisch et al. 2017).

We studied the post-release movements of elk reintroduced to Wisconsin from 2015-2017. Our objectives were to estimate home range (HR) sizes and identify release site fidelity patterns.

Elk were released into suitable habitat surrounding the release site, and the Wisconsin Department of Natural Resources (WDNR) planted a food plot adjacent to the quarantine facility to encourage elk to remain in the area. A soft release was used due to the quarantine requirement which allowed elk to form social bonds and acclimate to a new environment after transport.

Therefore, we expected release site fidelity to vary by sex, age, time post-release, and release year, but to remain high overall. We hypothesized that HR sizes would be highest immediately post-release and decrease over time, also varying by sex, age, time post-release, and release year (Larkin et al. 2004, Ryckman et al. 2010, Bleisch et al. 2017).

METHODS

Study Area

Using the habitat suitability model developed by Gilbert et al. (2010), the WDNR, identified our study area as having the potential to support a population of elk (Figure 1.). The core study area is located on Black River State Forest (BRSF) properties, surrounded by a large quantity of land managed by Jackson County Department of Parks and Forestry (JCDPF). The study area is centered approximately 19 km east of Black River Falls, WI which is located in the Central Sand Plains ecological zone. The mean annual temperature of the study area is 6.5°C, and mean annual precipitation and snowfall are 83.3 cm and 114.3 cm respectively (WDNR 2014). The mean growing season is 135 days, which is almost 19 days less than other southern Wisconsin ecological landscapes (WDNR 2014). Elevations lie primarily between 259 and 275 m, with a range of 220 to 429 m. The geology is characterized by lacustrine and outwash sand that originated from a large glacial lake that once covered the Central Sand Plains region (WDNR 2014). The vegetation mosaic consists primarily of pine (*Pinus spp.*), oak (*Quercus spp*.), and aspen (*Populus spp.*) forest, with intermittent plantations of red pine (*Pinus resinosa*). Hydrology is characterized by large areas of wetlands and a number of generally low-gradient streams. On wet sites the forests are of two major types: tamarack and black spruce in the peatlands, and bottomland hardwoods in the floodplains of the larger rivers (WDNR 2014).

Agriculture is limited, but it is one of the top cranberry producing regions of Wisconsin and multiple cranberry farms are present east and southeast of the study area.

Elk Trapping and Translocation

In December 2014, WDNR and the Kentucky Department of Fish & Wildlife Resources (KDFWR) finalized a 5-year agreement to provide Wisconsin with up to 150 wild elk. Beginning in January 2015, elk were captured near Stoney Fork, Kentucky using baited corral traps. The corral traps consisted of 3 m tall panels covered with black cloth to reduce the risk of elk injuring themselves, and to limit their visibility when being corralled into trailers for transportation to the quarantine facility. Upon arrival at the quarantine facility, the age and weight of each the individual was recorded, and the animal received 2 numbered ear tags for identification purposes.

As required by the United States Department of Agriculture (USDA) and the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP), a quarantine period was established to reduce the risk of interstate disease transmission. Captured elk were transported to a holding facility and the official quarantine began the day after the last elk was added to the confined cohort. After 30 days of quarantine in Kentucky, the elk were tested for tuberculosis (TB) and brucellosis. At day 45 of quarantine, the elk were transported using commercial stock trailers to a 2.85 ha holding facility in Jackson County, WI to complete the quarantine. Rotating staff from WDNR, JCDPF, University of Wisconsin – Stevens Point (UWSP), and the Ho-Chunk Nation provided security at the facility, provided food and water, and monitored the health of the elk daily. At the end of the quarantine period, a final series of health tests were performed, and the elk were fitted with PIT tags and GPS collars.

In 2015, 26 elk were transported to a holding facility in BRSF. They were held during the second phase of the quarantine period for 146 days. During that time, 5 elk succumbed to babesiosis (*Babesia spp.*), a tick born parasite. One adult female died from complications associated with birthing, and 1 adult male that initially tested positive for TB had to be euthanized for additional health testing. Four calves were born in the holding facility during the quarantine, and subsequently fit with PIT tags and expandable VHF radio collars (Advance Telemetry Systems, Insanti, MN) to monitor for mortalities. Elk (*n*=23, 2 adult males, 6 yearling males, 5 adult females, 6 yearling females, and 4 calves) were released on August 20, 2015.

Using the same capture and quarantine procedures, 39 elk were captured in 2016. During the quarantine, they were held in Kentucky for 45 days and for 112 days in Wisconsin. The elk were held until all known pregnant females had given birth, allowing WDNR biologists to fit newborn calves with PIT tags and VHF radio collars. Elk (*n*=50, 4 adult males, 4 yearling males, 9 yearling females, 22 adult females, and 11 calves) were released on July 11, 2016.

Elk Monitoring and Spatial Data Collection

To monitor adult elk movements, we fitted each individual (*n*=58) with a GPS collar manufactured by Vectronic Aerospace (Berlin, Germany). To estimate GPS accuracy, multiple collars were left in stationary locations, both under canopy and in the open. We used the 2 distance root mean squared (2 DRMS) method to estimate GPS accuracy (NRC 1995). Mean GPS accuracy was 8.39 m (12.96 m under canopy and 3.82 m in the open). The collars possessed satellite uplink capabilities allowing for remote monitoring and real-time data collection. Notifications were emailed to researchers in the event of a mortality. The collars also utilize VHF transmitters to aid in monitoring elk in the field and locating mortalities. All elk from the 2015 cohort (*n*=19), and most elk from the 2016 cohort (*n*=35), received collars programmed to record GPS coordinates in 13-hour intervals. Yearling males (*n*=4) of the 2016 cohort were fitted with collars that recorded locations on an hourly basis. We filtered data from those collars to be consistant with the data from the collars with 13 hour fix rates.

Analytical Methods

Elk movements patterns were characterized for 1-year post-release for both release years. Release dates differed by 7 weeks in the respective years, and to evaluate the effect of release on elk movements, time periods established were based on days post-release instead of biological seasons. Due to relatively low temporal resolution for GPS locations, a maximum of 2 per day, time frames were established to allow for enough data collection to properly estimate HR size and utilization distributions (UD). We evaluated responses for each surviving elk at 1-30 days, 31-60 days, 61-90 days, 91-180 days, and 181-365 days post-release.

To assess release site fidelity, we determined maximum distances traveled for each time period, for each individual elk using the Near tool in ArcGIS 10.5.1 (ESRI 2017). We summarized and formatted data for analysis using the ddply function of the plyr package in R Studio (Wickham 2011; RStudio Team 2016).

We conducted analysis regarding HR size and UD using time scaled local convex hull (t-locoh) using the t-locoh package in R studio (Lyons et al. 2013; RStudio Team 2016). T-locoh is derived from the local convex hull method (locoh) (Getz and Wilmers 2004), that uses a set of nearest neighbors for each point to construct local minimum convex polygons (MCP) and incorporates the time stamp of each point in nearest neighbor selection and sorting of hulls during UD construction (Lyons et al. 2013). Nearest neighbor selection is based upon a distance metric known as time-scaled distance (TSD), which transforms the time interval between any 2 points into a third axis of Euclidean space (Lyons et al. 2013).

T-locoh requires the researcher to define the parameters for the nearest neighbor selection and TSD. Three methods for nearest neighbor selection are available for use with locoh methods. The k-method selects the k^{th} nearest neighbors around each point, the r-method includes all points within a fixed radius (r), while the adaptive a-method selects all points whose cumulative distance to the parent point is less than or equal to (a) (Lyons et al. 2013). The time and space components of TSD are weighted by defining parameter (s), which specifies the maximum amount of time at which spatially neighboring, but not necessarily sequential, GPS fixes are still considered to be temporally correlated to the parent point and considered to be a nearest neighbor (Lyons et al. 2013; Stark et al. 2017). As values of (s) increase, time becomes more influential in defining the degree of correlation between the spatial distance and the length of time between fixes (Dürr and Ward 2014; Stark et al. 2017). When “s” equals 0, time is not considered in the analyzes (Lyons et al. 2013).

Prior to analyses, we removed locations recorded as false mortalities to avoid bias using the method described by Lyons (2014). The a-method was used for nearest neighbor selection, as it is better suited for studies where both, high and low point densities of GPS locations can be expected (Getz and Wilmers 2004; Schweiger et al. 2015). To make comparisons between the animals possible, for each time period, data from each individual were examined to determine the cumulative distance that stabilized the isopleths’ edge to area ratio before creating a jump in the isopleths’ area, thus balancing type I (including area that is not used) and type II errors (omitting area that is used) (Lyons et al. 2013; Dürr and Ward 2014; Lyons 2014; Schweiger et al. 2015) That distance was recorded for each animal and the mean value was used for the “a” parameter for all individuals. Lyons (2014) recommends values of “s” be set so 40-80% of hulls are time selected. Analogous to the study by Stark et al. (2017), values of “s” equal 50% were used, so both the spatial and temporal data were being considered relatively equal in the analysis.

Fifteen candidate models (Table 1) were developed representing different hypotheses regarding post-release elk movement patterns using the covariates time (post-release), sex, age, and release year (Bleisch et al. 2017). To account for variation between maternal cows, and cow without calves, we had 3 levels for the sex covariate (Male, Female, and Maternal Female).

We used repeated measures, mixed-effects models for each movement response using the lmer function in the lme4 package in R Studio (Bates et al. 2015). We used Akaike’s Information Criterion corrected for small sample sizes (AIC_C) to evaluate support for each model (Burnham and Anderson 2002, Bleisch 2017). Candidate models were fit using maximum likelihood methods to achieve AIC_C values and models with at least one-eighth support relative to the top model were included in the confidence set for each response (Bonnot et al. 2011, Bleisch 2017). Models were refit using restricted maximum likelihood to achieve unbiased estimates and standard errors, and models with at least one-eighth support relative to the top model were then model averaged using the maximum likelihood Akaike weights (Bonnot et al. 2011, Bleisch 2017). Unconditional variance estimates were used to determine confidence intervals (Burnham and Anderson 2002, Bleisch 2017)

RESULTS

For the 23 animals of the 2015 release, 4 GPS collars were lost due to malfunction (1 adult male, 3 yearling males). Eight elk were lost to mortality. Four were killed by wolves (1 yearling male, 1 yearling female, and 2 adult females), 2 adult females were killed by vehicle collisions, 1 yearling female died of unknown causes, and 1 yearling female died of a meningeal worm infection (*Parelaphostrongylus tenuis*).

For the 50 animals of the 2016 release, 1 collar on an adult female was lost due to malfunction, and 8 were lost due to mortality. Mortalities included 1 adult male, 1 adult female and 2 yearling females killed by wolves, 2 yearling females died from meningeal worm, 1 yearling female died from a vehicle collision, and 1 adult female died from a bacterial infection.

For any time-period where an individual elk survived the duration, data were included in the analyses. For animals that died, or that had collar malfunctions, data were censored so that incomplete time periods were not considered in the analyses. Collar failures on 2 adult males and the mortality of 2 adult females occurred less than 30 days post-release in 2015, and 1 adult female died less than 30 days post-release in 2016. Therefore, they were censored from the analyses. After filtering and censoring the GPS data, we used 24,911 locations from 53 elk for the analyses (2015 n = 5,235; 2016 n = 19,676).

Initial Elk Movements

Elk from both release years showed differing patterns of movement behaviors following release. As a group, in 2015, all the elk made exploratory movements immediately following the release, with the exception 1 maternal female who remained at the release site. Over the course of 12 days, the group tracked a clockwise course, leaving and returning to the release site. After 3 days, they were located approximately 7.4 km southeast of the release site, and spent days 4-9 approximately 5.2 km south of the release site. On day 10 they moved to within 2.9 km southwest of the release site, and by day 12, all elk were within 0.5 km of the release site. At day 30, all elk were within 1 km of the release site, with the exception of 3 (2 adult females 5.85 km southwest, and 1 yearling female 6.85 km southeast).

After the 2016 release, one adult male and 1 adult female had travelled together 8.8 km south, and 1 adult female had travelled 8.3 km northeast of the release site where they remained through the first 30 days. One adult female travelled 13.6 km northwest of the release site, on day 13. On day 15 she moved approximately 16.5 km east, where she remained through day 30. The remaining elk were located within 1 km of the release site, two weeks post-release. Between days 17 – 20, several groups of elk began dispersing. At day 20, the 4 yearling males were grouped together 1.9 km southeast of the release site, and a group of 23 elk (1 adult male, 8 yearling females, and 14 adult females) had dispersed 3.7 km in the same direction. By day 30, 2 adult males and 2adult females were located within 1 km of the release site, and 2 adult females dispersed individually approximately 16 km from the release site (1 northwest, and 1 south). Aside for the aforementioned individuals, the remaining elk were loosely grouped 5 – 6 km southwest to southeast of the release site.

At the time of the 2016 release, most elk from the 2015 cohort had localized their movements to an area approximately 10.5km south-southeast of the release site. Although many elk of the 2016 cohort made exploratory movements in the first 30 days post-release, the 2 cohorts remained isolated from each other. Approximately 120 days post-release, 6 members of the 2016 cohort located and began interacting with the 2015 cohort. Those animals formed the basis of the largest group of elk observed throughout the remainder of the study.

Release Site Fidelity

Maximum distance traveled from the release site was stable over the first 3 time- periods, but increased substantially over the last 2 time-periods. Between days 1-90, mean maximum distance traveled of all elk was 10.055 km (2015 = 9.21 km, 2016 = 10.9 km; Figure 2). Between days 91-180, mean maximum distance traveled doubled to 20.135 km (2015 = 19.29 km; 2016 = 20.98 km). Mean maximum distance increased approximately 36% between time periods 90-180 and 181-365 to 27.45 km (2015 = 26.57 km; 2016 = 28.26).

The age effect on maximum displacement show that adult elk traveled further distances from the release site than yearlings (Figure 3). Model averaging predicted that adult elk would be 3.57 km farther than yearlings for any of the 5 time-periods.

Maternal females remained closer to the release site compared to males and females without calves, but females without calves travelled farther distances from the release site than males (Figure 4). Model averaging indicated that for any time-period, females without calves were predicted to be 1.89 km and 3.01 km, farther from the release site than males and maternal females respectively.

Home Range

Home range size decreased over the first 3 time-periods, but increased substantially over the last 2 time-periods. Mean home range size for all elk 30 days post-release was 438.9 ha (Figure 5). Between days 31-90, mean home range sizes decreased 156% to 170.9 ha. Mean home range sizes were 296.6 ha between days 1-90, but between days 91-180, mean home range sizes increased approximately 230% to 986.1 ha. Home range sizes continued to increase thorough days 181-365 to 1275.8 ha, a 29% increase from range sizes between days 91-180.

The effect of age on elk home range sizes was minimal between adults and yearlings (Figure 6). In each of the 5 time-periods, adult elk had home range sizes only 9.3 ha larger than yearlings.

Maternal females and females without offspring had similar range sizes, with only a 7.4 ha difference between the 2 classes for any time-period. Male home range size was 129.4 ha larger than females without calves and 136.8 ha larger than maternal females (Figure 7).

DISCUSSION

Our results indicated that there were only minor differences in maximum distance traveled and home range sizes between the 2015 and 2016 cohorts. The amount of time post-release and age had the most influence on the release site fidelity, while time post-release and sex mostly influenced elk home range sizes. Site fidelity remained high over the first 90 days, but decreased during the remainder of the study duration. We expected home range sizes to be highest immediately post-release and to decrease over time. This was the trend between days 1-90 post-release, but home range sizes increased substantially 91-365 days post-release. In ungulate reintroductions, older animals often travel farther than younger animals (Larkin et al. 2004; Ryckman et al. 2010; Le Gouar et al. 2012). In our study, yearling elk were more likely to be located near the release site than adults, and Bliesch et al. (2017) reported that elk reintroduced to Missouri exhibited a similar response. Male elk typically have larger home ranges than females (Ryckman et al. 2010; Bleisch et al. 2017). Elk in our study were no different, and only slight differences in home range sizes were observed between maternal and non-maternal females. Maternal females were most likely to remain near the release site, and our results support those found by Bliesch et al. (2017) who reported that maternal elk are likely to remain near the release site after release, as the calves they are supporting are less mobile and cannot make extensive movements. Non-maternal females travelled farther from the release site than males. This is likely due to several individual adult females that made extensive movements, and the fact that most of the males were yearlings that remained with the main herd.

Following a similar pattern found in elk reintroduced to Missouri (Bliesch et al. 2017), Wisconsin elk exhibited a multiphasic movement strategy post-release. Elk initially departed the release site making exploratory movements, and then established home ranges while including previously used habitat. Most elk made short exploratory movements, but returned to the release site within 45 days post-release where they used the food plot planted by the WDNR. Elk released in 2015 immediately left the release site, but after 12 days post-release, all elk were within 0.5 km of the release site. Bliesch et al. (2017) reported similar result, noting that elk released in Missouri were transient for 10 days before settling into a home range phase. Elk released in 2016 showed a similar pattern to the 2015 cohort, but less temporally constrained. Elk began dispersing approximately 18 days post-release in 2016. By day 30, only 4 elk remained within one km of the release site. Between days 31-90, most elk had returned to the release site to used the food-plot, but even the ones that did not were localizing their movements to areas with preferred resources. As elk were dispersing between days 18 - 30, trail cameras located near the release site indicated increased wolf activity (Roepke 2016). Elk likely dispersed in response to the disturbance, but many returned to the release site as wolf activity decreased. Home range sizes reflected these movement patterns, averaging 438.9 ha 30 days post-release. Between days 31-90 they decreased 156% to 170.9 ha. Fall transitioned into winter 90 – 180 days post-release, and most elk began leaving the release site in search of suitable wintering habitat that the food-plot and the surrounding area could not provide. Maximum distance travelled increased approximately 200%, and home ranges sizes increased 230%. The 181 - 365 day time period covered late winter through mid-summer. During this time frame, maximum distance travelled, and home range slightly increased compared to the previous period. Elk remained in established winter ranges during the first half of the 181 - 365 day time period, and began leaving their winter range between days 250 – 300 as winter gave way to spring. The majority of elk movements during the 181 - 365 day time period occurred during the last 75 days. Males began making more exploratory movements, while females were searching for calving areas.

One year post-release, 9 Black River elk had made excursions ≥ 25 km from the release site, with 3 traveling ≥ 60 km, and 1 traveling as far as 172 km. Black River elk will likely shift their ranges, and may disperse farther distances from the release site. Yott et al. (2011) reported that of elk released in eastern Ontario, Canada, a year and a half post-release, only 16% of the elk were located within 10 km of the release site, 27% within 20 km, whereas 37% were >40 km away. Haydon et al. (2008) and Bliesch et al. (2017) reported that reintroduced elk often travel farther when solitary, and our study showed comparable results. Adult females and their calves form the most constant part of elk herds (Franklin et al. 1975), and they are structured by dominant cows (Millspaugh et al. 2004 and Bliesh et al. 2017). Franklin et al. (1975) reported that yearling females and 2 year-old females associated most strongly with the cow/calf herds, but observed too few encounters between cows 3 years and older to determine whether an absolute or partial dominance hierarchy existed. The quarantine period allowed elk to form social bonds and establish a dominance hierarchy prior to release. The 3 individuals that travelled more than 60 km from the release site were adult females, ≥ 3 years old, without offspring. They dispersed earlier than most other elk, and it is likely that they were subordinate to the dominant females and rejected from the main herds that coalesced upon release.

Limiting factors to this study were the lack of temporal resolution between GPS fixes, and the reduced ability of GPS collars to acquire satellites and record GPS locations as canopy cover increased. The combination of these factors led to gaps in GPS location data. In one instance, 3.5 days elapsed between GPS fixes for 1 of the collars. Interstate 94 is a significant barrier to elk movements, and the t-locoh home range method was used because it is particularly robust to variations in sampling intensity, detecting barriers, and accounts for both spatial and temporal autocorrelation of GPS data (Schweiger et al. 2015; Stark et al. 2017). T-locoh does not estimate home range sizes outside of known locations and likely underestimates true home range size. This method may not be suitable for other home range studies (Stark et al. 2017), and in locations where movement barriers are less frequent, probability-based home range estimators such as kernel density estimators (Worton 1989, Seaman and Powell 1996, and Kie 2013), Brownian bridge movement models (Horne et al. 2007 and Kranstauber et al. 2012), and biased random bridge models (Benhamou 2011) likely provide more accurate home range estimates.

Only minor differences were observed regarding elk release site fidelity and home range size between the 2015 and 2016 cohorts. Overall, site fidelity was high, and home range sizes were small, 90 days post-release. This is most likely due to the soft release required for the quarantine, and the availability of a high-quality food source immediately upon release. Throughout the remainder of the study period maximum distance travelled increased, and home range sizes reflected that trend. Adult elk were more likely to travel farther than yearlings, but home range sizes were nearly equal between the age classes. Maternal females were most likely to remain near the release site, and non-maternal females travelled farther from the release site than both males and maternal females.

Most GPS collars used in this study can collect data on elk locations for up to 4 years, and further research should be conducted to identify range shifts and dispersal patterns of the Black River elk herd beyond the scope of our study. All but four of the collars were programmed to record GPS locations in 13-hour time intervals. This allows for longer battery life, but sacrifices temporal resolution. When summer canopy is at its maximum, the ability of the GPS collars to acquire satellites was reduced. This often led to missing a GPS fix. When the

GPS failed to record a location, a minimum of 13 hours elapsed before another fix was attempted. Elk can make extensive movements in 26 hours, and large gaps between successful GPS fixes reduces the accuracy of home range estimates and may not record the true maximum distance from the release site. Future reintroductions should use the highest fix rate possible, while ensuring enough battery life to sustain the collars for the duration of the study period. Using a GPS fix rate of 3 – 8 hours will increase temporal resolution and the accuracy of home range estimates, and when a GPS collar fails to record a location, the length of time between successful fixes is reduced.

MANAGEMENT IMPLICATIONS

For ungulate reintroductions to be successful, release site fidelity is critical for maintaining initial herd growth, continued reproductive success, and mitigating human-wildlife conflict. Future reintroduction efforts should be made to encourage elk to remain near the release site. The food-plot planted by WDNR at the release site was heavily used by most elk up to 90 days post-release. It enabled them to make exploratory movements, while providing a known source of high quality forage, and was key in encouraging release site fidelity immediately post-release. Elk often seek edge habitats (Larkin et al. 2004), and managers can expect elk to seek open lands when reintroducing them in heavily forested environments (Bliesch et al. 2017). Releasing elk where a patchwork of open habitat is interspersed within a forested environment can encourage release site fidelity among elk. Bliesch et al. (2017) released elk from multiple release sites and the reported less transience in animals from the site where higher edge densities and well managed open spaces were more abundant. Elk often seek conspecifics following reintroduction (Ryckman et al. 2010), and observations by (Bliesch et al. 2017) indicated that release site fidelity was higher when other elk were on the landscape prior to releasing secondary cohorts.

When planning an elk reintroduction, we recommend prudent selection of the release site, using a soft release, grouping elk so typical social bonds can be formed, planting food plots near the release site, releasing elk near conspecifics if possible, recognizing the potential of elk exhibiting multiphasic movement patterns, and understand that some solitary individuals may travel extreme distances from the release site.

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FIGURES

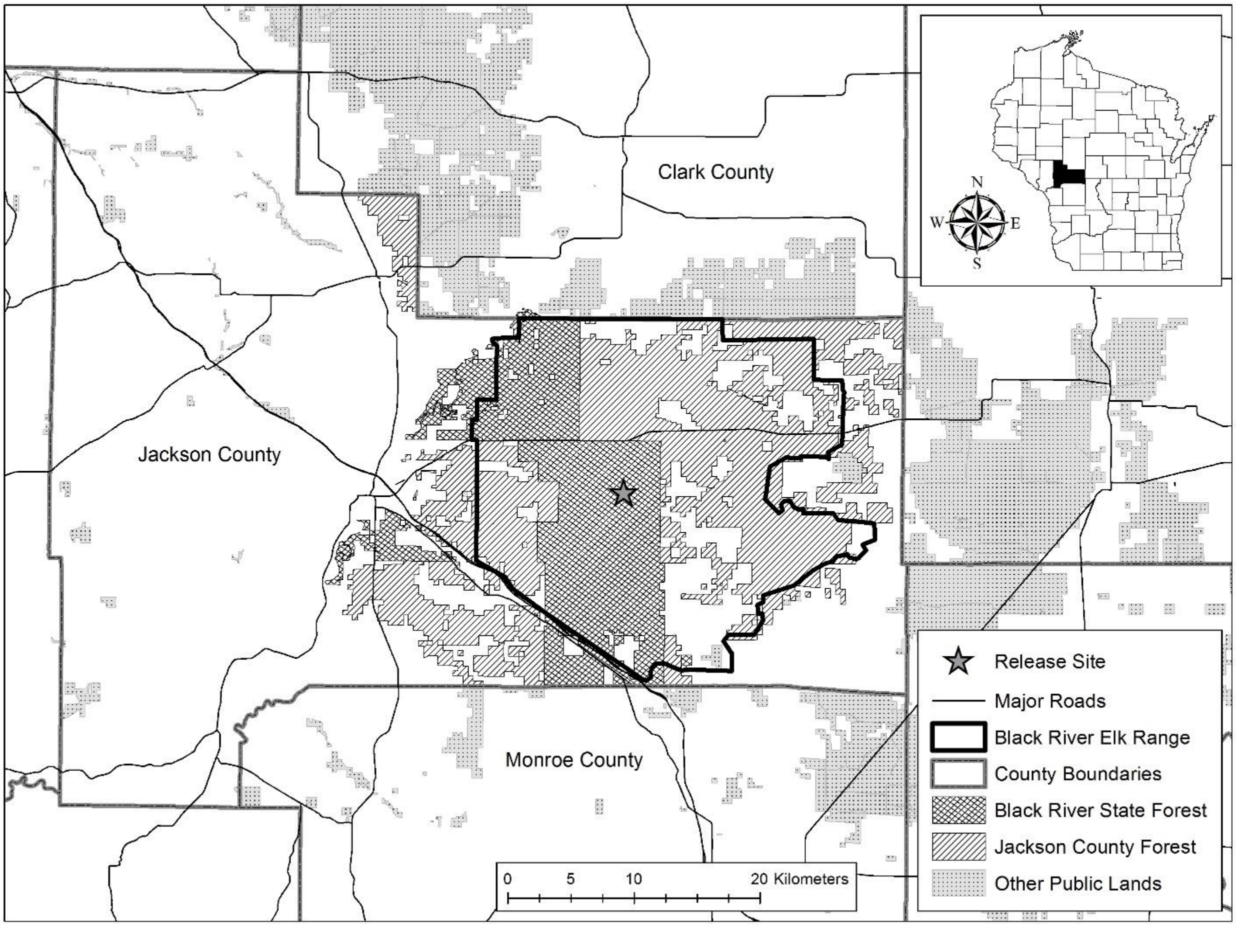

Figure 1. Black River Elk herd study area in Jackson County, WI. Primary elk range consists mostly of lands managed by Black River State Forest and Jackson County Department of Parks & Forestry. Other public lands are present in adjacent counties.

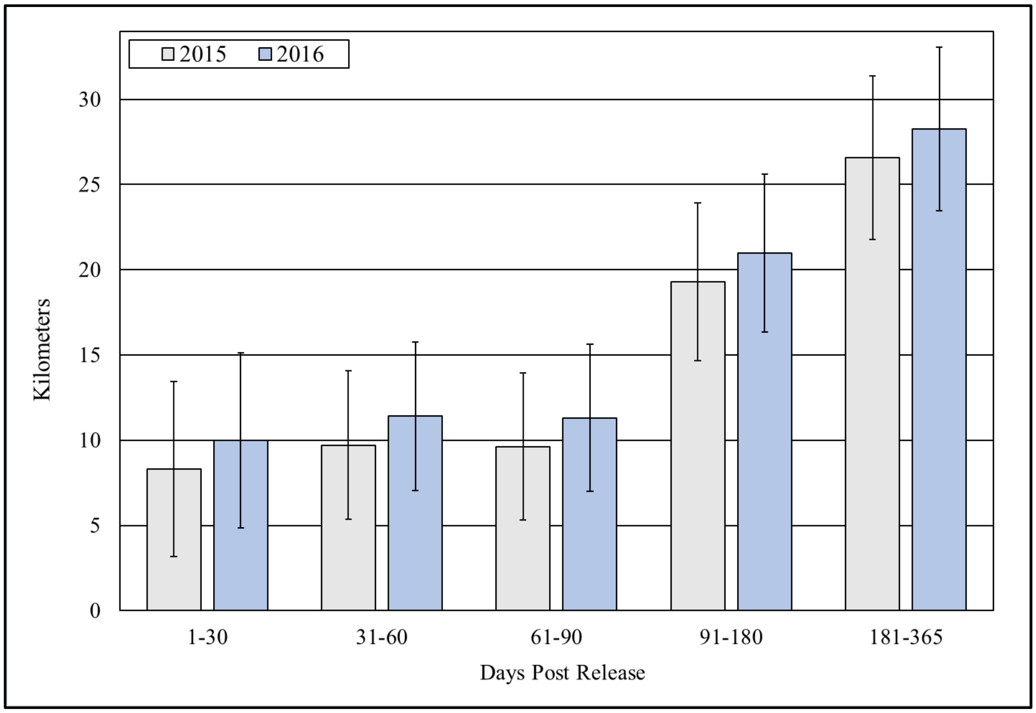

Figure 2. Model-averaged estimates for the release year effect on maximum displacement from the release site for elk reintroduced to Jackson County in 2015 and 2016. Error bars equal 95% confidence interval.

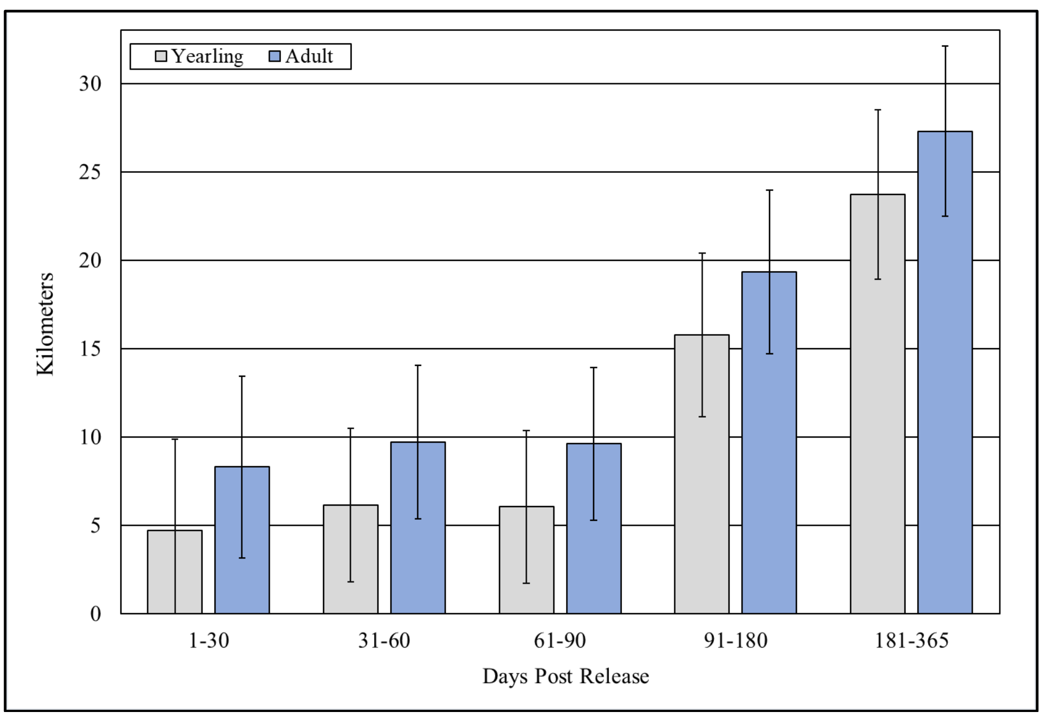

Figure 3. Model-averaged estimates for the age effect on maximum displacement from the release site for elk reintroduced to Jackson County in 2015 and 2016. Error bars equal 95% CI.

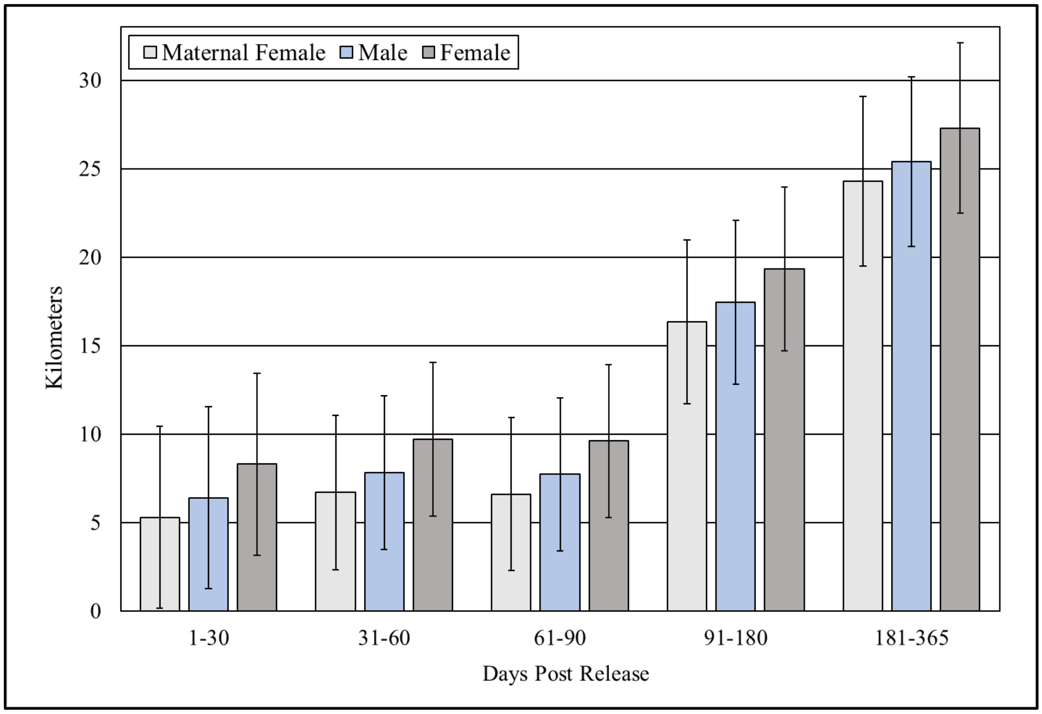

Figure 4. Model-averaged estimates for the sex effect on maximum displacement from the release site for elk reintroduced to Jackson County in 2015 and 2016. Error bars equal 95% CI.

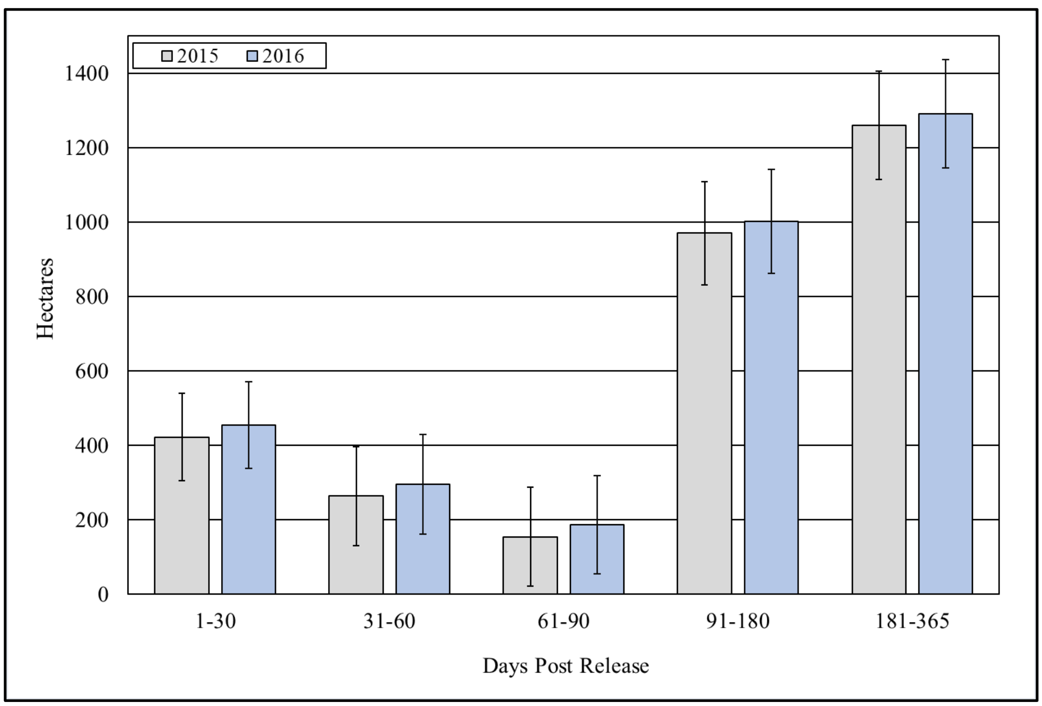

Figure 5. Model-averaged estimates of home range size by release year for elk reintroduced to Jackson County in 2015 and 2016. Error bars equal 95% CI.

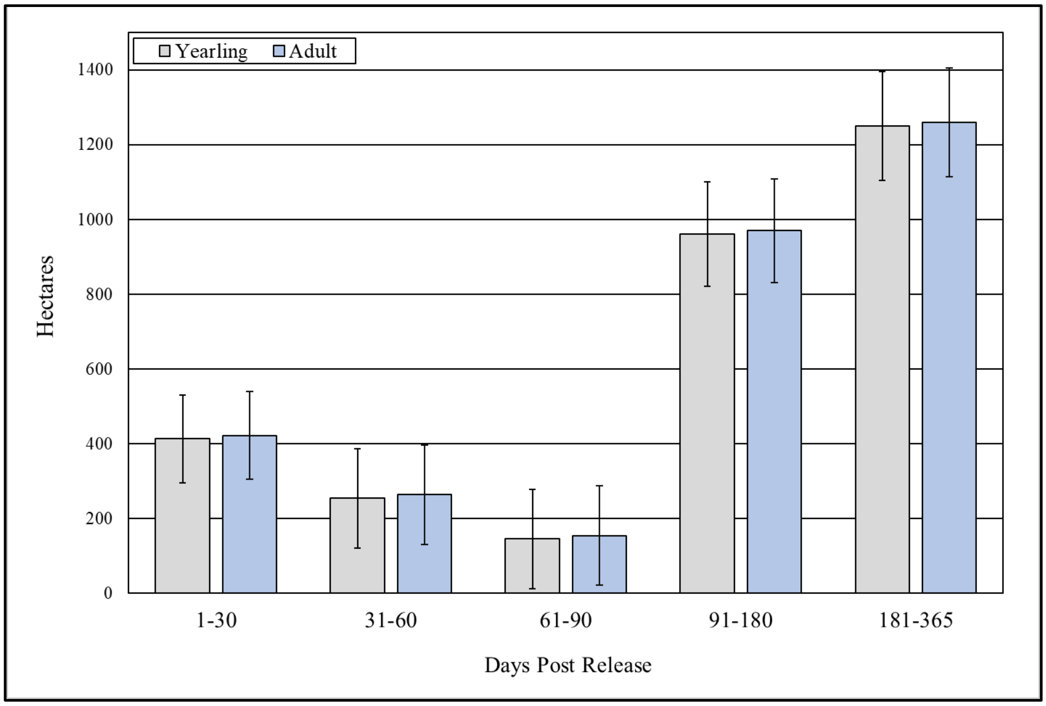

Figure 6. Model-averaged estimates of home range size by age class for elk reintroduced to Jackson County in 2015 and 2016. Error bars equal 95% CI.

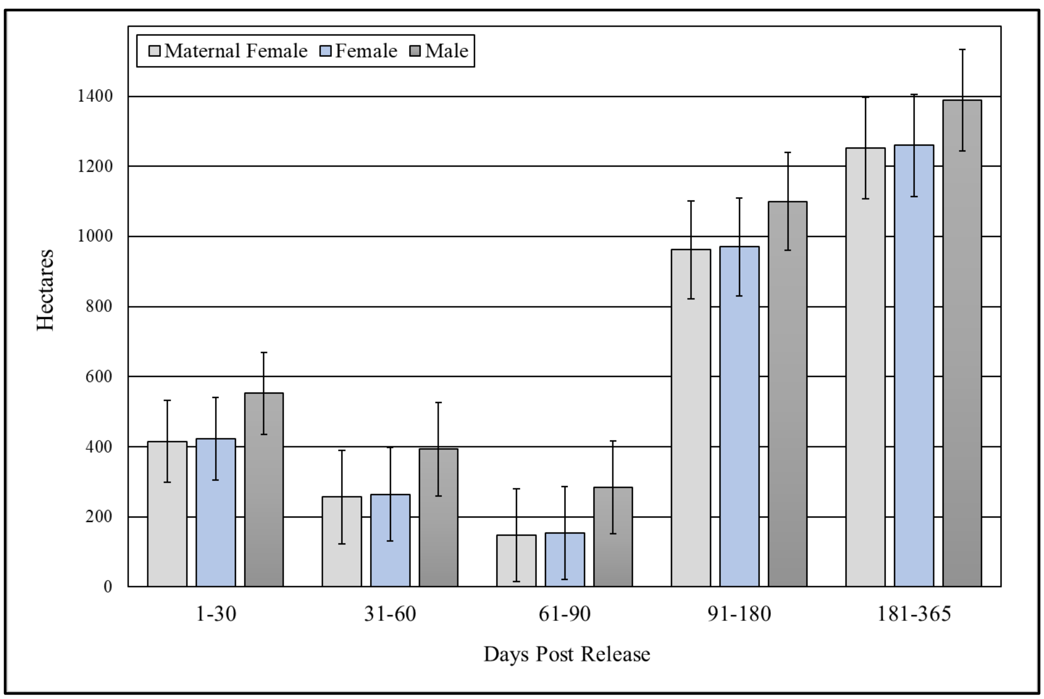

Figure 7. Model-averaged estimates of home range size by sex class for elk reintroduced to Jackson County in 2015 and 2016. Error bars equal 95% CI.

TABLES

Table 1. Candidate models used to assess the relative importance of time post-release, release year, sex, and age on maximum distance traveled from the release site and home range size per time-period for elk reintroduced to Jackson County in 2015 and 2016.

Candidate Model Structure
1. Null Model
2. Time
3. Release Year
4. Sex
5. Age
6. Time + Release Year
7. Time + Age
8. Time + Sex
9. Time + Age + Sex
10. Release Year + Age
11. Release Year + Sex
12. Release Year + Age + Sex
13. Time + Release Year + Age
14. Time + Release Year + Sex
15. Time + Release Year + Age + Sex (Global Model)

Table 2. Model selection results for maximum distance traveled from the release site for elk reintroduced to Jackson County in 2015 and 2016. Models 2, 6, 7, 8, 9, and 13 were used for model averaging.

Rank	Model	Model Components	Intercept	K	logLik	AICc	ΔAICc	wi
1.	2	Time	7.810	7	-922.479	1859.455	0	0.329
2.	7	Time + Age	9.267	8	-921.604	1859.851	0.395	0.270
3.	6	Time + Release Year	6.318	8	-922.233	1861.108	1.653	0.144
4.	13	Time + Release Year + Age	8.362	9	-921.537	1861.882	2.426	0.098
5.	9	Time + Age + Sex	10.760	10	-920.922	1862.835	3.379	0.061
6.	8	Time + Sex	8.795	9	-922.107	1863.021	3.565	0.055
7.	14	Time + Release Year + Sex	7.323	10	-921.881	1864.754	5.298	0.023
8.	15	Global Model	9.930	11	-920.866	1864.927	5.471	0.021
9.	1	Null Model	13.157	3	-958.776	1923.658	64.202	0
10.	3	Release Year	10.324	4	-957.998	1924.171	64.715	0
11.	4	Age	14.868	4	-957.655	1923.485	64.029	0
12.	5	Sex	15.210	5	-956.890	1924.045	64.590	0
13.	10	Release Year + Age	12.535	5	-957.265	1924.795	65.339	0
14.	11	Release Year + Sex	12.214	6	-956.064	1924.500	65.045	0
15.	12	Release Year + Age + Sex	15.664	7	-954.369	1923.237	63.781	0

Table 3. Model selection results for home range size for elk reintroduced to Jackson County in 2015 and 2016. Models 2, 6, 7, 8, 9, and 14 were used for model averaging.

Rank	Model	Model Components	Intercept	K	logLik	AICc	ΔAICc	wi
1.	8	Time + Sex	415.415	9	-1638.180	3295.186	0	0.326
2.	2	Time	450.031	7	-1640.820	3296.159	0.973	0.201
3.	14	Time + Release Year + Sex	389.977	10	-1637.950	3296.917	1.731	0.137
4.	9	Time + Age + Sex	425.039	10	-1638.100	3297.228	2.043	0.118
5.	6	Time + Release Year	433.178	8	-1640.740	3298.137	2.951	0.075
6.	7	Time + Age	445.555	8	-1640.800	3298.266	3.08	0.07
7.	15	Global Model	397.867	11	-1637.920	3299.078	3.893	0.047
8.	13	Time + Release Year + Age	421.304	9	-1640.680	3300.189	5.003	0.027
9.	1	Null Model	589.105	3	-1740.320	3486.754	191.568	0
10.	3	Release Year	500.830	4	-1739.250	3486.690	191.504	0
11.	4	Age	601.798	4	-1740.230	3488.641	193.456	0
12.	5	Sex	603.002	5	-1738.750	3487.769	192.584	0
13.	10	Release Year + Age	500.726	5	-1739.250	3488.782	193.596	0
14.	11	Release Year + Sex	497.359	6	-1737.200	3486.779	191.594	0
15.	12	Release Year + Age + Sex	545.766	7	-1736.790	3488.088	192.903	0

IDENTIFYING RESOURCE SELECTION PATTERNS OF A REINTRODUCED ELK HERD: JACKSON COUNTY, WISCONSIN

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ABSTRACT

One of 6 subspecies of elk (*Cervus canadensis*), the eastern elk (*C. c. canadensis*), once ranged throughout the majority of Wisconsin, but local elk populations were extirpated by the late 1800s. The reintroduction of elk has been an important tool in restoring extirpated populations to their historical range, and we studied the post-release movements of elk reintroduced to Wisconsin from 2015-2017. Elk were captured near Stoney Fork, Kentucky and transported to Jackson County, Wisconsin. Adult elk were fitted with GPS collars to collect spatial data. Twenty-three elk were released on August 20, 2015, and 50 elk were released on July 11, 2016. Our objective was to identify elk resource selection patterns during one year post-release. We used resource selection function models (RSF) to identify resources that elk preferred. Reintroduced elk selected for a suite of vegetation cover types, but they consistently selected against the cranberry, shrubland, wetland, and open water habitats. They preferred sloped terrain and selected for aspects that provided for thermoregulatory advantages as seasons changed. Elk initially avoided roads, but as time progressed, elk often utilized resources near major roads and human development. Overall, elk did not avoid wolf activity centers, but they selected against them during the time period that coincided with winter. We recommend selecting release sites near high quality resources. The addition of supplement resources, such as

food plots, provide an immediate source of high quality forage. Implementing multiple food plots near release sites will help decrease predation risk where wolves are present. Elk often use agricultural areas which may cause conflict with agriculture producers, and management actions may be needed to mitigate these conflicts. Where elk congregate near roads, signs warning motorist of the presence of elk would be prudent.

INTRODUCTION

Prior to European colonization of North America, approximately 10 million elk (*Cervis canadensis*) ranged throughout significant portions of North America (Popp et al. 2014). One of six subspecies, the now extinct eastern elk (*C. c. canadensis*), once inhabited substantial portions of Wisconsin. Historic records indicate that elk were present in 50 of 72 counties (Schorger 1954). Unregulated hunting and conversion of suitable elk habitat for agricultural purposes quickly extirpated local elk populations and the last recorded harvest of an elk in Wisconsin occurred in 1868 (Schorger 1954).

In 1989, the Wisconsin Department of Natural Resources (WDNR) began assessing the feasibility of reintroducing elk to Wisconsin. In 1995, 25 elk from the Pigeon River State Forest in northern Michigan were acquired to initiate the reintroduction of elk to Wisconsin near the town of Clam Lake (Fawcett 2004). In May 1999, the reintroduction study was considered a success, and by May 2011, the estimated population of the Clam Lake elk herd was 151, representing an average annual growth rate of 12.5% (Roepke 2012).

Efforts to establish a second herd near Black River Falls, WI began in 2012, and in December 2014, the Wisconsin Department of Natural Resources (WDNR) and the Kentucky Department of Fish & Wildlife Resources (KDFWR) finalized a five-year agreement to potentially provide Wisconsin with up to 150 wild elk. 23 elk were released in the summer of 2015, and 50 elk were released in the summer of 2016.

Fryxell et al. (2006) defines habitat as a suite of resources and environmental conditions that determine the presence, survival, and reproduction of a population. One of the key components of any reintroduction effort is to ensure that proper habitat is available for the species that is being released. Without high habitat quality, translocations have low chances of success regardless of how many organisms are released or how well they are prepared for the release (Griffith et al. 1989).

Understanding how anthropogenic and environmental factors influence habitat selection is critical in establishing conservation objectives for wildlife populations (Beck et al. 2013), and this is especially true when reintroducing a species to its former range. To obtain resources such as forage and cover, elk select numerous habitat features from within their home range. They tend to avoid anthropogenic features such as roads, and topographic features including elevation, slope, and aspect influence elk habitat selection throughout the year (Rowland et al. 2000 and Beck et al. 2013). Resources are uniformly distributed and the rate at which they are used may change over time as resource availability changes (Fawcett 2004). Landscape processes, including wildfire, grazing, and anthropogenic habitat manipulation may influence the nutritional value of available resources, and the timing and intensity of those processes may increase or decrease the nutritional value of resources available to ungulates, including elk (Fuhlendorf et al. 2009, Ranglack et al. 2016). Seasonal differences influence plant phenology and availability, and adverse weather conditions can affect elk resource selection, particularly in winter when forage is least accessible, and snow hinders mobility (Beck et al. 2013, Fawcett 2004).

Predation risk is another factor that significantly influences elk movements and resource selection. Trade-offs between predation risk and forage fundamentally drive resource selection by animals (Hebblewhite & Merrill 2009).   Wolves (*Canis lupus*), coyotes (*Canis latrans*) and black bears (*Ursus americanus*) are known predators of elk, and all 3 species are present within the study area. Predation pressures may differ by season and elk are most susceptible to wolf predation during winter when snow depth limits the mobility of elk (Fawcett 2004). Coyotes may opportunistically kill adult elk, and (Gese and Grothe 1995) directly observed elk predation by coyotes when elk were caught in deep snow cover, and were in poor nutritional condition. While wolves often kill adult elk, coyotes and black bears typically prey opportunistically on elk calves (Fawcett 2004).

Resource managers often need to characterize which resources a species selects, and the resource selection function model (RSF) is a commonly applied tool to do so. During the last decade, there has been a proliferation of statistical methods for studying resource selection by animals (Lele et al. 2013). As defined by (Manly 2007), a RSF is defined as any function that is proportional to the probability of use by an organism, and for most applications, usefulness is evaluated by how well the model predicts the location of organisms on a landscape (Boyce et al. 2002). We often assume that a species will select for the highest quality resources, and that the use and availability of resources may change over time. RSF models are interfaced with geographical information systems (GIS) to map the probability of use, and ultimately populations, across landscapes (Boyce & McDonald 1999). The use of global positioning system (GPS) data allows for fine-scale assessments of habitat selection, and typically analysis is constructed in a use– availability framework (Northrup et al. 2013). RSF's are a commonly used tool, and have often been used to investigate elk resource selection (Anderson et al. 2005;

Anderson et al. 2008; Barbknecht et al. 2011; Proffit et al. 2011; Beck et al. 2013; Buchanan et al. 2014; Lehman et al. 2016; Morris et al. 2016; Ranglack et al. 2016).

The purpose of the study was to evaluate post-release resource selection of elk reintroduced in Jackson County, WI. Our objective was to develop RSF models to predict adult elk resource selection between 4 distinct time periods (1-90, 91-180, 181-270, and 270-365 days post-release), and to identify factors influencing resource selection. For each period, elk resource selection is expected to reflect influences of habitat type, road features, distance from wolf activity centers, and the topographic attributes of slope and aspect.

METHODS

Our study area is located on Black River State Forest (BRSF) properties, surrounded by a large quantity of land managed by Jackson County Department of Parks and Forestry (JCDPF). The study area is centered approximately 19 km east of Black River Falls, WI which is located in the Central Sand Plains ecological zone. The mean annual temperature of the study area is 6.5$°^{C}$, and mean annual precipitation and snowfall are 83.3 cm and 114.3 cm respectively (WDNR 2014). The mean growing season is 135 days, which is almost 19 days less than other southern Wisconsin ecological landscapes (WDNR 2014). Elevations lie primarily between 259 and 275 m, with a range of 220 to 429 m. The geology is characterized by lacustrine and outwash sand that originated from a large glacial lake that once covered the Central Sand Plains region (WDNR 2014). The vegetation mosaic consists primarily of pine (*Pinus spp.*), oak (*Quercus spp*.), and aspen (*Populus spp.*) forest, with intermittent plantations of red pine (*Pinus resinosa*). Hydrology is characterized by large areas of wetlands and a number of generally low-gradient streams. On wet sites the forests are of two major types: tamarack and black spruce in the peatlands, and bottomland hardwoods in the floodplains of the larger rivers (WDNR 2014).

Agriculture is limited, but it is one of the top cranberry producing regions of Wisconsin and multiple cranberry farms are present east and southeast of the study area.

Elk Trapping and Translocation

In December 2014, WDNR and the Kentucky Department of Fish & Wildlife Resources (KDFWR) finalized a 5-year agreement to provide Wisconsin with up to 150 wild elk. Beginning in January 2015, elk were captured near Stoney Fork, Kentucky using baited corral traps. The corral traps consisted of 3 m tall panels covered with black cloth to reduce the risk of elk injuring themselves, and to limit their visibility when being corralled into trailers for transportation to the quarantine facility. Upon arrival at the quarantine facility, the age and weight of each the individual was recorded, and the animal received 2 numbered ear tags for identification purposes.

As required by the United States Department of Agriculture (USDA) and the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP), a quarantine period was established to reduce the risk of interstate disease transmission. Captured elk were transported to a holding facility and the official quarantine began the day after the last elk was added to the confined cohort. After 30 days of quarantine in Kentucky, the elk were tested for tuberculosis (TB) and brucellosis. At day 45 of quarantine, the elk were transported using commercial stock trailers to a 2.85 ha holding facility in Jackson County, WI to complete the quarantine. Rotating staff from WDNR, JCDPF, University of Wisconsin – Stevens Point (UWSP), and the Ho-Chunk Nation provided security at the facility, provided food and water, and monitored the health of the elk daily. At the end of the quarantine period, a final series of health tests were performed, and the elk were fitted with PIT tags and GPS collars.

In 2015, 26 elk were transported to a holding facility in BRSF. They were held during the second phase of the quarantine period for 146 days. During that time, 5 elk succumbed to babesiosis (*Babesia spp.*), a tick born parasite. One adult female died from complications associated with birthing, and 1 adult male that initially tested positive for TB had to be euthanized for additional health testing. Four calves were born in the holding facility during the quarantine, and subsequently fit with PIT tags and expandable VHF radio collars (Advance Telemetry Systems, Insanti, MN) to monitor for mortalities. Elk (*n*=23, 2 adult males, 6 yearling males, 5 adult females, 6 yearling females, and 4 calves) were released on August 20, 2015.

Using the same capture and quarantine procedures, 39 elk were captured in 2016. During the quarantine, they were held in Kentucky for 45 days and for 112 days in Wisconsin. The elk were held until all known pregnant females had given birth, allowing WDNR biologists to fit newborn calves with PIT tags and VHF radio collars. Elk (*n*=50, 4 adult males, 4 yearling males, 9 yearling females, 22 adult females, and 11 calves) were released on July 11, 2016.

Elk Monitoring and Spatial Data Collection

To monitor adult elk movements, we fitted each individual (*n*=58) with a GPS collar manufactured by Vectronic Aerospace (Berlin, Germany). To estimate GPS accuracy, multiple collars were left in stationary locations, both under canopy and in the open. We used the 2 distance root mean squared (2 DRMS) method to estimate GPS accuracy (NRC 1995). Mean GPS accuracy was 8.39 m (12.96 m under canopy and 3.82 m in the open). The collars possessed satellite uplink capabilities allowing for remote monitoring and real-time data collection. Notifications were emailed to researchers in the event of a mortality. The collars also utilize VHF transmitters to aid in monitoring elk in the field and locating mortalities. All elk from the 2015 cohort (*n*=19), and most elk from the 2016 cohort (*n*=35), received collars programmed to record GPS coordinates in 13-hour intervals. Yearling males (*n*=4) of the 2016 cohort were fitted with collars that recorded locations on an hourly basis. We filtered data from those collars to be concurrent with the data from the collars with 13 hour fix rates.

Habitat Variables

We identified variables for 12 habitat classes, use of manipulated habitat, road density, distance to nearest road, distance to wolf pack centers, and topographic features of slope and aspect. Habitat data were collected from the Wiscland2 land cover dataset (WDNR 2016), which is derived from satellite imagery acquired from the Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM) and Landsat 8 Operational Land Imager (OLI). Twelve habitat covariates were collected from the third level of the dataset. Habitat classes considered were developed, agricultural crops, cranberry fields, grassland, coniferous, aspen, oak, hardwoods, mixed coniferous/deciduous, shrubland, wetland, and standing water. The WDNR planted a food plot adjacent to the release site, which was classified as grassland. Spatial data regarding habitat manipulations were supplied by WDNR and JCDPF foresters and consisted of any habitat treatment that occurred between 2007 - 20017.

Spatial data were analyzed in ArcGIS 10.5.1 (ESRI 2017). We used the line density tool to create a road density map, and the Near tool to measure the distance between the nearest road and each used and available location. Road data were collected from TIGER line shapefiles produced by the United States Census Bureau (USCB 2015). We digitized wolf pack centers based on the WDNR wolf pack detection map (WDNR 2017), and the distance to the nearest wolf pack center was recorded for each used and available location. Slope and aspect data were determined using the Spatial Analyst tool using a 30 x 30 m resolution digital elevation model

(USGS 2000). Aspect was classified into 5 categories; flat (no aspect), North (315º - 359º, 0º - 45º), East (45º - 135º), South (135º - 225º), and West (225º - 315º).

Study Design

Elk resource selection was characterized 1-year post-release for both release years. Release dates differed by 7 weeks in the respective years, and to evaluate the effect of release on elk resource selection, time periods established were based on the number of days post-release, instead of biological seasons. We implemented a use-availability RSF design to evaluate post-release resource selection (Boyce et al. 2002, Johnson et al. 2006, Manly et al. 2007, Beck et al. 2013), and responses were evaluated over 4 time periods (0-90, 91-180, 181-270, and 271-365 days post-release). We identified resource use using GPS locations collected by GPS collars fitted to each elk. Locations were pooled across individual elk from both release years to assess habitat selection response at a population level (Type I design; Manly et al. 2007), and habitat selection was observed for the second order of selection (Johnson 1980). We determined the availability extent by constructing a 100% minimum convex polygon (MCP) around all elk locations. The MCP was truncated along U.S. Interstate 94 because it proved to be a significant barrier to elk movements (Figure 2). To ensure complete coverage of the availability extent, we generated random points at a 5:1 ratio of used to available locations (Lehman et al. 2016).

Analytical methods

We used logistic regression with used and available locations for model selection, and for each time period, we estimated the relative probability of use within the availability extent. Used and available locations were the dependent variables and a suite of habitat characteristics constituted our set of predictor variables (Johnson et al. 2006 and Beck et al. 2013). We implemented a Pearson's correlation matrix to test for multicollinearity among variables.

Correlation coefficients (r) for all variables remained below the recommended threshold of 0.5 – 0.7 r (Doherty et al. 2010, Dormann 2013, Beck 2013). The highest coefficient was 0.412, therefore, all variables were retained for logistic regression analysis. We used Akaike's Information Criterion corrected for small sample sizes (AIC_C) to evaluate support for, and rank, all candidate models for each time- period (Burnham and Anderson 2002). Akaike weights (w_i) were computed for all candidate models to provide weights of evidence in support of each model being the most parsimonious of the candidate models for each time-period (Burnham and Anderson 2002, Beck 2013). Analyses were conducted using R Studio statistical software (RStudio Team 2016).

Goodness of fit tests were used to validate RSF models using the model validation method described by (Johnson et al. 2006). Elk locations for each time period were subset into training and testing data, with 75% of the used and available locations were randomly selected to use for training the logistic regression models. The remaining 25% were set aside for model validation. RSF values were predicted in GIS and probability maps were generated. We then reclassified pixels into ordinal bins based on natural breaks, and the midpoint of each bin was determined. We then calculated utilization values for each bin *i* using the formula:

$$U(x_i) = w(x_i)A(x_i) / \sum_j w(x_j)A(x_j)$$

Where:

$U(x_i)$ = utilization value

$w(x_i)$ = midpoint of bin *i*

$A(x_i)$ = area of bin *i*

The expected number of validation observations for each bin was determined using the formula:

$$N_i = N \times U(x_i)$$

Where:

N_i = expected number of observations of bin i

N = total number of training data observations

$U(x_i)$ = utilization value

The number of used locations for the model testing data were counted for each RSF bin and compared to the number of expected number of observations using chi-squared tests.

RESULTS

For the 23 animals of the 2015 release, 4 GPS collars were lost due to malfunction (1 adult male, 3 yearling males). Eight elk were lost to mortality. Four were killed by wolves (1 yearling male, 1 yearling female, and 2 adult females), 2 adult females were killed by vehicle collisions, 1 yearling female died of unknown causes, and 1 yearling female died of a meningeal worm infection (*Parelaphostrongylus tenuis*).

For the 50 animals of the 2016 release, 1 collar on an adult female was lost due to malfunction, and 8 were lost due to mortality. Mortalities included 1 adult male, 1 adult female and 2 yearling females killed by wolves, 2 yearling females died from meningeal worm, 1 yearling female died from a vehicle collision, and 1 adult female died from a bacterial infection.

For any time-period where an individual elk survived the duration, data were included in the analyses. For animals that died, or that had collar malfunctions, data were censored so that incomplete time periods were not considered in the analyses. Collar failures on 2 adult males and the mortality of 2 adult females occurred less than 30 days post-release in 2015, and 1 adult female died less than 30 days post-release in 2016. Therefore, they were censored from the analyses. After filtering and censoring the GPS data, we used 24,911 locations in the analyses (2015 n = 5,235; 2016 n = 19,676).

The global model prevailed as the top ranked model for all 4 time periods, and very little support was shown for the remaining candidate models as Akaike weights for global model in each time period were ≥ 0.963 (Tables 4-7).

Habitat variables

In relation to coniferous forest, elk showed the strongest preference towards grassland, and positive associations also were seen with crops, oaks and mixed coniferous/deciduous forests between days 1 – 90 post-release (Table 8). Grassland and oaks were used more proportionately than their availability, and crops and mixed forest were used in proportion to availability (Figure 13). A slight negative association occurred regarding aspen, hardwoods and wetlands, and stronger negative associations occurred regarding developed, cranberry, shrubland, and water habitat classes. Positive parameter estimates indicate positive association towards areas were habitat manipulation has recently occurred. During the 91 – 180 day time period, elk showed the strongest preference towards crops and grassland, and positive associations occurred regarding developed and oak habitat classes (Table 9). Aspen, mixed coniferous/deciduous and shrubland classes were used in proportion to availability (Figure 14), and negative associations occurred regarding cranberry, hardwoods, wetland, and open water classes. Slight negative association occurred regarding areas where habitat manipulation had recently occurred (Table 6). Elk showed the strongest preference towards the crop habitat class, and had positive associations with the developed, grassland and oak classes between days 181 – 270 (Table 10). Conifer, mixed coniferous/deciduous and shrubland classes were utilized in proportion to availability (Figure 15), and there was a negative association with the cranberry, aspen, hardwoods, shrubland, wetland, and open water classes. During this time period, elk locations were negatively associated with areas where habitat manipulation has recently occurred (Table 10).

Elk showed the strongest preference towards the grassland habitat class, and had positive associations with the crop, developed, oak, hardwoods, and mixed forest classes during the 270 - 365 day time period (Table 11). Crop, grassland and oak classes were used more in proportion to what was available, while mixed coniferous/deciduous, hardwoods, and developed classes were used in proportion to availability (Figure 16). Slight negative associations occurred regarding cranberry, aspen, shrubland, wetland, and open water classes, and during this time period, and elk locations were positively associated with areas where habitat treatments had recently occurred.

Topography

A slight positive association occurred with areas of sloped terrain between days 1 – 90. Elk selected for northern and eastern aspects as opposed to southern, western, and flat aspects (Table 8). A positive association with sloped terrain occurred between days 91 – 180, as well as toward northern and eastern aspects (Table 9). Flat and southern aspects were used at a similar frequency, and there was a negative association with western slopes (Figure 19). A positive association occurred regarding sloped terrain between days 181 – 270, and elk selected southern, western, and flat aspects over northern and eastern aspects (Table 10 and Figure 19). Positive association occurred regarding sloped terrain (Table 11), and parameter estimates indicate that elk selected areas with flat aspects over those of the four cardinal directions between days 270 – 365 (Table 11 and Figure 19).

Road features

Parameter estimates for road distance and density indicate that elk used areas devoid of roads between days 1 – 90 (Table 8). Road distance and density parameter estimates indicate that elk mostly utilized areas without roads between days 91 - 180, but to a lesser extent than the previous time period (Table 9). Parameter estimates for road distance and density indicate that elk mostly did not avoid areas with roads between days 181 – 270 (Table 10). Parameter estimates were lowest between days 271 – 365, indicating that avoidance of roads by elk declined even further (Table 11).

Wolf pack proximity

Parameter estimates indicate that elk did not avoid areas located near wolf pack centers during the first 90 days post-release (Table 8), and parameter estimates were nearly identical between days 91 -180 (Table 9 and Figure 18.). Between days 181 -270 elk showed the most avoidance wolf pack centers, but elk locations were still closer to wolf pack locations compared to what was available (Table 10). Avoidance of wolf pack centers decreased between days 270 – 365, and parameter estimates were similar to days 1 – 180 (Table 11 and Figure 18.)

Model validation

We created probability maps by applying model coefficients to the model variable raster datasets, from which model validation was performed (Figures 9-12). Model validation indicated that the global model was a strong predictor of elk habitat use for all 4 time periods (Days 1-90: $X^2 = 3.13$, df = 9, P = 0.959; Days 91-180: $X^2 = 0.308$, df = 9, P = 0.999; Days 181 – 270: $X^2 = 0.123$, df = 9, P = 0.999; Days 271 – 365: $X^2 = 0.197$, df = 9, P = 0.999).

DISSCUSION

Habitat variables

The WDNR planted a 2.85 ha food plot adjacent to the elk quarantine facility. Elk were released in mid to late summer, and the food plot provided immediate access to a high-quality source of forage, which allowed them to maximize caloric intake prior to winter. Most elk made short exploratory movements etween days 1-90, but most returned to the release site and localized their resource use around the food plot. Elk disproportionately used grassland and oak over the remaining habitat classes (Figure 13). The food plot was classified as grassland during the analyses, and substantial use of it during the first 90 days post-release was reflected in our results. Approximately 28% of elk locations were classified as grassland, which encompasses only 1.8% of the availability extent. When elk where not occupying the area near the release site, they showed a preference for areas that had recently received habitat treatments. As winter approached, elk began shifting resource use away from the food plot as it was no longer able to provide adequate resources.

Between days 91 – 180, fall transitioned to winter, and elk began dispersing and establishing home ranges. Selection toward grasslands decreased, while selection toward the developed, crop, and oak habitat classes increased (Figure 14). Fawcett (2004) studied resource selection of elk of the Clam Lake elk herd (CLEH), and found that elk locations were most positively associated with coniferous forest, mixed coniferous/deciduous forest, and aspen forest during fall. The Black River elk herd (BREH) used coniferous habitat, but in lower proportion to what was available. Use of aspen and mixed forest was proportional to availability, but they used the developed, grassland, crop and oak habitats in greater proportion than what was available (Figure 14). Elk in central Ontario, Canada, often used areas where forestry practices manipulated habitats (McGeachey 2014). In contrast, the BREH selected for habitats that had not been recently manipulated.

The 181-270 day time period encompassed the majority of winter and early spring, and elk had localized their resource selection to winter ranges. The BREH continued to use the developed, crop, and oak habitat classes at a greater proportion that what was available, but utilization of the grassland habitat declined and only 3.3% of locations were classified in grassland habitats. Fawcett (2004) reported that the CLEH mostly associated with mixed coniferous/deciduous forests, wetlands, and aspen forest in winter. The BREH had a slight positive association with mixed forests during this time period, but unlike the CLEH, they avoided wetland and aspen habitats while the use of coniferous forests increased. Use of coniferous habitats was greatest for the BREH during this time frame. Thirty-six percent of elk locations were classified as coniferous, compared to 40% that were considered available (Figure 15). Lyon & Christensen (1992) define a stand of coniferous trees 40 feet tall, or taller, with average crown closure of 70 percent as thermal cover, and elk likely used coniferous habitats to alleviate the effects of winter weather. Although thermal cover is typically associated with coniferous habitats, (Skolvin et al. 2002) note that in some cases, topography and other vegetation types may meet an animal's needs for thermoregulation.

Winter gave way to spring at the beginning of the 271 - 365 time period which coincided with some elk leaving their winter ranges. Elk continued to use crops at approximately the same rate as the previous time period. Selection of coniferous habitat declined, but use of the grassland, hardwood, and oak classes increased (Figure 16). In contrast, the CLEH primarily utilized coniferous forest, mixed coniferous/deciduous forest, and aspen stands in spring and summer (Fawcett 2004). Elk often prefer areas that contain open areas for feeding while having escape cover nearby, and Dewar (2006) identified the proximity to a forage-cover edge as the main factor driving summer resources selection in northwestern Ontario, Canada.

Topography

Topography can be an important determinant of elk resource use. In the western United States where topographic relief can be quite drastic, elk are generally migratory in respect to elevation (Hebblewhite & Merrill 2009, Nelson et al. 2012, DeVore 2014). Toweill & Thomas

(2002) present elevation as a crucial factor influencing overall elk movements. Although elevation does not affect elk behavior on a day-to-day basis, it is important in terms of habitat use because precipitation, snow accumulation and plant phenology are directly related to elevation (Skolvin et al. 2002). In contrast, most current elk populations inhabiting eastern states live in temperate climates with low to moderate topographic relief. Therefore, assuming an adequate supply of food is available, eastern elk should show little to no tendency to migrate and have greater fidelity to local ranges (Cox 2011). The range in elevation in our study area was only 210 m between the highest and lowest elevations. Therefore, it likely had little effect on elk resources use and movements, but our results indicate that elk still use topography that is advantageous to them.

The topography near the release site is primarily of slopes < 2.5, and our results indicated that slope had the least amount of influence on resource selection by the BREH over the first 90 days post-release. As elk were making exploratory movements, many of them encountered a ridge network (Wildcat ridge), where they selected for northern and eastern aspects over southern and western aspects (Figure 19). The influence of slope between days 91 -180 increased as elk began using Wildcat ridge, which is one of the few locations within the availability extent that provides topographic relief. Elk displayed a preference for eastern aspects while selecting against western aspects.

Between days 181 – 270, the influence of slope remained similar to the previous time period, but selection towards aspect shifted from eastern, to southern and western aspects. Southern and western aspects receive more direct solar radiation during winter, and are generally warmer than northern and eastern aspects.

Among the 4 time periods, the maximum parameter estimate for slope was estimated between days 270 - 365. This may indicate that slope was most influential during this time frame, but this seems to be contradicted by negative parameter estimates for the 4 cardinal directions of aspect when compared to areas with no aspect (Figure 19). These results likely are due to the distribution of elk during this time frame. Approximately 50% of elk remained in the Wildcat ridge area where the highest concentration of topographic relief occurs, and the area used by elk encompasses a varying degree of both slope and aspect. The remaining elk were distributed in smaller groups 20 – 30 km to the northwest where topographic relief is minimal.

Road features

Elk typically avoid roads (Beck 2013), and parameter estimates for road density and distance were highest between days 1-90 post-release. This may indicate that elk of the BREH were avoiding roads, but these results may be misleading. The release site and food plot are in a restricted part of BRSF (Figure 9). The closest road is 2.3 km away, and the results are more likely a function of elk localizing their movements around the food plot, more so than specifically avoiding roads, as elk locations were often near roads when making exploratory movements. Anderson et al. (2005) used RSF's to study summer habitat use of the CLEH. They reported that areas near roads were avoided by elk when establishing a home-range, but areas near roads were selected for use within the established home range.

The BREH began expanding home ranges between days 91-180, and our results for this time-period indicate that elk began using habitats that were in proximity to roads (Figure 18).

The BREH had established winter ranges between days 181 - 270, and they selected habitats near roads, with the average distance to the nearest road being only 0.37 km.

Elk displayed a minimal amount of avoidance regarding road features during between days 270 -365 (Figure 18). Most elk that had not established home ranges in the Wildcat ridge area were primarily distributed within 10 km to the east and northeast of Black River Falls, where road density is highest.

Wolf pack proximity

McIntosh et al. (2014) identified predation by wolves as the most important proximate cause of mortality on reintroduced elk in Ontario, Canada, and our results indicate the same. 50% of elk mortalities in our study were attributed to predation, all of which were perpetrated by wolves. Our data suggests that elk did not explicitly avoid wolf activity centers 90 days post-release, but many elk of the 2016 release dispersed from the release site between days 18 – 30. Trail cameras located near the release site indicated increased wolf activity (Roepke 2016). Elk likely dispersed in response to the disturbance, but many returned to the release site, and food plot, as wolf activity decreased. Kittle et al. (2008) examined predation risk of white-tailed deer (*Odocoileus virginianus*), elk, and moose (*Alces alces*), and they noted that ungulates did not select resources based on avoiding areas of direct predation risk, but instead selected areas of use that tradeoff predation risk minimization with forage and/or mobility requirements. This is likely the case for elk of the BREH. Even with evidence of wolf activity near the release site, elk returned to maximize the use of the highest quality resource available to them. While the prevalence of high quality forage resources at release sites can increase fidelity of reintroduced elk, it may also increase mortality risk, potentially setting an ecological trap for animals naïve to local risks (Frair et al. 2007).

The influence of distance from wolf pack centers remained similar to the previous time period between days 91 -180, and elk often travelled within close proximity to these areas while establishing home ranges.

Elk avoided areas near wolf pack centers during the 181 – 270 day time frame. Although parameter estimates indicated a slight negative association regarding distance from wolf pack centers, parameter estimates were almost 450% higher in comparison to the mean parameter estimates of the other 3 time periods (Days 181 – 270 = -0.018; Days 1-180 and 271-365 μ = -0.08).

Avoidance of wolf pack centers decreased between days 270 -365, and parameter estimates were similar to those of the 1 - 90 and 91 - 181 day time periods. Where wolves are present, elk resource use often is influenced by wolf movements. Anderson et al. (2005) reported that at a large spatial extent, home-range establishment of the CLEH was largely explained by the spatial distribution of wolf territories, and wolves may have greater effects on elk dynamics than would be predicted on the basis of direct predation alone (Creel et al. 2005). Elk of the BREH increased use of habitats near roads and human development throughout the duration of the study period. They most likely used these areas to reduce predation risk. Compared to migratory elk, resident elk are exposed to higher predation risk, but they reduced predation risk at fine scales by using areas close to human activity, which wolves avoided (Hebblewhite and Merrill 2009).

Study limitations

The accuracy assessment of elk GPS collars indicated high spatial accuracy, but a lack of temporal resolution between GPS fixes is one of the limiting factors to this study. GPS locations were record in 13-hour intervals, and missed GPS fixes led to large gaps between recorded locations. This was particularly true during spring and summer as canopy cover increased, and the reduced ability of GPS collars to acquire satellites and record GPS locations. The combination of these factors led to gaps in GPS location data, and in some instances, 3.5 days elapsed between successful GPS fixes. Even without missed GPS fixes, elk can move considerable distances in 13 hours. The use of resources may be misrepresented, especially as elk were establishing home ranges. Elk occasionally made long distance movements in a 24 hour period and identifying the travel corridors that they used is difficult to determine.

Accuracy limitations of the Wiscland 2 data, and misidentified habitat classes likely influenced our RSF models. We used the third level of Wiscland 2 to differentiate between class of deciduous cover. At the third level, the estimated overall accuracy is 73% (WDNR 2016). The highest accuracy classes consisted of wetland, grassland and forest subtypes. Broad-leaved deciduous scrub/shrub (87%), pasture (80%), and pine (80%) were most accurately assessed, while the lowest accuracies are generally forest subtypes, including central hardwoods (34%), red maple (30%) and lowland aspen (19%) (WDNR 2016). Low accuracy classes are confused with compositionally similar classes, with aspen being misclassified as swamp hardwoods (11%), or oak (14%) and central hardwoods is misidentified as oak (28%) and northern hardwoods (12%). In each of these examples, the commission to the oak class indicates that oak is possibly over-estimated at Level 3 (WDNR 2016).

Wolves have dynamic social structures that change frequently, and pack sizes and ranges change over time. Limited access to wolf spatial data reduced our ability to identify how wolves influenced elk resource selection. Wolf pack locations had to be digitized visually from a WDNR map, with only a single, stationary point, being used to act a reference point for each wolf pack for each time period analyzed (WDNR 2017). Therefore, inference from the data should be treated with caution, and actual wolf locations may have been drastically different from the reference points. This likely induced bias in the results regarding the distance between wolf packs and elk locations.

RSF models help define what variables influence resource use by animals, and often a currency of use is identified to measure the investment made by an animal in securing resources, avoiding loss of resources, or otherwise optimizing fitness (Buskirk & Millspaugh 2006). During the last decade, there has been a proliferation of statistical methods for studying resource selection by animals (Lele et al. 2013). While statistical techniques for RSFs are advancing at a fast pace, there is confusion in the conceptual understanding of the meaning of various quantities that these statistical techniques provide (Lele et al. 2013). McDonald (2013) maintains that use-availability and presence-only analyses are synonyms, and both require two samples (one containing known locations, one containing potential locations) to estimate the same parameters. Keating and Cherry (2004) express 2 concerns regarding the use of logistic regression to estimate resource selection function. The first concern regards a theoretical concern when applying logistic regression to maximize the use-availability likelihood, with the second being that sample contamination can introduce bias into parameter estimates of RSF models. Johnson et al. (2006) note that Keating and Cherry's concerns are legitimate, but they argue that it does not invalidate current and past RSFs estimate from use – availability design. There is also the potential to misinterpret data that has been analyzed using RSFs. Northrup et al. (2013) note that the use-availability framework offers methodological challenges, and bias in parameter estimates may occur from incorrectly assessing and sampling the spatial extent of availability. Bias may also be introduced to RSF models when using telemetry data, as the 'quantity' of use at a specific instance is typically not accounted for (Lele et al. 2013). For example, a location may be visited for 1 minute as an animal moves between resources patches and at the next successive location may be visited for 2 hours, but they would be treated with equal weight in the analysis.

Summary

Overall our results indicate that reintroduced elk selected for a suite of vegetation cover types between each post-release time period, but they consistently selected against the cranberry, shrubland, wetland, and open water habitat classes. Use of topographic characteristics shifted throughout the study duration. Slope had little influence after the first 90 days post-release, while use of aspect varied. The influence of slope then increased and stabilized between days 91-365. The use of aspect shifted between the final 3 time periods, and elk selected for aspects that provided for thermoregulatory advantages as seasons changed. Elk mostly avoided roads for the first 90 days, but as time progressed, elk often utilized resources near major roads and human development. Elk avoided wolf activity centers between days 181 -270. They did not particularly avoid wolf activity centers between days 1-180 and 271-365, but they often selected toward areas closely associated with humans, which wolves tend to avoid.

Most GPS collars used in this study will potentially collect data on elk locations for up to 4 years, and further research should be conducted to identify how elk resource selection changes as the BREH expands and home ranges shift. Future reintroductions should use the highest fix rate possible for GPS collars, while taking into account the battery life needed to sustain the collars for the duration of the study period. A GPS fix rate of 3 – 8 hours will increase temporal resolution and resource selection can be examined at finer scale than those with longer with longer fix rates. When a GPS collar fails to record a location, the length of time between successful fixes is also reduced in collars with shorter fix rates. Wolves are the primary predators of the BREH, and identifying how wolf activity influences elk resource selection should be studied in greater depth. Future research should incorporate wolf location data into RSF analyses to provide a more detailed description of elk resource selection and how it is influenced by wolf activity. Spatial scale of environmental variables should also be considered when using RSFs. Results from Anderson et al. (2005) show that the effects of environmental variables on habitat use by elk were scale-dependent, and they emphasize the necessity of analyzing habitat use at multiple scales that are fit to address specific research questions.

MANAGEMENT IMPLICATIONS

Wildlife reintroductions often are intended to provide the public with recreational opportunities, and human disturbance at the release site may compromise the reintroduction effort (Bliesch 2014). Choosing the proper release site is paramount to a successful ungulate reintroduction or translocation, and they should be located where public access is limited. Selecting release sites near high quality resources is recommended, and the addition of supplement resources, such as food plots, provide reintroduced animals with easily accessible food sources of high quality. One downfall of supplement resources is that reintroduced animals are likely to congregate at these sites, and may incur a higher risk of predation, particularly where wolves are present on the landscape. Implementing multiple food plots near release sites will provide additional resources and will allow animals to move freely between those resources, which will help decrease predation risk. Managers should also avoid releasing elk in areas dominated by a homogenous cover types. Elk are known to prefer areas with high quantities of open-forest edge habitat. Manipulating habitat to create more open area and increased edge habitat is likely to be beneficial for reintroduced animals, particularly in spring in summer when new growth of grass, forbs, and browse contains the highest amount of nutrition. The location of food-plots and habitat manipulations should also be considered. Locating food-plots and habitat treatments in, or near, areas with topographic relief is recommended. Even in areas were elevational range is limited, elk still use topography to their advantage for thermoregulation and reducing predation risk. Elk often use agricultural areas when the opportunity arises. This may cause conflict with agriculture producers, and management actions may be needed to mitigate these conflicts. Resource managers should be prepared to take actions to prevent unwanted used of agricultural areas by elk and be prepared to work with the landowners to successfully mitigate such issues. Our results show that elk often used areas near roads and human development. Where elk congregate near roads, signs warning motorist of the presence of elk would be prudent. Prior to release, announcements on traditional television news outlets, radio stations, and on social media will also increase public awareness to the presence of reintroduced animals.

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FIGURES

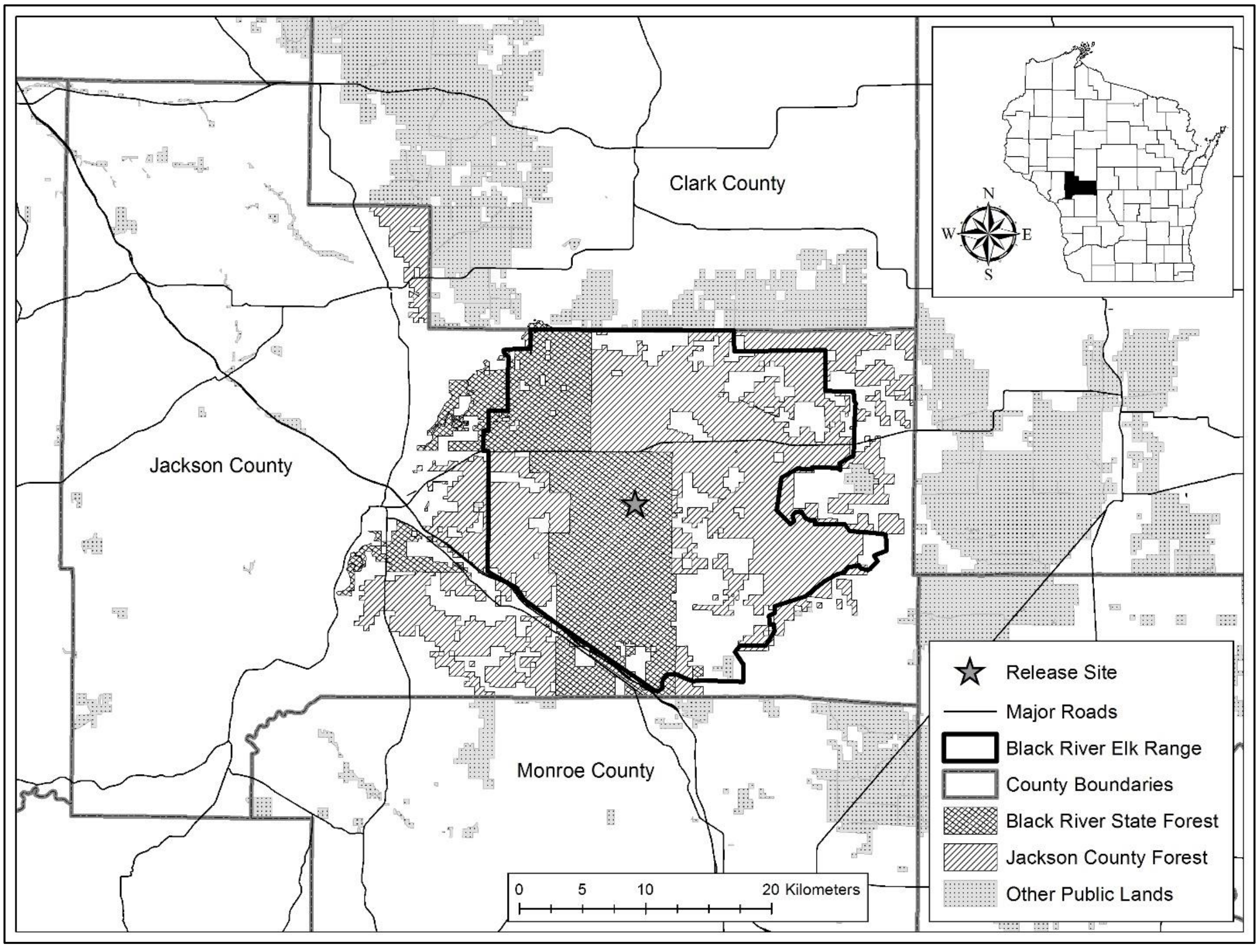

Figure 1. Black River Elk herd study area in Jackson County, WI. Primary elk range consists mostly of lands managed by Black River State Forest and Jackson County Department of Parks & Forestry. Other public lands are present in adjacent counties.

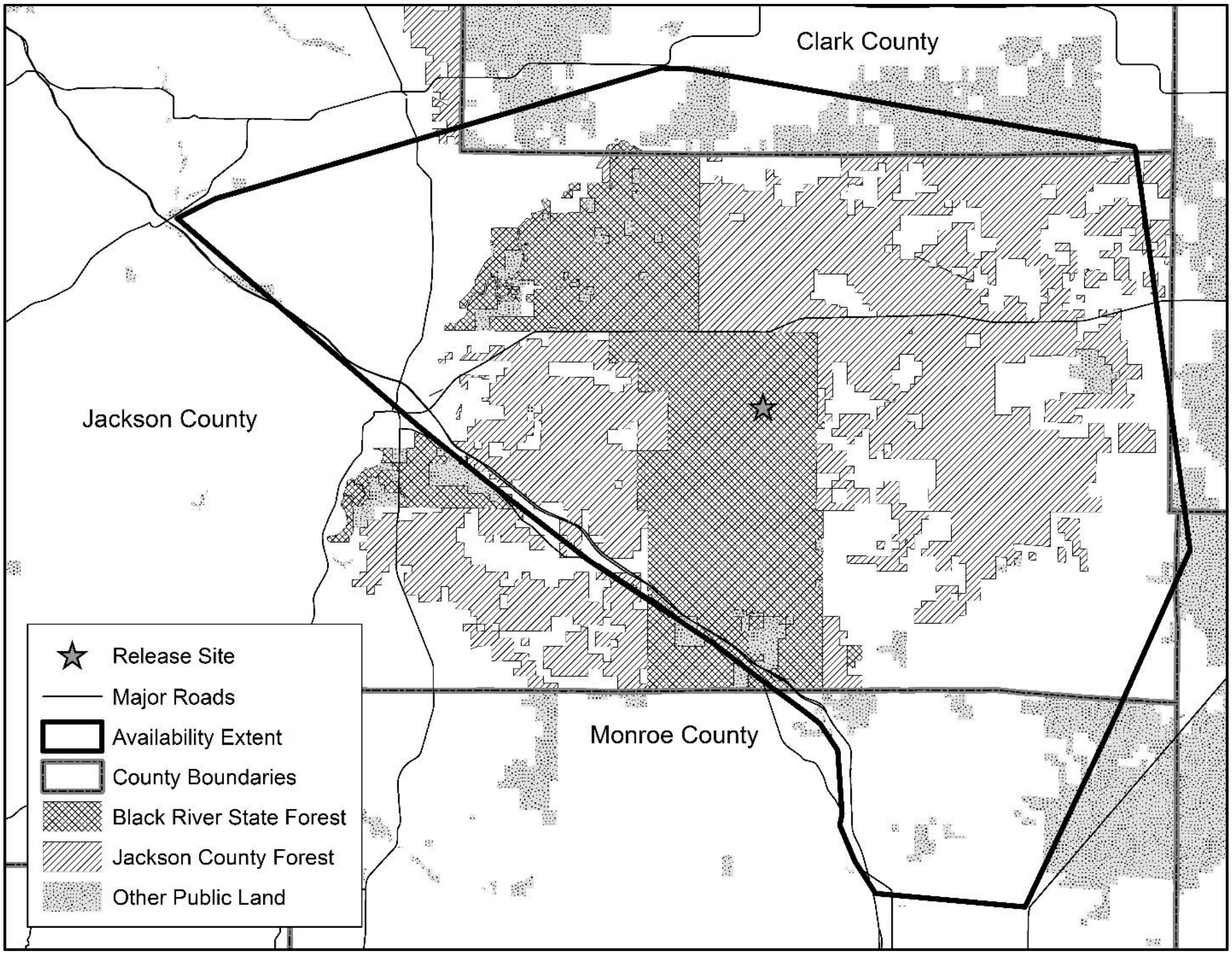

Figure 8. The availability extent constructed using a 100% MCP truncated along U.S. Interstate 94 as it proved to be a significant barrier to elk movements.

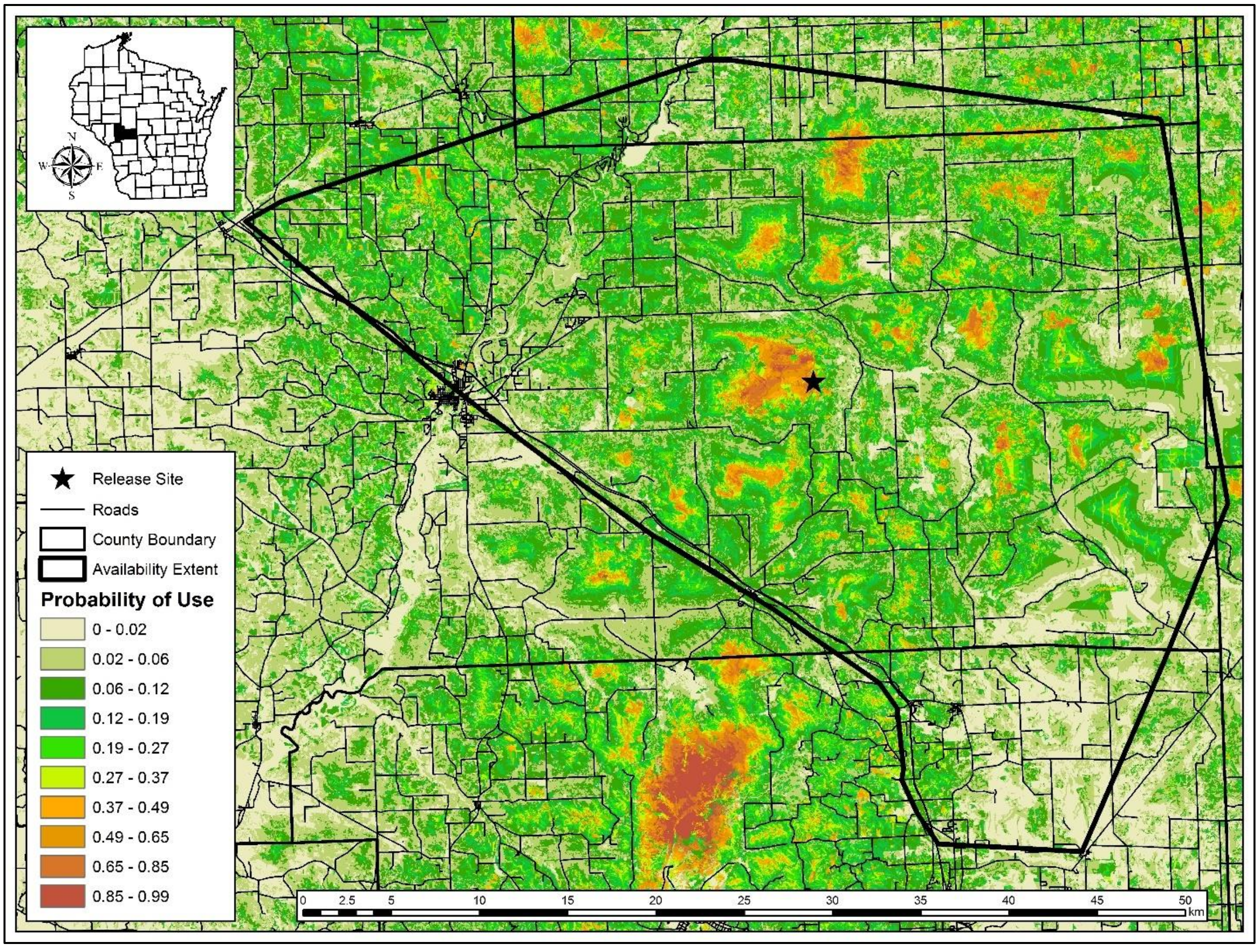

Figure 9. Probability map of elk habitat use for days 1 – 90 post-release for elk reintroduced to Jackson County in 2015 and 2016. The map was constructed by applying model coefficients to the model variable raster dataset. Probability values coincide with the 10 RSF bins used for model validation. RSF bins were sorted by natural breaks in ArcGIS.

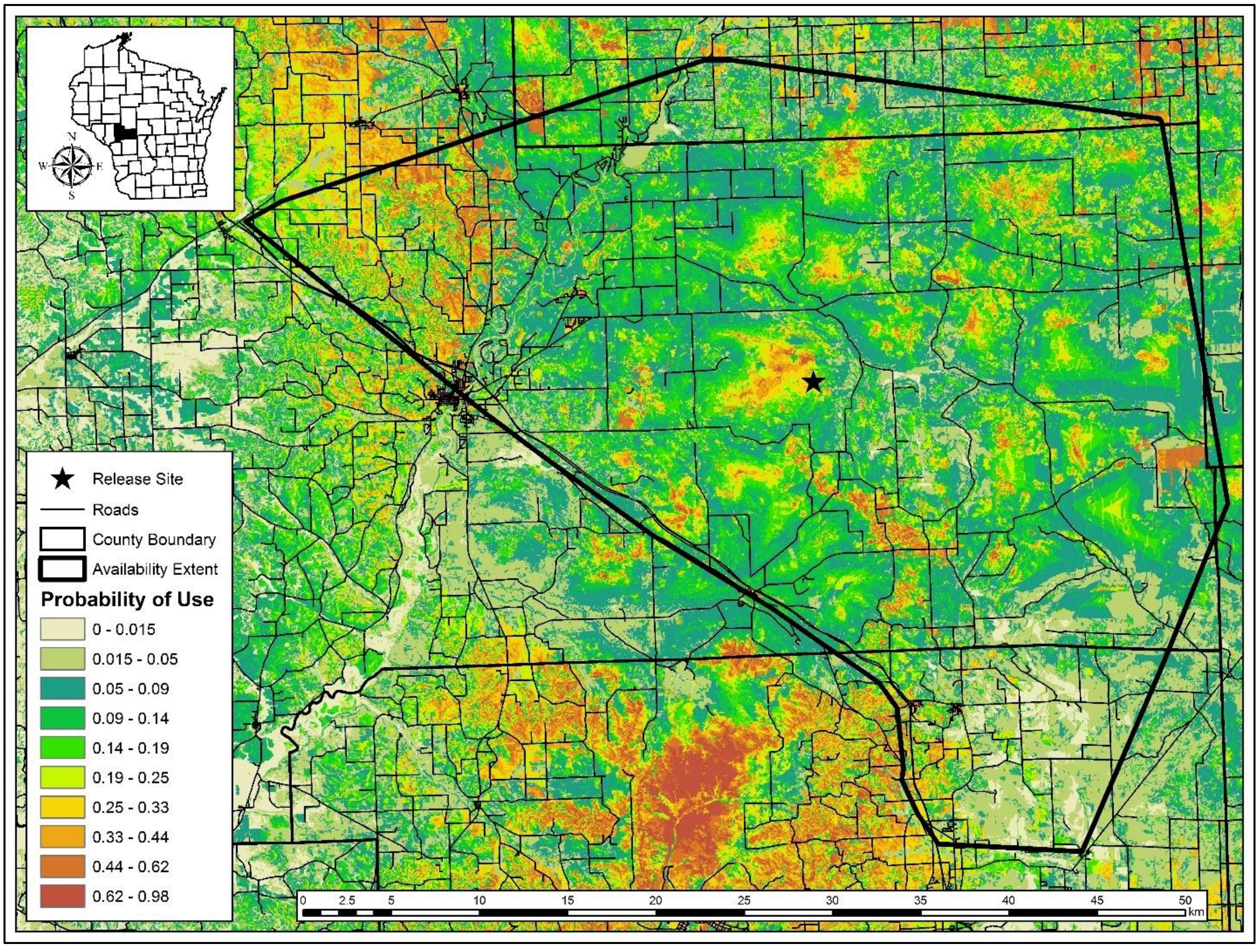

Figure 10. Probability map of elk habitat use for days 91 – 180 post-release for elk reintroduced to Jackson County in 2015 and 2016. The map was constructed by applying model coefficients to the model variable raster dataset. Probability values coincide with the 10 RSF bins used for model validation. RSF bins were sorted by natural breaks in ArcGIS.

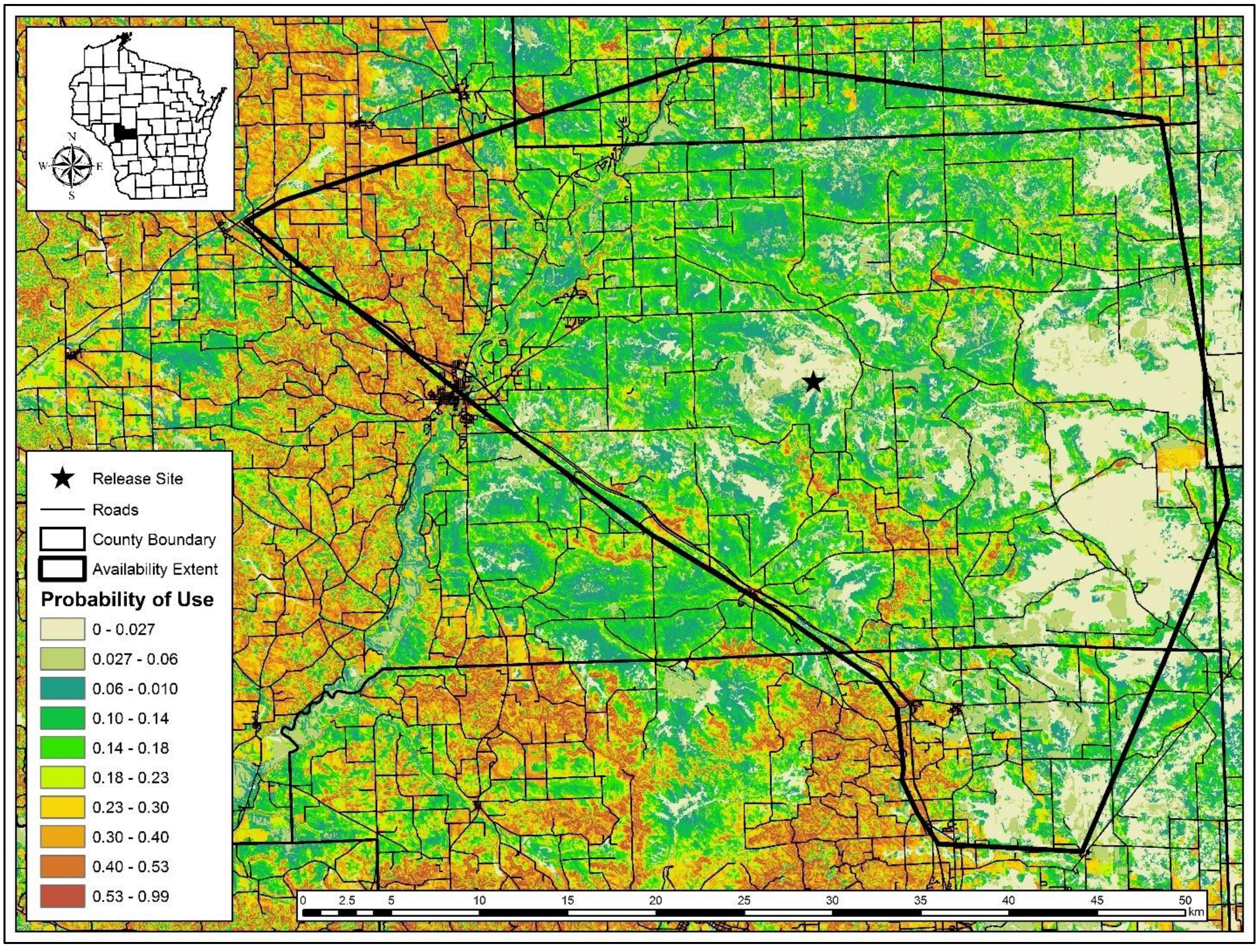

Figure 11 Probability map of elk habitat use for days 181 – 270 post-release for elk reintroduced to Jackson County in 2015 and 2016. The map was constructed by applying model coefficients to the model variable raster dataset. Probability values coincide with the 10 RSF bins used for model validation. RSF bins were sorted by natural breaks in ArcGIS.

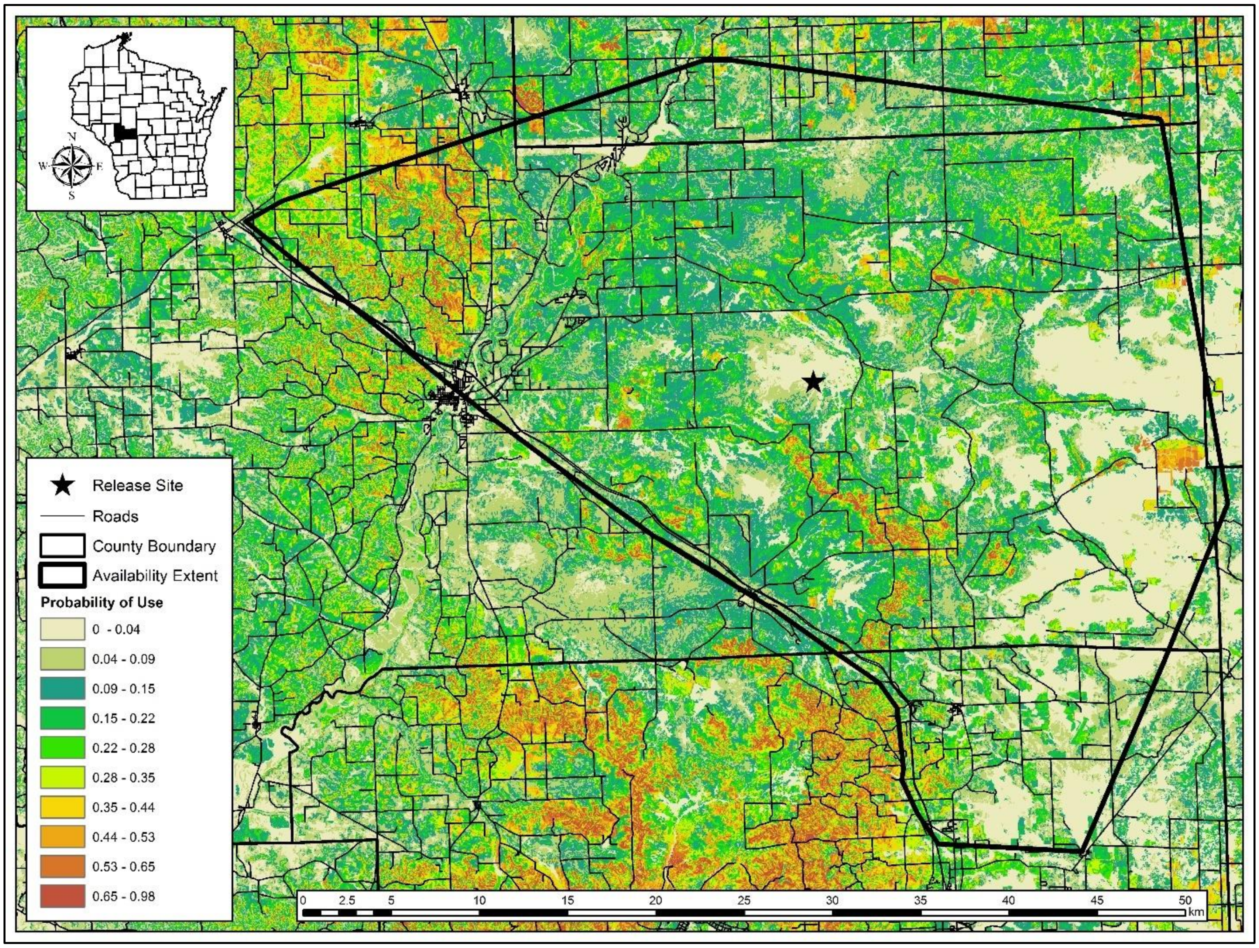

Figure 12. Probability map of elk habitat use for days 271 – 365 post-release for elk reintroduced to Jackson County in 2015 and 2016. The map was constructed by applying model coefficients to the model variable raster dataset. Probability values coincide with the 10 RSF bins used for model validation. RSF bins were sorted by natural breaks in ArcGIS.

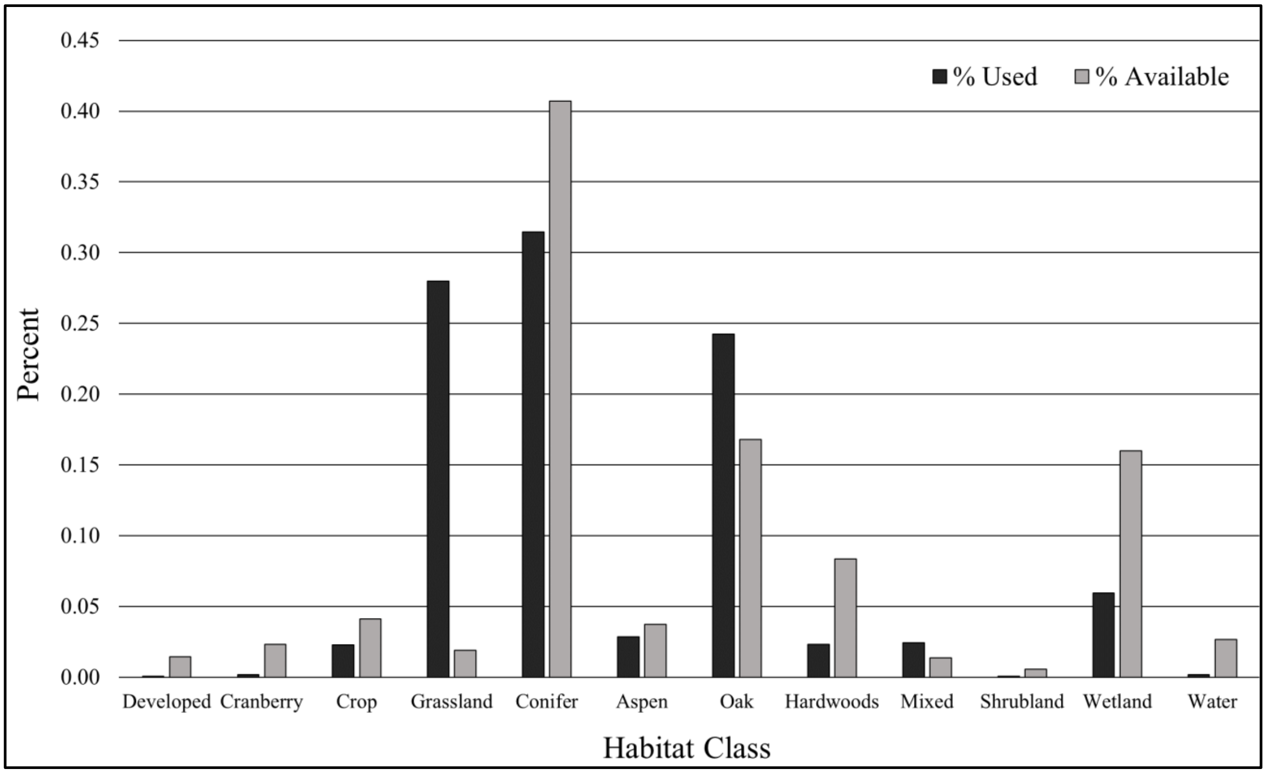

Figure 13. Percent use vs. percent of available habitat types within the availability extent, for elk reintroduced to Jackson County in 2015 and 2016,1 - 90 days post-release. Used is based on the habitat type at individual elk locations, and availability is based on the habitat type at the random locations.

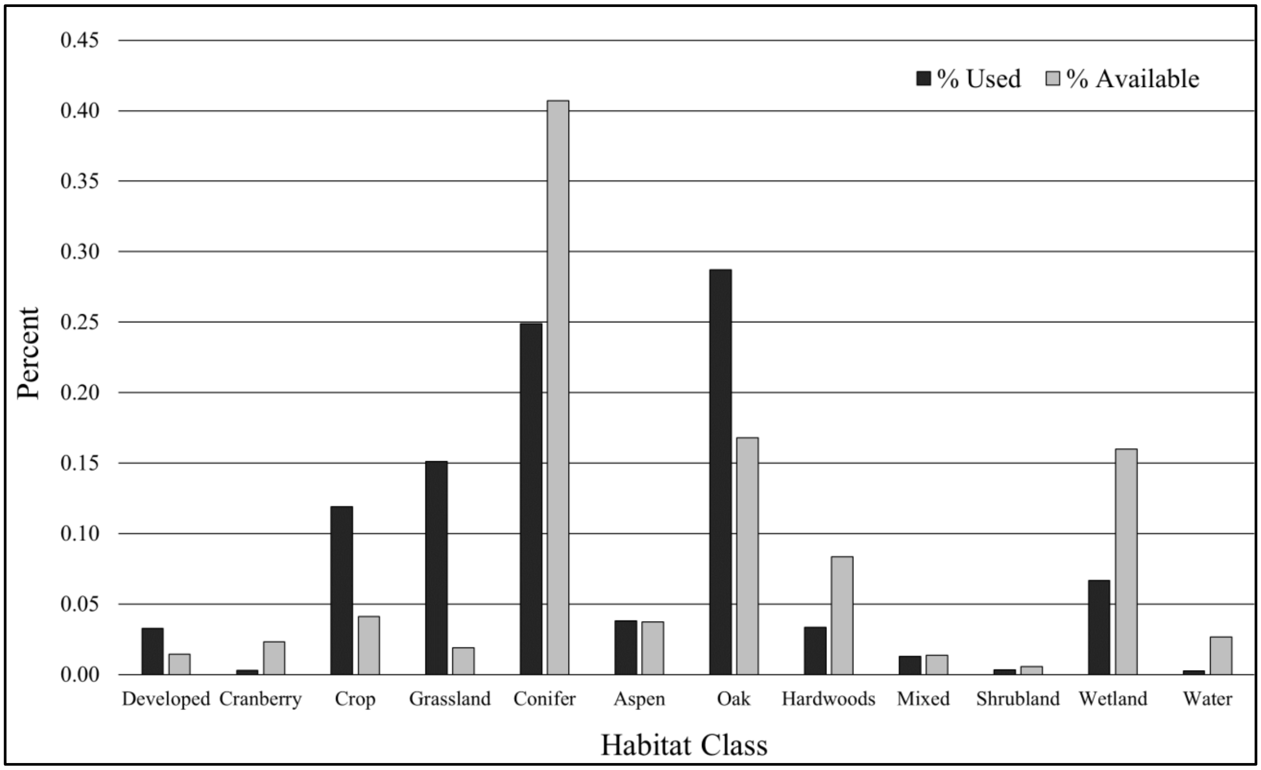

Figure 14. Percent use vs. percent of available habitat types within the availability extent, for elk reintroduced to Jackson County in 2015 and 2016,91 - 180 days post-release. Used is based on the habitat type at individual elk locations, and availability is based on the habitat type at the random locations.

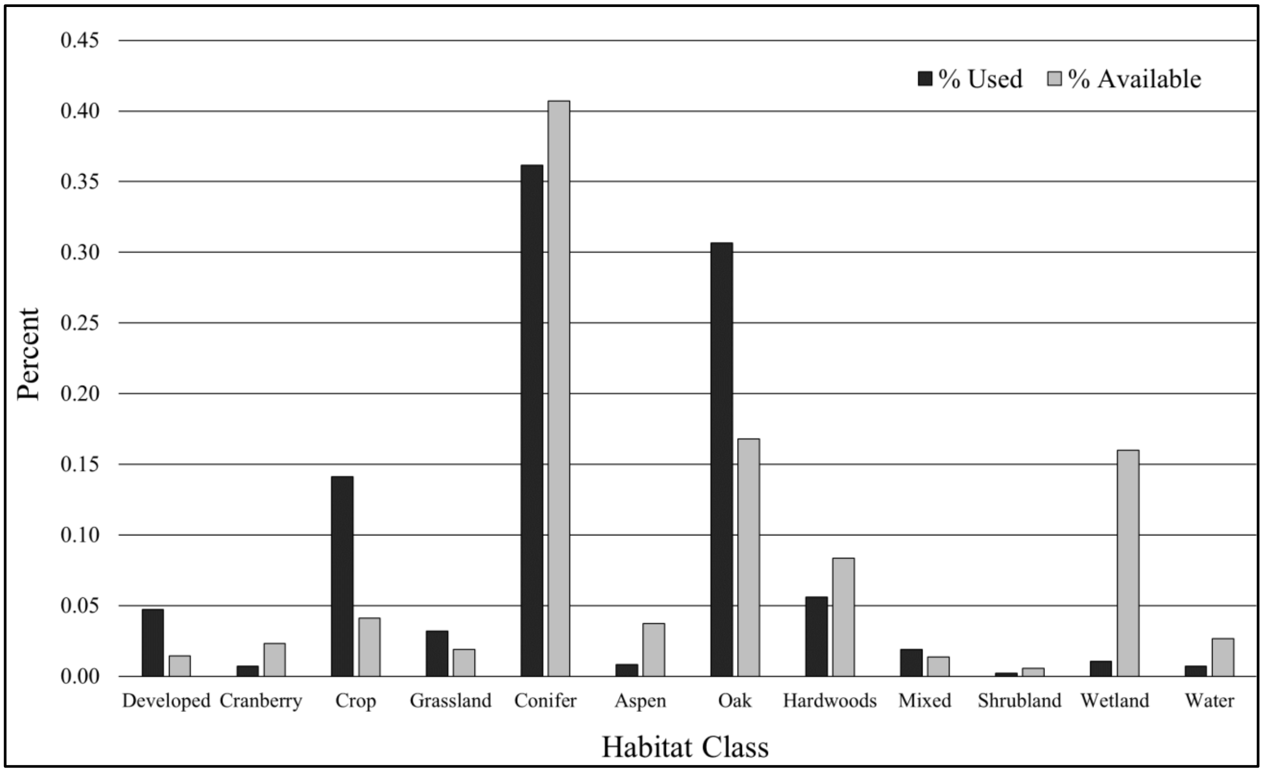

Figure 15. Percent use vs. percent of available habitat types within the availability extent, for elk reintroduced to Jackson County in 2015 and 2016,181 - 270 days post-release. Used is based on the habitat type at individual elk locations, and availability is based on the habitat type at the random locations.

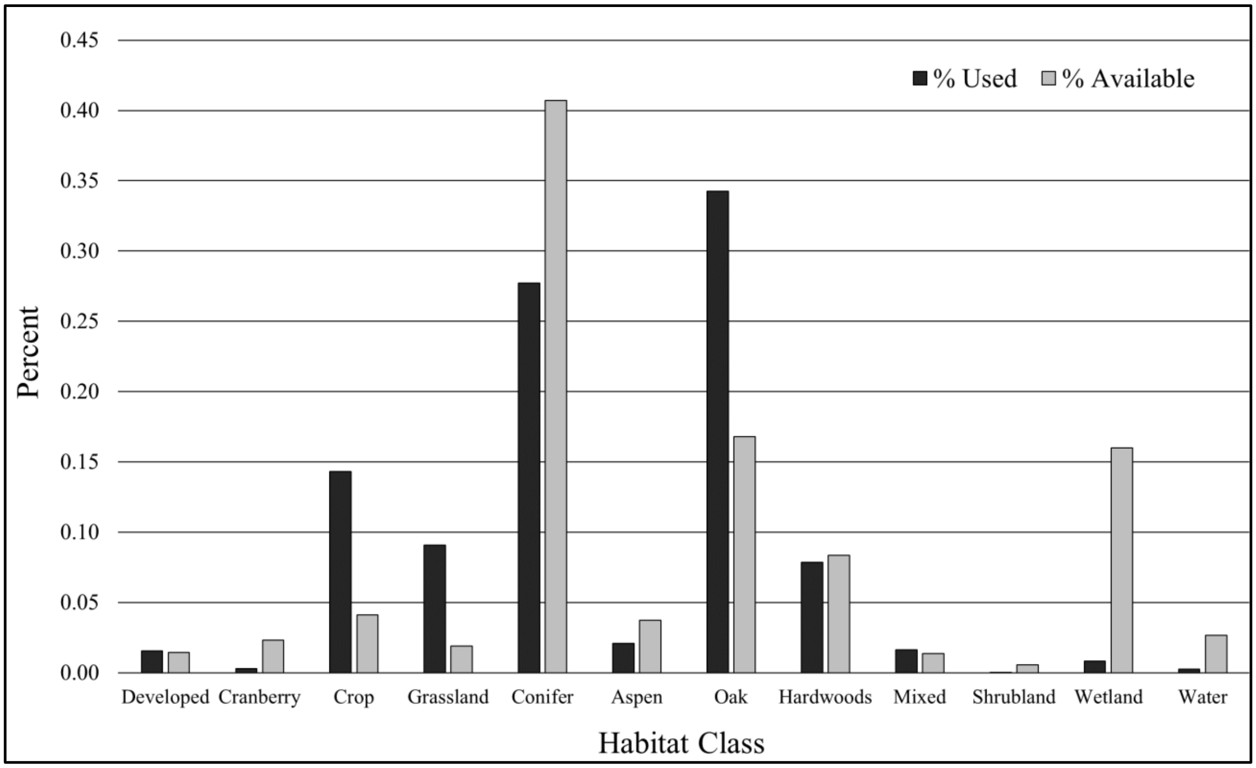

Figure 16. Percent use vs. percent of available habitat types within the availability extent, for elk reintroduced to Jackson County in 2015 and 2016,271-365 days post-release. Used is based on the habitat type at individual elk locations, and availability is based on the habitat type at the random locations.

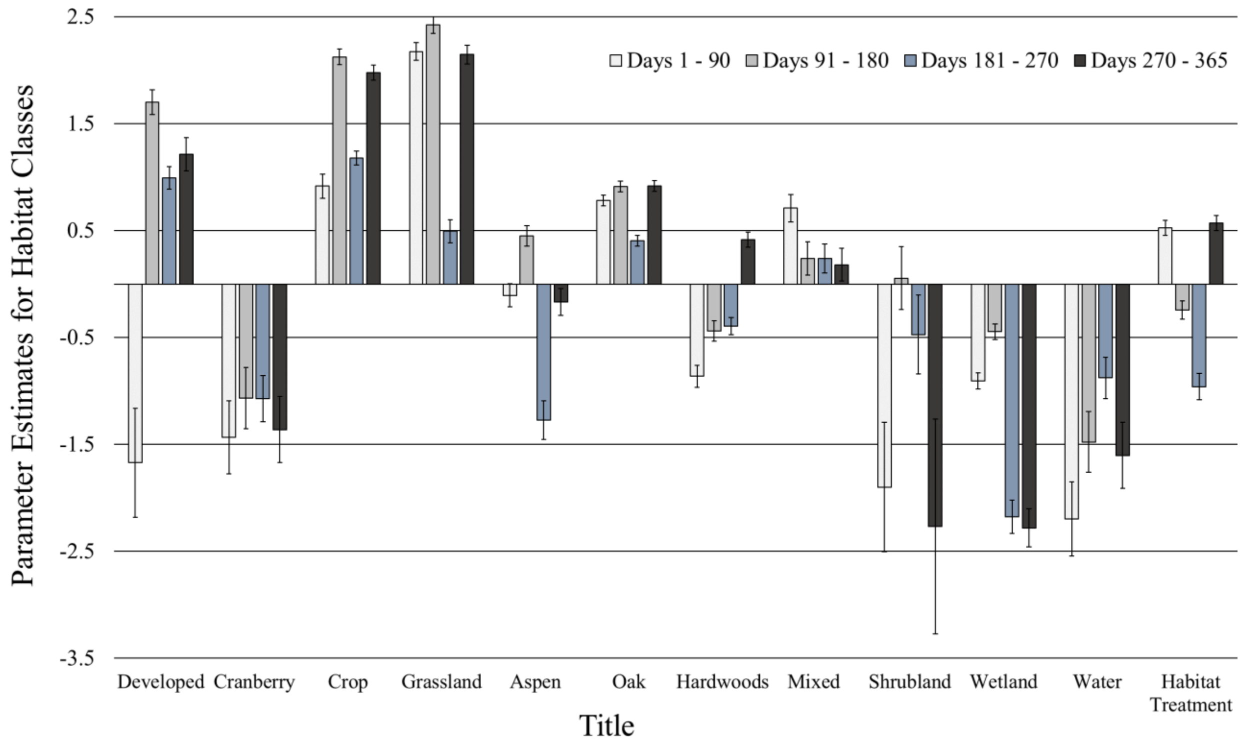

Figure 17. Coefficient estimates for the habitat variables of the RSF models for each time period for elk reintroduced to Jackson County in 2015 and 2016. Estimates are in reference to the coniferous habitat class. Error bars equal standard errors.

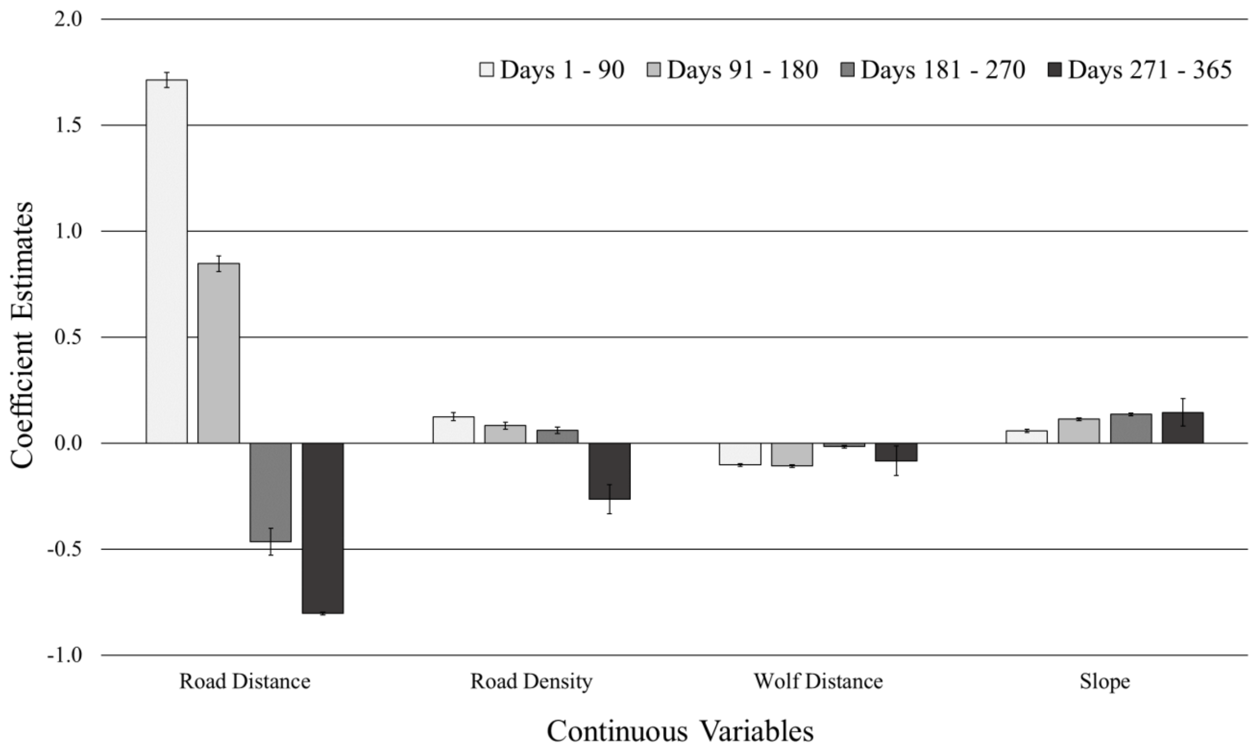

Figure 18. Coefficient estimates for the continuous variables of the RSF models for each time period for elk reintroduced to Jackson County in 2015 and 2016. Error bars equal standard errors.

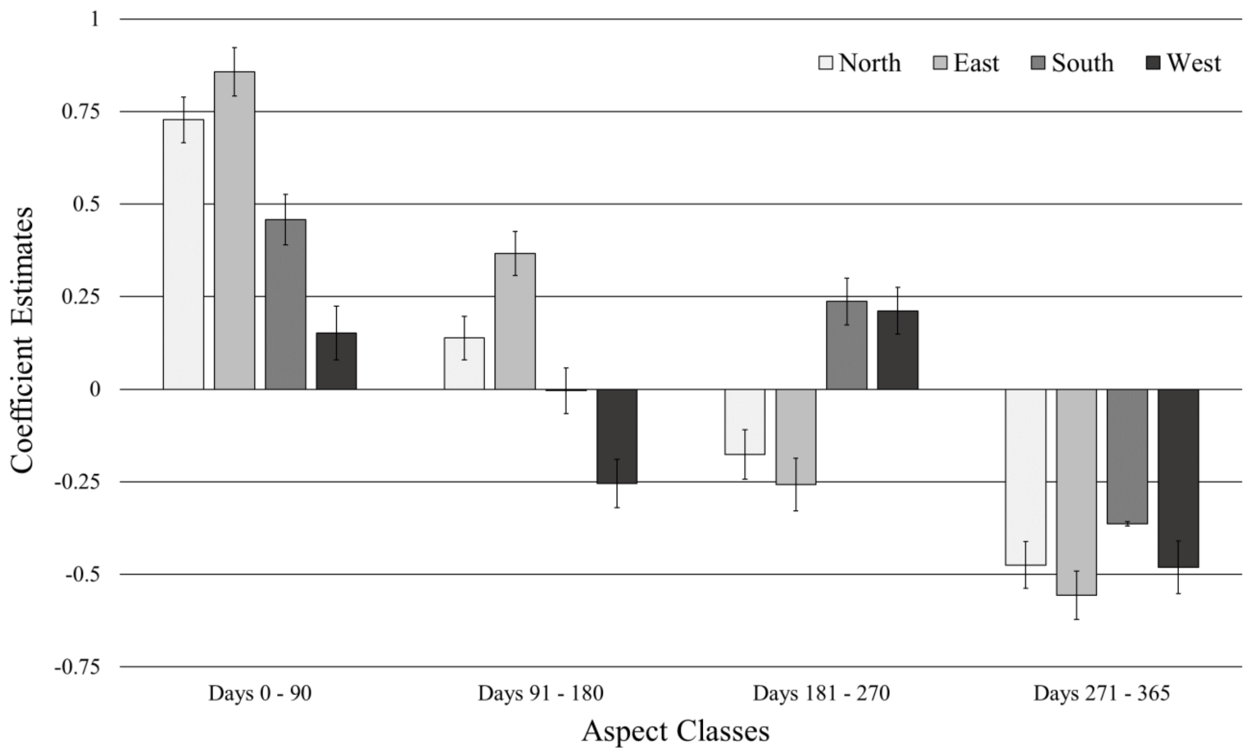

Figure 19. Coefficient estimates for the aspect classes of the RSF models for each time period for elk reintroduced to Jackson County in 2015 and 2016. Estimates are in reference to the no aspect class. Error bars equal standard errors.

TABLES

Days 1-90 Post-release

Rank:	Model:	Model Components	Intercept	K	logLik	AICc	ΔAICc	Wi
1.	Global	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-3.199	21	-8834.069	17710.173	0	1
2.	46	Habitat + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-3.038	20	-8851.749	17743.529	33.356	0
3.	27	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Habitat Treatment	-3.214	20	-8859.829	17759.690	49.517	0
4.	26	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope	-3.116	20	-8860.615	17761.260	51.088	0
5.	44	Habitat + Road Distance + Wolf Distance + Aspect + Habitat Treatment	-3.062	19	-8875.163	17788.355	78.182	0
6.	43	Habitat + Road Distance + Wolf Distance + Aspect + Slope	-2.965	19	-8876.665	17791.358	81.185	0
7.	23	Habitat + Road Density + Road Distance + Wolf Distance + Aspect	-3.13	19	-8887.532	17813.092	102.919	0
8.	40	Habitat + Road Distance + Wolf Distance + Aspect	-2.989	18	-8901.285	17838.595	128.422	0
9.	35	Habitat + Road Density + Road Distance + Wolf Distance + Slope + Habitat Treatment	-2.793	17	-8963.867	17961.757	251.584	0
10.	45	Habitat + Road Distance + Wolf Distance + Slope + Habitat Treatment	-2.624	16	-8983.473	17998.966	288.793	0

Table 4. Model selection results for resource selection by elk reintroduced to Jackson County in 2015 and 2016. 1 – 90 days post-release.

Days 91-180 Post-release

Rank:	Model:	Model Components	Intercept	K	logLik	AICc	ΔAICc	Wi
1.	Global	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-2.285	21	-9962.671	19967.378	0	0.963
2.	26	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope	-2.309	20	-9966.922	19973.876	6.499	0.037
3.	46	Habitat + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-2.16	20	-9975.392	19990.817	23.439	0
4.	43	Habitat + Road Distance + Wolf Distance + Aspect + Slope	-2.183	19	-9980.239	19998.506	31.128	0
5.	35	Habitat + Road Density + Road Distance + Wolf Distance + Slope + Habitat Treatment	-2.259	17	-10019.559	20073.141	105.763	0
6.	24	Habitat + Road Density + Road Distance + Wolf Distance + Slope	-2.286	16	-10024.234	20080.489	113.111	0
7.	45	Habitat + Road Distance + Wolf Distance + Slope + Habitat Treatment	-2.132	16	-10032.151	20096.323	128.945	0
8.	41	Habitat + Road Distance + Wolf Distance + Slope	-2.157	15	-10037.448	20104.914	137.537	0
9.	27	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Habitat Treatment	-2.312	20	-10139.689	20319.410	352.032	0
10.	23	Habitat + Road Density + Road Distance + Wolf Distance + Aspect	-2.335	19	-10144.345	20326.719	359.341	0

Table 5. Model selection results for resource selection by elk reintroduced to Jackson County in 2015 and 2016. 91 – 180 days post-release.

Days 181-270 Post-release

Rank:	Model:	Model Components	Intercept	K	logLik	AICc	ΔAICc	Wi
1.	Global	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-1.802	21	-9483.135	19008.307	0	0.999
2.	46	Habitat + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-1.677	20	-9491.554	19023.140	14.833	0.001
3.	34	Habitat + Road Density + Wolf Distance + Aspect + Slope + Habitat Treatment	-2.106	20	-9511.645	19063.323	55.016	0
4.	26	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope	-1.861	20	-9520.851	19081.734	73.427	0
5.	43	Habitat + Road Distance + Wolf Distance + Aspect + Slope	-1.731	19	-9530.302	19098.633	90.326	0
6.	35	Habitat + Road Density + Road Distance + Wolf Distance + Slope + Habitat Treatment	-1.754	17	-9541.661	19117.345	109.039	0
7.	45	Habitat + Road Distance + Wolf Distance + Slope + Habitat Treatment	-1.62	16	-9550.824	19133.669	125.363	0
8.	31	Habitat + Road Density + Wolf Distance + Aspect + Slope	-2.174	19	-9550.995	19140.019	131.712	0
9.	53	Habitat + Wolf Distance + Aspect + Slope + Habitat Treatment	-2.019	19	-9560.179	19158.388	150.081	0
10.	33	Habitat + Road Density + Wolf Distance + Slope + Habitat Treatment	-2.048	16	-9570.753	19173.527	165.220	0

Table 6. Model selection results for resource selection by elk reintroduced to Jackson County in 2015 and 2016. 181 – 270 days post-release.

Days 271 – 365 Post-release

Rank:	Model:	Model Components	Intercept	K	logLik	AICc	ΔAICc	Wi
1.	Global	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-0.998	21	-8828.076	17698.189	0	1
2.	26	Habitat + Road Density + Road Distance + Wolf Distance + Aspect + Slope	-0.941	20	-8858.409	17756.851	58.662	0
3.	35	Habitat + Road Density + Road Distance + Wolf Distance + Slope + Habitat Treatment	-1.32	17	-8869.500	17773.024	74.835	0
4.	24	Habitat + Road Density + Road Distance + Wolf Distance + Slope	-1.256	16	-8897.525	17827.071	128.882	0
5.	34	Habitat + Road Density + Wolf Distance + Aspect + Slope + Habitat Treatment	-1.576	20	-8904.670	17849.374	151.185	0
6.	46	Habitat + Road Distance + Wolf Distance + Aspect + Slope + Habitat Treatment	-1.456	20	-8907.026	17854.085	155.896	0
7.	53	Habitat + Wolf Distance + Aspect + Slope + Habitat Treatment	-1.641	19	-8926.299	17890.629	192.440	0
8.	31	Habitat + Road Density + Wolf Distance + Aspect + Slope	-1.509	19	-8931.605	17901.239	203.050	0
9.	43	Habitat + Road Distance + Wolf Distance + Aspect + Slope	-1.403	19	-8939.250	17916.529	218.340	0
10.	33	Habitat + Road Density + Wolf Distance + Slope + Habitat Treatment	-1.864	16	-8942.672	17917.364	219.175	0

Table 7. Model selection results for resource selection by elk reintroduced to Jackson County in 2015 and 2016. 271 – 365 days post-release.

Model Variable	Parameter Estimate	SE	Lower 95% CI	Upper 95% CI
(Intercept)	-3.199	0.079	-3.354	-3.046
Developed	-1.670	0.510	-2.855	-0.800
Cranberry	-1.433	0.343	-2.180	-0.821
Crop	0.915	0.111	0.695	1.129
Grassland	2.175	0.085	2.010	2.342
Aspen	-0.105	0.106	-0.316	0.099
Oak	0.781	0.050	0.682	0.879
Hardwoods	-0.862	0.104	-1.070	-0.662
Mixed Conifer/Deciduous	0.710	0.128	0.456	0.957
Shrubland	-1.899	0.604	-3.327	-0.875
Wetland	-0.906	0.076	-1.055	-0.759
Water	-2.195	0.347	-2.951	-1.573
Habitat Treatment	0.526	0.071	0.387	0.664
Road Distance	1.712	0.035	1.644	1.781
Road Density	0.124	0.020	0.085	0.163
Wolf Distance	-0.104	0.007	-0.118	-0.089
Slope	0.057	0.008	0.042	0.071
Aspect North	0.727	0.062	0.606	0.850
Aspect East	0.857	0.065	0.729	0.985
Aspect South	0.458	0.068	0.325	0.592
Aspect West	0.152	0.072	0.010	0.293

Table 8. Parameter estimates, standard errors, and 95% confidence intervals for habitat variables of the top model as determine by AIC for the 1 – 90 day time period.

Model Variable	Parameter Estimate	SE	Lower 95% CI	Upper 95% CI
(Intercept)	-2.285	0.069	-2.421	-2.150
Developed	1.701	0.116	1.473	1.926
Cranberry	-1.066	0.285	-1.676	-0.550
Crop	2.125	0.071	1.986	2.263
Grassland	2.422	0.080	2.266	2.579
Aspen	0.449	0.095	0.260	0.633
Oak	0.911	0.050	0.813	1.008
Hardwoods	-0.439	0.093	-0.625	-0.260
Mixed Conifer/Deciduous	0.239	0.156	-0.076	0.537
Shrubland	0.055	0.294	-0.563	0.597
Wetland	-0.445	0.073	-0.590	-0.303
Water	-1.476	0.285	-2.087	-0.960
Habitat Treatment	-0.245	0.086	-0.416	-0.079
Road Distance	0.846	0.037	0.774	0.918
Road Density	0.081	0.016	0.050	0.112
Wolf Distance	-0.108	0.006	-0.120	-0.096
Slope	0.112	0.006	0.101	0.124
Aspect North	0.138	0.059	0.023	0.254
Aspect East	0.367	0.060	0.249	0.484
Aspect South	-0.004	0.062	-0.125	0.117
Aspect West	-0.255	0.065	-0.383	-0.127

Table 6. Parameter estimates, standard errors, and 95% confidence intervals for habitat variables of the top model as determine by AIC for the 91 – 181 day time period.

Model Variable	Parameter Estimate	SE	Lower 95% CI	Upper 95% CI
(Intercept)	-1.802	0.073	-1.947	-1.659
Developed	0.993	0.105	0.785	1.199
Cranberry	-1.072	0.217	-1.525	-0.671
Crop	1.180	0.065	1.052	1.308
Grassland	0.494	0.108	0.280	0.702
Aspen	-1.274	0.180	-1.645	-0.937
Oak	0.405	0.049	0.308	0.502
Hardwoods	-0.394	0.080	-0.553	-0.240
Mixed Conifer/Deciduous	0.240	0.136	-0.032	0.501
Shrubland	-0.473	0.369	-1.281	0.186
Wetland	-2.177	0.157	-2.499	-1.883
Water	-0.877	0.192	-1.274	-0.519
Habitat Treatment	-0.959	0.124	-1.209	-0.723
Road Distance	-0.465	0.064	-0.591	-0.341
Road Density	0.060	0.014	0.031	0.088
Wolf Distance	-0.018	0.006	-0.029	-0.006
Slope	0.135	0.006	0.124	0.146
Aspect North	-0.176	0.067	-0.308	-0.045
Aspect East	-0.257	0.071	-0.397	-0.118
Aspect South	0.237	0.063	0.114	0.361
Aspect West	0.212	0.063	0.088	0.336

Table 7. Parameter estimates, standard errors, and 95% confidence intervals for habitat variables of the top model as determine by AIC for the 181 – 270 day time period.

Model Variable	Parameter Estimate	SE	Lower 95% CI	Upper 95% CI
(Intercept)	-0.998	0.077	-1.148	-0.848
Developed	1.213	0.154	0.902	1.508
Cranberry	-1.362	0.308	-2.028	-0.808
Crop	1.978	0.071	1.839	2.117
Grassland	2.146	0.086	1.976	2.315
Aspen	-0.169	0.125	-0.420	0.070
Oak	0.916	0.051	0.816	1.015
Hardwoods	0.415	0.073	0.271	0.556
Mixed Conifer/Deciduous	0.181	0.153	-0.126	0.473
Shrubland	-2.268	1.006	-5.138	-0.765
Wetland	-2.280	0.178	-2.647	-1.948
Water	-1.602	0.308	-2.268	-1.048
Habitat Treatment	0.571	0.071	0.431	0.709
Road Distance	-0.803	0.069	-0.941	-0.669
Road Density	-0.265	0.023	-0.311	-0.221
Wolf Distance	-0.084	0.006	-0.096	-0.072
Slope	0.144	0.006	0.133	0.156
Aspect North	-0.475	0.064	-0.601	-0.348
Aspect East	-0.556	0.069	-0.691	-0.422
Aspect South	-0.363	0.064	-0.488	-0.239
Aspect West	-0.481	0.065	-0.609	-0.353

Table 8. Parameter estimates, standard errors, and 95% confidence intervals for habitat variables of the top model as determine by AIC for the 271 – 365 day time period.