Summer distribution, abundance, movements and diet of reintroduced elk (*Cervus canadensis*) in habitats created by clearcutting in the boreal forest

by

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Abstract

The Ontario elk restoration program involved 443 elk (*Cervus canadensis*) from Elk Island National Park, Alberta, re-introduced into four areas of Ontario during 1998–2001. In northwestern Ontario, the Lake of the Woods (LOW) region received a total of 104 elk in 2000 and 2001. Currently, the region supports a small, free-ranging elk population with a relatively slow rate of increase; most often the elk occupy grassy clearcuts created by logging. In this study, population size and use of foraging patches and roads are described for the spring – summer period. Seasonal home range and activity patterns are evaluated using motion activated cameras, radio-telemetry and direct observation. Spring – summer diet composition is described from microhistological analysis of fecal pellets.

Camera-based capture-mark-recapture was an effective tool for assessing population size and activity. A large photo set (*n*=450,000) was used to estimate the number of elk individuals, their average residence time in each foraging patch, and the relative frequency of shared use of foraging patches with moose (*Alces americanus*) and white-tailed deer (*Odocoileus virginianus*). Of 252 elk photo-captures (average of 3.5 photos/camera), 193 were in foraging patches and 59 were on revegetated roads. Capture frequency in foraging patches ranged from 1 to 37 captures/individual elk, with 21 of 39 unique individuals captured only once. On revegetated roads, capture frequency ranged from 1 to 12 captures/individual elk, with 15 of 39 unique individuals captured only once. The individual identification allowed capture-mark-recapture estimates by sex of 29 females (SE = 6.82, 95% CI = 21-51 individuals) and 19 males (SE = 0.36, 95% CI = 19-19 individuals). Overall, the LOW region has a minimum of 39 elk (SE = 0.98, 95% CI = 39-46 individuals). Residence time in foraging patches varied with patch size and spatial distribution. Minimum residence time ranged from 1-181 minutes with the highest number of visits and residence time on revegetated roads during June and July, and in foraging patches during August and September. Activity was relatively higher at dusk and dawn.

Of 9,300 epidermal fragments from 31 fecal pellets samples, 42% were identified as woody browse (8 genera and 15 species), 33% forbs and ferns (2 genera and 13 species), 22% grasses (7 species), and 3% sedges (3 species). In winter-spring, elk consumed a higher fraction of woody browse (53%) than forbs (25%), and in the spring-summer, a higher fraction of forbs (42%) and grasses (30%) than woody browse (26%). Research on diet selectivity is necessary to explain in detail the observed feeding patterns.

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General Introduction

Elk, eastern red deer or wapiti (*Cervus canadensis*; Randi et al., 2001) were once the most widespread member of the deer family (Cervidae), occurring across North America and also occupying most of Europe and Asia (Seton, 1927; O'Gara and Dundas, 2002). Due to pressure from human expansion, habitat loss and exploitative hunting throughout the 1800s and early 1900s, elk populations across North America radically declined and in some areas were extirpated (Bryant and Maser, 1982; Ranta, 1979). At present, there are three subspecies of elk in North America: Roosevelt elk (*Cervus canadensis roosevelti*), Tule elk (*C. c. nannodes*), and Rocky Mountain elk (*C. c. nelson*; Polziehn et al., 1998, 2000; Randi et al., 2001). Once native to Ontario and now extinct, a fifth subspecies (*C. c. canadensis*) previously occupied the eastern deciduous forest westward to approximately 95 degrees longitude, northward to about the 47th parallel, and southward to about the 34th parallel (Bryant and Maser, 1982; Hamr et al., 2016). The eastern subspecies was apparently non-migratory (Murie, 1951). Rocky Mountain elk successfully introduced into original eastern elk range likewise have not displayed migratory behaviour (Moran, 1973).

Regardless of migratory behaviour, the availability of large areas of habitat is important to elk, not only in terms of maximizing forage availability, but also to allow for spatial redistribution of elk groups during calving, resting, feeding and breeding. Seasonal movement of an animal, over short distances or longer migrations, can be influenced by numerous factors, including habitat overlap with competitors, changes in forage availability, weather conditions (Nelson and Leege, 1982; Anderson et al., 2005), and predation (Gower et al., 2008). Behaviours associated with movement can also vary with body mass, gender and age (Mysterud et al., 2001). Rocky Mountain elk generally move to higher elevations in the summer and to lower elevations in winter in search of more digestible forage (Boyce, 1991; Middleton et al., 2013).

Elk restoration in Ontario

Several unsuccessful attempts to introduce Rocky Mountain elk into Ontario occurred in the early 1900s. In the 1930s, the Ontario Department of Lands and Forests translocated a number of elk from Alberta to Pembroke Game Preserve, the Nipigon-Onamon Game Preserve, the Chapleau Game Preserve, the Goulais River Ranger Lake Game Preserve, and the Burwash Industrial Farm (Hamr et al., 2016). Many of these animals were thought to be infested with liver fluke (*Fascioloides magna*), and were subsequently killed because of a perceived health risk to livestock and other local cervids, (Rosatte et al., 2007). A small population managed to survive in the Nipissing/French River area of Ontario, and has been protected since 1980. In 1996 this population was estimated to number approximately 60 animals (Bellhouse and Broadfoot, 1998) and is currently estimated at 150 animals (J. Hamr, pers. comm.).

The Ontario Ministry of Natural Resources (OMNR), along with many partner organisations, undertook a new elk restoration program, in 1995, and 443 elk were eventually translocated from Elk Island National Park (EINP), Alberta, to several locations in Ontario, including Nipissing/French River, Bancroft/North Hastings, Lake Huron/North Shore, and the Lake of the Woods area (LOW; Rosatte et al., 2002). Over the winters of 1999-2000 and 2000-2001, 104 Rocky Mountain elk, including 73 radio-collared individuals, were soft-released into the area of Cameron Lake Road in northwestern Ontario, approximately 25 km northeast of the town of Nestor Falls. These animals and their offspring eventually became known as the LOW elk population (Rosatte et al., 2002). In January 2000, 60 elk (21 males and 39 females) were translocated from EINP to LOW. Among the males, 8 were calves (8-9 months old), 1 was a yearling (20-21 months old), and 12 were adults (>2.5 years old). Among the females, 6 were calves, 1 was a yearling, and 32 were adults. Nine adult males and 21 adult females were fitted with VHF (very high frequency) radio-collars equipped with motion sensitive mortality sensors (Model LMRT-4; 148-151 MHz; Lotek Engineering Inc., Newmarket, Ontario). In February 2001, an additional 44 elk (22 males and 22 females) were translocated from EINP to LOW. Among the males, 9 were calves, 6 were yearlings, and 7 were adults, and among the females, 5 were calves, 6 were yearlings, and 11 were adults. Of these, 18 males and 25 females were fitted with VHF radio-collars. Prior to translocation, all animals were tested and treated for various diseases and parasites, ear tagged, and fitted with radio collars using the process outlined in Rosatte et al. (2002).

Shortly after release, 70% of the collared elk remained within a 20-km radius of the release site, while 30% dispersed, mostly to a location approximately 90 km south of the release site (McIntosh, 2003). The LOW area continues to support only a small elk population with a relatively low rate of increase, compared to elk populations at other Ontario re-introduction sites (OMNR 2013).

Previous studies in the Lake of the Woods region

The low rate of increase in the LOW elk population has been a concern for those interested in the successful re-establishment of elk. Factors limiting LOW population growth may include competition from moose (*Alces americanus*; Bradley et al., 2014) and white-tailed deer (*Odocoileus virginianus*) for forage resources and predation by wolves (*Canis lupus*) and black bear (*Ursus americana*). At present, explanations for the low rate of increase are speculative, but one major concern is that the landscape does not contain the resources required to support a large population of elk. Previous studies on elk in northwestern Ontario, comprising three Master's theses at Lakehead University that were supported by groups interested in elk restoration, have attempted to clarify some of the limiting factors:

1. ***McIntosh, T. E. 2003*** **–** *Movements, survival and habitat use by elk reintroduced to Northwestern Ontario.*

The objectives were to examine spatial behaviour, habitat relationships, and population characteristics of recently reintroduced elk in the Cameron Lake region. In order to assess the relative risk of newly re-introduced elk becoming infected with either liver fluke (*Fascioloides magna*) or brainworm (*Parelaphostrongylus tenuis*), fecal pellets were collected from white-tailed deer resident near Cameron

Lake.

Fifty-nine of the original 73 radio-collared elk were repeatedly relocated by radio telemetry to provide reliable information on post-release dispersal and movement. Throughout the study period, 70% of the elk released in 2000 and 2001 were consistently relocated within a 20-km radius of the release site, and remained near forest clear-cuts and roads. The remaining 30% dispersed southward to a location approximately 90 km from the release site, near the communities of Fort Frances and Rainy River.

2. ***Dewar, N. E. 2006*** – *Development and evaluation of inductive and deductive models of elk* (*Cervus elaphus*) *summer resource suitability in Northwestern Ontario*

A deductive model was based on published elk – resource relationships in Canada and United States and developed in the form of a Habitat Suitability Index.
An inductive model was based on the ratio of available habitat to telemetry location data and presented in the form of a Resource Utilization Function.

Foraging opportunities for elk in the LOW region were different from those in the western states and western provinces of North America, where elk often occupied open, grassy meadows. LOW elk were influenced in their habitat choice by the arrangement of areas of forage and cover, rather than by the extent of foraging areas alone. The major foraging areas for elk in the Cameron Lake region were recent clear-cuts and reforested stands, which provided increased amounts of edge between areas of forage and cover. Elk also preferentially used areas with higher road densities, and it was inferred that roadsides provide better forage, making them attractive to elk for this reason.

3. ***Moreira, A. 2012*** – *Using a novel methodology to test whether group size affects foraging behaviour in elk.*

Foraging behaviour of farm elk was explored with respect to group size. Larger group sizes in farm elk (Egli's Sheep Farm, Minnitaki, Ontario) were associated with lower levels of vigilance during feeding trials. Elk appeared to manage predation risk using group formation, and an optimal landscape allows for foraging opportunities of larger groups. Moreira (2012) predicted the LOW elk population will grow faster when larger groups are more common.

The current study

Throughout their range in North America, elk are found in habitats that include hardwood and coniferous forests and grasslands (Skovlin, 1982). Their distribution overlaps with moose and white-tailed deer to varying extents, where interaction among the species is possible. These interactions may take several forms such as exploitation and interference competition. The major interaction among cervids is competition for resources such as food and cover affected by diet similarity, range overlap, timing of habitat use, and population size (Nelson, 1982; Miller, 2002; Jenkins et al., 2007; Darmon et al., 2012). The greatest competition for food is likely to occur in areas where elk browse, such as patches created by clear cutting, which offer a unique elk habitat in the Boreal-Great Lakes/St. Lawrence Ecotone forest common to the LOW area.

In this study, I used camera traps for capture-mark-recapture, closed-population estimates of the LOW elk population size. I evaluated the interaction of elk with other large herbivores and predators, their seasonal movements, diet composition, food availability, and residence times in foraging patches created by clear cutting.

Objectives

The primary objectives of this study were to investigate:

- whether low density elk populations can be adequately sampled and estimated using capture-mark-recapture, closed-population models and remotely triggered camera traps;
- how elk allocate their time among foraging patches that vary in size, distribution and quality;
- how elk allocate time among reforested patches and roads in the LOW region.
- whether competitors such as moose, white-tailed deer, black bear, and wolf use the same foraging patches at the same time as elk in the LOW region and how the diet of elk in the LOW region compares to the diets of elk from elsewhere.

In the western states and provinces of North America, the grassland biome is the natural range for elk. According to McIntosh (2003), similar landscapes in the LOW region are wetlands, which elk did not select as habitat. Mixed forest habitats and regenerating clear-cuts in the LOW region; however, appear to offer a patch work matrix selected by foraging elk, with an abundance and diversity of forage species likely higher than grasslands. In parts of their western range, where grasslands are limited, elk regularly use aspen forests following logging, and prefer south-facing hillsides, particularly during spring (White, 1998; YEMPT, 2008). Logging activities create only a temporary displacement for elk, and they may habituate to disturbances if logging occurs over long periods (Beall, 1976). Evidence suggests that elk respond to non-disturbance by decreasing the buffer zone (500–1000 m) around disturbed areas and by moving into preferred areas for foraging. There is no evidence that elk will not eventually return to previously logged areas (Edge and Marcum, 1985). Marcum (1977) suggested that logging activities in winter resulted in less movement compared to the similar activity in summer.

The results of this study are organized into two chapters: (i) evaluating foraging patch use, seasonal activity patterns, and reliability of population estimates using motion activated cameras; and (ii) identifying diet composition by microhistological analysis of elk fecal pellets.

Study area

The area inhabited by the re-introduced elk population encompasses approximately 10,000 km^2 in the Lake of the Woods (LOW) region of northwestern Ontario. The town of Sioux Narrows is to the north, the United States border to the south, the Ontario/Manitoba border to the west, and the town of Fort Frances to the east ($49^0$16'N, $93^0$42'W; Figure 1). The study area lies in a transition zone between the Boreal Forest Biome and the Great Lakes/St. Lawrence Ecotonal Forests, and habitat varies markedly from north to south (Rowe and Halliday, 1972).

The northern part of the study area is more typical of the Boreal Forest, dominated by coniferous trees, including black spruce (*Picea mariana*), white spruce (*P. glauca*), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), and larch (*Larix laricina*). White birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), large-toothed aspen (*P. grandidentata*) and balsam poplar (*P. balsamifera*) are also found in the region. The terrain varies from lowland peat bogs to exposed bedrock with many lakes and ponds. Elevation ranges from 100 m above sea level (a.s.l.) to 490 m a.s.l. and the mean elevation is 350 m a.s.l. (Rowe and Halliday, 1972).

The southern part of the area is more typical of the Great Lakes/St. Lawrence Lowland Forest, characterized by a mixture of coniferous and deciduous forests. It is dominated by white pine (*Pinus strobus*), red pine (*P. resinosa*), jack pine (*P. banksiana*), black spruce, white cedar (*Thuja occidentalis*), large-toothed aspen, trembling aspen, paper birch, mountain maple (*Acer spicatum*), and red maple (*A. rubrum*), Bebb's willow (*Salix bebbiana*) and white willow (*S. alba*). Here, elevation ranges from 240 m a.s.l. to 470 m a.s.l. with a mean of 340 m a.s.l. (Rowe and Halliday, 1972).

Both parts of the study area support ongoing forestry activities (harvesting and forest fire suppression), resulting in a patchwork of different aged stands. Regeneration initiatives are both artificial and natural, and mainly consist of red pine, white pine, spruce and aspen. The climate is cold temperate conditional, with some local moderation by larger lakes and other topographic features (Brunskill and Schindler, 1971). Climate varies from north to south, in terms of mean total snow depth, which on the last day of January, is considerably greater in the northern part of the study area (37 cm) than in the southern part (27 cm; Environment Canada, 2010).

The study area is home to a diversity of fauna including moose and white-tailed deer. Potential predators are wolves, coyotes (*Canis latrans*), and black bears. Other wildlife species, including lynx (*Lynx canadensis*), bobcat (*L. rufus*), red fox (*Vulpes vulpes*), marten (*Martes americana*), beaver (*Castor canadensis*), snowshoe hare (*Lepus americanus*), and a diversity of bird species also occur here. Although data comparing the relative abundance of wildlife species in the northern and southern region of the study area are few, the density of white-tailed deer is higher in the southern region (Huchinson et al., 2003).

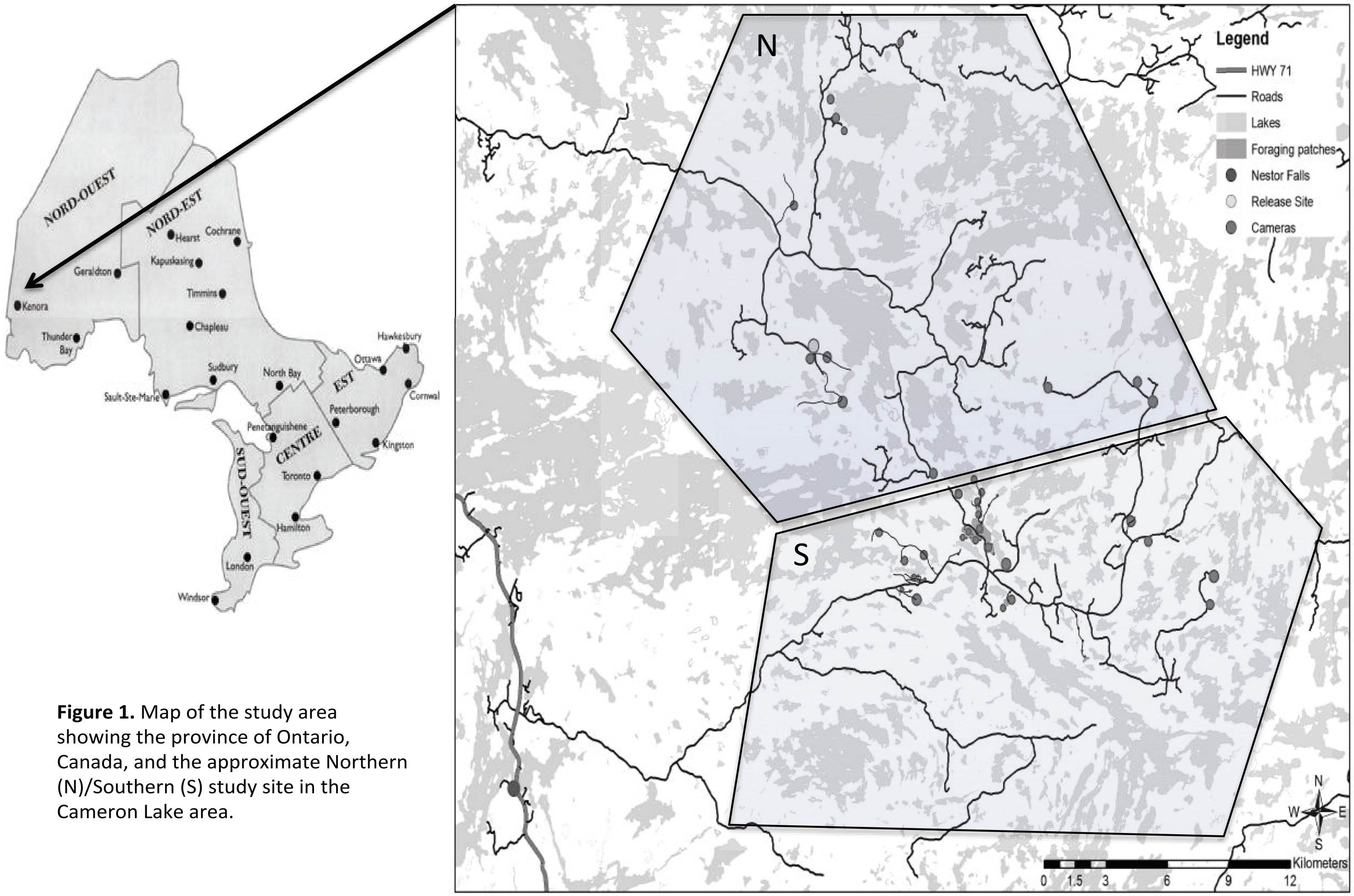


Figure 1. Map of the study area showing the province of Ontario, Canada, and the approximate Northern (N)/Southern (S) study site in the Cameron Lake area.

Chapter 1. Use of remote cameras in habitats created by clear cutting to identify population size, patch residence time, patch selection and movements of North American elk introduced to the Lake of the Woods region, Ontario

1.1. Introduction

Knowledge of movement and the use of space in animals is fundamental to conservation and wildlife management. The use of automated cameras to monitor and detect free ranging wildlife has a long history, and many models of such systems have been described (Gysel and Davis, 1956; Dodge and Snyder 1960; Carthew and Slater, 1991). Assessing free ranging wildlife populations with a method that is economically practical and also effective, can be a challenge for wildlife researchers. Motion-activated cameras with settings for continuous recording have been used for decades to study animal behaviour (Pearson, 1959; Savidge, 1988; Roberts et al., 2006; Alam et al., 2015). Traditional surveying methods such as strip counts, drive counts and capture-mark-recapture with animal handling can be expensive, labour-intensive, intrusive, and limited to habitats with good visibility (Lancia et al., 1994; Jacobson et al., 1997). As a result, researchers have begun to opt for less expensive alternatives such as remote cameras, to survey wildlife populations. However, studies using cameras may be influenced by increased human activity and scent, and the presence of equipment may alter animal behaviour (Laurance and Grant, 1994; Picman and Schriml, 1994).

Motion activated cameras are more useful for studying wildlife activity and behaviour in remote areas, too difficult to use traditional methods (Kucera and Barrett, 1993). Installing cameras is less labour-intensive than employing surveys with human observers (Seydack, 1984), and cameras provide permanent documentation of photo-captured animals (Bull et al., 1992; Picman and Schriml, 1994). Due to their relatively small size, automated functions and robust sampling duration, remote cameras can gather data during inclement weather and at night, and can be left in the field with minimal human attention, for long periods providing information on behaviour less affected by human intrusion. Also, motion activated cameras with infrared night vision settings provide the ability to observe animals throughout the day and night to develop population estimates based on capture-mark-recapture techniques without physically having to capture an individual (Jackson et al., 2006; Gupta et al., 2009).

Understanding use of space and the food habits of a species is fundamental to interpreting behaviour and allowing positive management decisions in wildlife conservation. Key to the management of large ungulates, evaluating diet quality, preference and competition is essential to clarify limiting factors affecting population density and sustainability. Since the reintroduction, studies on the introduced elk population have attempted to clarify some of these limiting factors, including dispersal, habitat use and predation (McIntosh, 2003; Dewar, 2006; Moreira, 2012). The population has been regularly monitored and surveyed, aerially or from the ground using radio-telemetry (Rosatte et al., 2007). This study is a preliminary appraisal of the use of camera data as a supplement to monitoring and estimating the population size and activity of the LOW elk population in northwestern Ontario.

The objective of this appraisal was to provide answers to the following questions:

(1) Can a low-density elk population be adequately sampled and capture-mark-recapture closed population models applied to obtain reasonable estimates of the LOW elk population size by using camera-traps?

I predicted that the LOW elk population can be adequately sampled by using camera-traps combined with direct observations to obtain a reasonable estimate of the population size and their approximate home range.

(2) How do elk allocate their time among foraging patches that vary in size, distance and quality?

I predicted that increased travel time among foraging patches leads to longer patch residence time.

(3) How do elk allocate time among reforested patches and roads in the LOW area?

I predicted that foraging patch use would vary among foraging patch size, distribution and the use of other apparent competitors. Also, I predicted that the use of revegetated roads will be mainly used for travel among foraging patches and escape routes.

(4) How can foraging patch use by other large herbivores and predators influence elk spatial distribution?

I predicted that the presence of other large herbivores and predators in the same foraging patch would affect elk residence time and patch use.

1.2. Materials and methods

1.2.1. Animal monitoring and camera placements

Since re-introduction, annual aerial calf survey, elk capture and collaring and ground-based radio telemetry have been occurring on a semi-regular basis. The primary objectives between 2007 and 2013 were to capture uncollared animals, fit them with new collars, monitor the radio-collared elk bi-weekly, and to conduct annual photo surveillances to determine movement, the size and status of the population, habitat use and survival. During this period, 8 elk were fitted with new radio-collars. Elk capture and collaring, annual aerial surveys, and photo surveillance were conducted by the LOW elk restoration committee. Members included OMNR (Centre for Northern Forest Ecosystem Research; CNFER), the Rocky Mountain Elk Restoration Inc. Thunder Bay (RMER, Inc.), the Northwestern Ontario Elk Restoration Coalition (NOERC), and Lakehead University.

A preliminary survey was carried out from May−September 2014, in which 2 adult females with functioning VHF collars were monitored on a daily basis to identify seasonal home ranges and movements. Radio-telemetry locations were obtained by triangulation from roads and travel corridors using a portable receiver (Model Lotek SRX 400A), a 4-element directional antenna and a hand-held global positioning system (GPS; Model Garmin eTrex 30). In addition, direct observations were conducted daily during the field season in early mornings and late evenings to identify individuals and new foraging patches.

Sunrise and sunset times for Nestor Falls were obtained from the Astronomical Applications Department, U.S. Naval Observatory Washington, DC. Day was defined as the interval from one-half hour post sunrise to one-half hour prior to sunset. Night was defined as the period between one-half hour post sunset to one-half hour prior to sunrise. The one-hour periods around sunrise and sunset were defined as crepuscular hours. Foraging patches were defined as clear-cuts containing early successional plant communities (McIntosh, 2003). Typical woody plants in these communities were young stems of aspen (*Populus* spp.), green alder (*Alnus viridis*), cherry (*Prunus* spp.), maple (*Acer* spp.), pine (*Pinus* spp.), willow (*Salix* spp.), paper birch, red-osier dogwood (*Cornus stolonifera*), raspberry (*Rubus* spp.), and honeysuckle (*Lonicera* spp.). Patch boundaries were defined by secondary roads, lakes, mature forest, and regenerated forested areas that were older than 10 years.

Based on the previous and current locations of detected elk, motion-activated cameras (Moultrie D-444; n = 17) with settings for continuous, interval-based recording and infrared night vision were strategically placed at the edge of foraging patches (n = 54) and along roads (n = 17) used by elk during the 2014 field season (May–September; Figure 1). Cameras were set up following manufacturer's instructions for date, time, sensitivity, and activation interval. They automatically recorded the date and hour for each photograph. All camera locations (n = 71) were marked with GPS coordinates, and camera units were attached to vegetation and wooden stands available in the area, with the infrared beam set at a height of 1.3 m.

Each camera was rotated biweekly among the 71 camera stations during the study period. Stations were spaced 1–20 km apart, depending on the availability of cameras, and were set to motion detection, with a photographic interval of 3 seconds multi-shot. After each photo set, the camera delay was kept at the minimum setting (15 seconds) and the sensor was set at high sensitivity. Cameras functioned continuously for a period of 140 days. They were checked for correct functioning every 4–7 days, and reloaded with memory cards or batteries as necessary. No scents or baits were used during the study period, and gloves were used during the setup process to reduce the amount of human scent left on equipment.

The Moultrie D-444 uses an infrared sensing (motion sensor) device with a normal detection coverage of 55^{0}, sensitive to motion within 15 m. To satisfy the assumption that all animals had some chance of being photographed, some camera stations were established in areas with previous elk sightings, such as along game trails (corridors between foraging patches) and on overgrown logging roads with signs of elk and their predators (wolves and bears). Frequency of use by elk was also judged from tracks, fecal pellet density, direct observation and the most recent telemetry data. Date, time and location of each photographic capture of elk, other large herbivores (moose and white-tailed deer) and their predators were noted. Photographs with distorted perspectives or those that lacked clarity, were not used for identification of individuals. Photographs were excluded from analysis when identification of an animal was uncertain.

1.2.2. Analysis of camera data

The resulting photo set (n = 450,000) included the 2014 camera-trap data collected by members of the Northwestern Ontario Elk Restoration Coalition (Bruce Ranta and Murray English). It was used to estimate camera success, the number of unique elk individuals captured in photos, their average residence time in each foraging patch, and the relative frequency of shared use of foraging patches with moose and white-tailed deer. Camera success was defined as the total number of unique elk photographed divided by the number of active stations. Active stations included cameras that functioned properly more than 85% of the study period. The photo set was also used to track movements along primary and secondary roads and between foraging patches. Multiple photo-captures of the same individual over a short period were defined as equivalent to one visit and multiple photo-captures over this period were used to calculate minimum residence time. Patch residence time was defined as the interval between the first photograph after the arrival of one or more elk and the last photograph before departure from a foraging patch. Primary roads were defined as year-round gravel roads open to public for recreational purposes such as hunting or used extensively for forestry activities, mining, trapping, elk tracking, and by local residents. Secondary roads were defined as old revegetated logging roads that connected foraging patches and were partially removed after forest operations created to limit vehicle use and hunting pressure.

Each individual was assigned an identifying number for a capture-mark-recapture population estimate. Closed capture-mark-recapture models, which assume sampling without replacement (individuals are encountered at most once per sampling occasion), were used in the program MARK (White and Burnham, 1999). Sampling occasion was defined as a 7-day period pooled across all cameras, yielding a total of 22 sampling occasions during the study period. If an individual was photo-captured at least once within any given 7-day sampling occasion, it was considered captured for that occasion. It was assumed that the probability of photo-capturing an elk the first time and the probability of subsequent photo-captures were the same. A null model, in which the probability of photo-capture remains constant through time, was compared to a time model in which the probability of photo-capture is allowed to vary over the 22 sampling occasions. Separate model comparisons for female and male adults were made and used Akaike's Information Criterion (AICc) corrected for small sample sizes (Peruggia, 2003). A behavioural model, in which photo-recapture is different from initial photo-capture, was rejected because the camera stations were not baited and the cameras had no signal that could deter or attract elk.

A Chi-square test of homogeneity was used to compare seasonal activity between females and males in terms of patch residence time and the period (day, night or crepuscular hours) and the number of visits to a patch. Pearson correlation coefficients were used to describe the strength of relationships among elk residence time, foraging patch size, frequency of common forage species, which included aspen (*Populus* spp.), honeysuckle (*Lonicera* spp.), clover (*Trifolium* spp.), blue-joint grass (*Calamagrostis canadensis*), common hair grass (*Deschampsia flexuosa*), and visits by moose, white-tailed deer, black bear and wolves in the same foraging patches.

1.2.3. Measuring forage plant availability

The frequency of forage plant species was measured in foraging patches (n = 7) and on revegetated roads (n = 12) throughout the study period in the south part of the study area. Sampling plant frequency followed the procedure described by Bonham (1989). A sample unit in a foraging patch included a minimum of 100 points (4 transects running at 90^0 to each other originating from the same point, such that each transect comprised 25 points). Each point was spaced at 1 m and the number of sample units was chosen according to the patch size. A total of 21 sample units (2,100 points) were sampled in foraging patches. On revegetated roads, a sample unit included a minimum of 20 points (4 transects running at 90^0 to each other originating from the same point, such that each transect comprised 5 points) spaced at 30 m. A total of 425 sample units (8,500 points) were sampled on revegetated roads. Eighty-nine plant species were identified and categorized into four groups: forbs and ferns, grasses, sedges, and shrubs and trees. An *A-shaped* measuring tool (1 m from tip to tip) was used to measure the distances between points and to record frequency of each of the plant species at each point (Figure 1.1). The following formula was used to calculate plant frequency:

$$\textbf{\% freq. Spp}_1 = \left[\frac{\#\ \boldsymbol{of\ hits\ of\ Spp_1}}{\boldsymbol{Total}\ \#\ \boldsymbol{of\ points}}\right] \text{x } 100$$

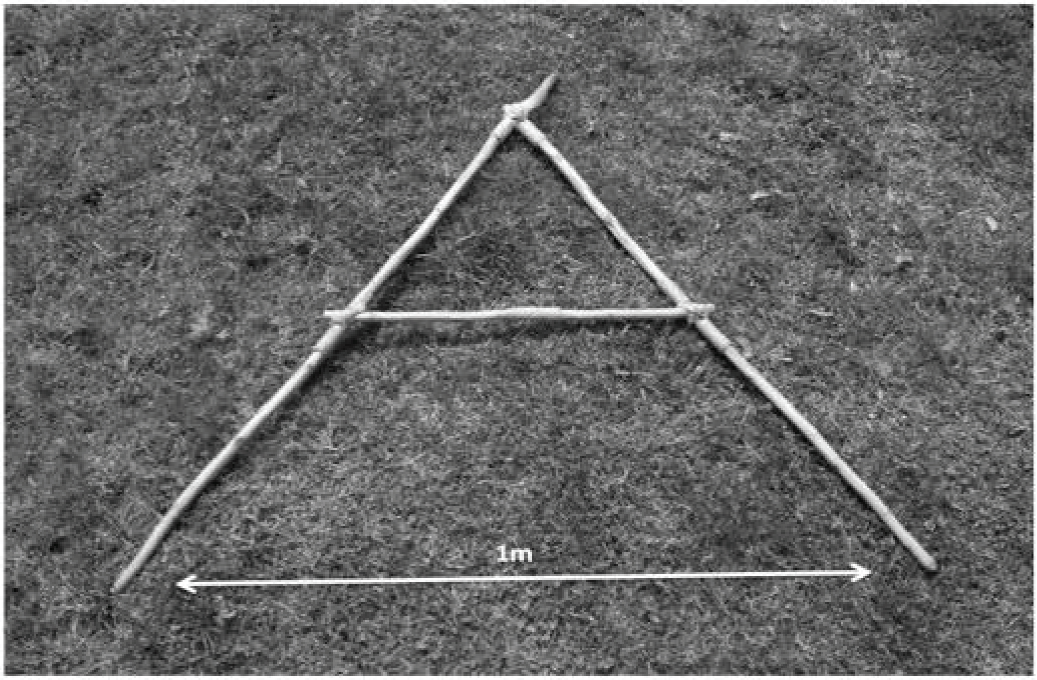


Figure 1.1. The "*A-shaped*" measuring tool used to sample forage plant frequency in foraging patches and revegetated roads in the study area.

1.3. Results

1.3.1. Camera trap records and seasonal use of foraging patches

By the end of the study, a total of 879 photographs of animals were taken at 71 camera stations. Sixty-two percent of camera stations photo-captured more than one elk, of which 252 (29%) were unique elk visits. The success rate was 3.5 photos/camera, ranging from 0.45 to 1.02 photos/camera, with the highest monthly success during August–September. Capture frequency in foraging patches ranged from 1 to 37 captures/individual elk, with 21 of 39 unique individuals captured only once. On revegetated roads, capture frequency ranged from 1 to 12 captures/individual elk, with 15 of 39 unique individuals captured only once.

Other photographed species included white-tailed deer (43%), moose (3%), black bears (14%), birds (6%), wolves (3%), and red foxes (1%) of the photographs.

Based on photographic evidence and direct observations, a minimum of 39 unique elk individuals were identified (18 females, 19 males and 2 calves) by a combination of distinguishing characters, including antler mass and configuration (number of points, their relative length, angle of projection, and relative locations on the antler beam), body traits, and ear tags (Appendices 1, 2). In most cases, it was possible to identify unique individuals with the help of additional daylight photos, which were taken during direct observations, and in other cases by eliminating duplication based on size, sex, or by the presence of ear tags and radio collars. It was also possible to estimate 4 age classes: primes were defined as all animals older than 5 years, teens between 1 and 4 years old, and calves up to the age of 12 months.

The camera-trapping resulted in a total of 193 elk visits in 8 of the 54 foraging patches and 2,046 min of residence time. There were 59 visits on 10 of 17 revegetated roads with a total of 254 min of residence time. Residence time for individual photo sets ranged from 1–181 min (Figures 1.2, 1.3). The highest number of visits and residence time across all foraging patches occurred during August - September, whereas the highest number of visits and residence time on sampled revegetated roads occurred during June–July.

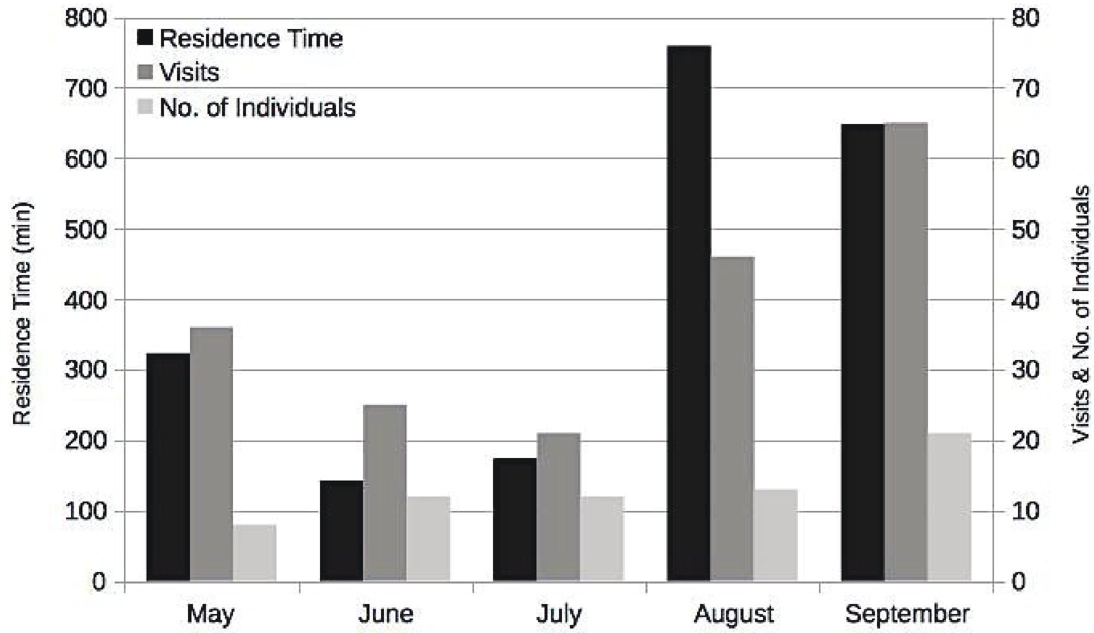


Figure 1.2. Use of sampled foraging patches by elk in the LOW study area.

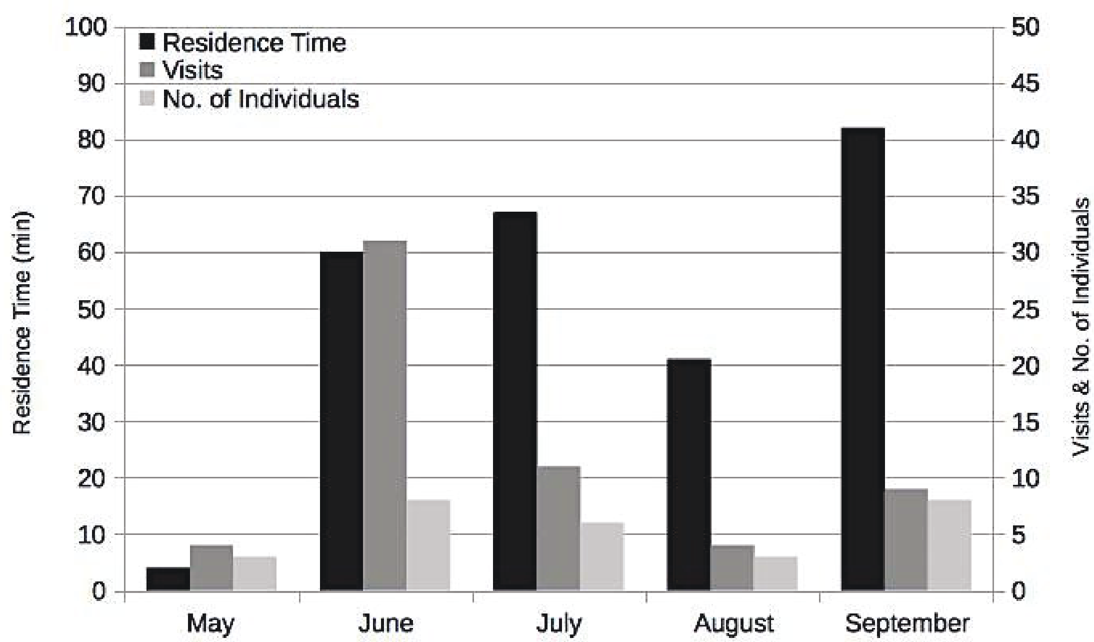


Figure 1.3. Use of sampled revegetated roads by elk in the LOW study area.

Foraging patches in the LOW area differed in size and availability of forage plant species (Tables 1.1, 1.2). Foraging patches ranged in size from 0.1−48.4 ha and their spatial distribution ranged from 440−8,248 m between nearest neighbours (Table 1.3). Photo captures were more frequent in certain areas during certain parts of the study period. Elk were photo-captured more frequently in foraging patches further away from the main roads throughout the spring and autumn months (Figure 1.2), whereas the highest number of photo captures on revegetated roads occurred during the summer months (Figure 1.3). Elk were more often photo-captured in smaller foraging patches in relatively close proximity, connected by revegetated roads (Figures 1.4, 1.5a–c). The distance between patches where elk were encountered and main roads ranged from 389−3,242 m (Table 1.3).

Elk spatial distribution varied as a function of foraging patch quality (abundance and diversity of forage species), direct and indirect effects of other large herbivores (white-tailed deer and moose), and predators (wolf and bear). However, the use of some foraging patches was not related to forage abundance or forage plant preference. For example, P2 had the lowest plant diversity and abundance in the study area, but received more use than P1, where forage plant diversity and abundance were very similar to P6 and P8. It appeared that elk were avoiding foraging patches near primary roads. Two of the smaller patches that received relatively less use (P1 and P2) were situated near a primary road (Pipestone Rd) that crossed the southern part of the study area (Figure 1.5b).

Table 1.1 Common forage species consumed by elk and the % availability of plant species in foraging patches in the LOW area.

Forage species *(Forbs and Ferns)*	Forage patch						
	P1	**P2**	**P3**	**P5**	**P6**	**P7**	**P8**
Birdsfoot trefoil, *Lotus corniculatus*	21	0	18	8	18	40	32
Bracken fern, *Pteridium aquilinum*	4	0	1	7	0	0	1
Clover, Trifolium spp.*[a]	11	0	14	2	2	19	13
Common evening-primrose, *Oenothera biennis*	0	0	0	0	0	0	0
Common strawberry, *Fragaria virginiana*	17	10	34	27	24	34	4
Creamy peavine, *Lathyrus ochroleucus*	4	0	17	18	2	1	1
Daisy fleabane, *Erigeron annuus*	0	0	0	0	0	0	0
Dandelion, *Taraxacum officinale*	0	0	1	0	0	0	0
Field horsetail, *Equisetum arvense*	19	0	7	0	20	17	20
Fireweed, *Camerion angustifolium*	2	0	4	1	1	0	2
Hawkweed, *Hieracium caespitosum*	17	0	17	10	11	1	8
Rough-fruited cinquefoil, *Potentilla recta*	0	0	0	0	0	0	0
Sweet clover, *Melilotus officinalis*	1	0	0	0	0	0	0
Wild geranium, *Garanium maculatum*	0	2	0	0	0	0	0

[a]*Trifolium:* Palmate hop-clover (*Trifolium aureum*), Red clover (*Trifolium pratense*), and White clover (*Trifolium repens*).

Forage species *(Grasses and Sedges)*	Forage patch						
	P1	**P2**	**P3**	**P5**	**P6**	**P7**	**P8**
Blue-joint grass, *Calamagrostis canadensis**	11	0	49	17	16	38	22
Common hairgrass, *Deschampsia flexuosa**	0	0	5	1	2	9	1
False melic grass, *Schizachne purpurascens*	10	2	0	8	0	0	3
Poverty oat grass, *Danthonia spicata*	4	0	0	30	2	9	2
Rough mountain rice, *Oryzopsis asperifolia*	0	0	2	1	0	0	0
Timothy grass, *Phleum pratense*	3	1	0	9	3	0	1
Wheat grass, *Elymus smithii*	0	0	0	5	0	0	0
Sedge, *Carex spp.*[a]	14	3	10	3	5	2	5

[a]*Carex:* Brownish sedge (*Carex brunnescens*), Bladder sedge (*Carex intumescens*), and Beaked sedge (*Carex utriculata*).

Forage species *(Shrubs and Trees)*	**Forage patch**						
	P1	**P2**	**P3**	**P5**	**P6**	**P7**	**P8**
American mountain ash, *Sorbus americana*	0	0	0	0	0	0	0
Aspen, *Populus spp.**[a]	7	6	2	1	13	4	1
Balsam fir, *Abies balsamea*	0	1	0	0	0	0	0
Beaked hazel, *Corylus cornuta*	1	3	4	8	2	0	3
Black spruce, *Picea mariana*	1	0	0	0	0	0	0
Canada buffaloberry, *Shepherdia canadensis*	0	0	0	0	0	0	0
Cherry, *Prunus spp.*[b]	1	2	1	0	0	0	0
Common juniper, *Juniperus communis*	0	0	1	2	0	0	0
Downy arrow-wood, *Viburnum rafinesquianum*	0	1	1	3	0	0	0
Eastern white cedar, *Thuja occidentalis*	0	0	0	0	0	0	0
Elderberry, *Sambucus canadensis*	0	0	0	0	0	0	0
Green alder, *Alnus viridis*	3	2	0	0	0	0	0
Honeysuckle, *Lonicera spp.**[c]	4	9	16	4	6	1	4
Juneberry, *Amelanchier spp.*[d]	0	3	0	4	0	0	0
Maple, *Acer spp.*[e]	0	1	2	3	4	1	7
Paper birch, *Betula papyrifera*	8	4	2	0	0	0	4
Pine, *Pinus spp.*[f]	0	1	1	2	1	1	4
Prickly wild rose, *Rosa acicularis*	0	5	0	9	0	0	0
Raspberry, *Rubus spp.*[g]	2	17	29	17	17	6	39
Red oiser dogwood, *Cornus stolonifera*	7	0	3	4	0	0	0
Wild gooseberry, *Ribes hirtellum*	1	0	0	0	0	0	0
Wild red currant, *Ribes triste*	0	0	0	0	0	0	0
Willow, *Salix spp.*[h]	15	1	1	2	7	5	6

[a]*Populus:* Large-toothed aspen (*Populus grandidentata*) and Trembling aspen (*Populus tremuloides*).
[b]*Prunus:* Chokecherry (*Prunus virginiana*) and Pin cherry (*Prunus pensylvanica*).
[c]*Lonicera:* Bush honeysuckle (*Diervilla lonicera*), Bracted honeysuckle (*Lonicera involucrata*), and Glaucous honeysuckle (*Lonicera dioica*).
[d]*Amelanchier:* Mountain juneberry (*Amelanchier bartramiana*) and Red-twigged serviceberry (*Amelanchier sanguinea*).
[e]*Acer:* Red maple (*Acer rubrum*) and Mountain maple (*Acer spicatum*).
[f]*Pinus:* Eastern white pine (*Pinus strobus*), Jack pine (*Pinus banksiana*), and Red pine (*Pinus resinosa*).
[g]*Rubus:* Dwarf raspberry (*Rubus pubescens*) and Wild red raspberry (*Rubus idaeus*).
[h]*Salix:* Bebb's willow (*Salix bebbiana*) and White willow (*Salix alba*).
*Species marked with the ***** occurred in all 31 fecal samples.

Table 1.2 Common forage species consumed by elk and the % availability by plant species on revegetated roads in the LOW area.

	Revegetated road											
Forage species *(Forbs and Ferns)*	**P1R**	**P1L**	**P2**	**Kakagi**	**KakagiL**	**Sandhill**	**Stanbury**	**P5**	**P6**	**P7**	**P8**	**BrookR**
Birdsfoot trefoil, *Lotus corniculatus*	17	1	0	13	0	3	50	30	48	19	57	2
Bracken fern, *Pteridium aquilinum*	0	3	1	2	4	2	1	0	0	0	0	0
Clover, *Trifolium spp.**[a]	2	0	0	14	7	31	6	4	10	8	9	5
Common evening-primrose, *Oenothera biennis*	0	0	0	1	1	0	0	0	0	0	0	1
Common strawberry, *Fragaria virginiana*	40	53	3	34	42	14	12	15	5	24	2	3
Creamy peavine, *Lathyrus ochroleucus*	7	9	2	1	1	3	0	2	0	1	1	0
Daisy fleabane, *Erigeron annuus*	0	0	0	0	0	0	0	0	0	0	0	0
Dandelion, *Taraxacum officinale*	0	0	0	0	0	0	1	0	0	0	0	1
Field horsetail, *Equisetum arvense*	37	4	1	6	8	5	2	4	1	6	0	1
Fireweed, *Camerion angustifolium*	0	0	0	1	1	0	0	0	0	0	1	1
Hawkweed, *Hieracium caespitosum*	6	21	1	25	20	53	15	12	8	5	11	6
Rough-fruited cinquefoil*, Potentilla recta*	0	0	0	0	0	0	0	0	0	0	0	2
Sweet clover, *Melilotus officinalis*	0	0	0	2	0	0	0	0	0	0	0	1
Wild geranium, *Garanium maculatum*	0	0	4	0	0	0	0	0	0	0	0	0

[a]*Trifolium:* Palmate hop-clover (*Trifolium aureum*), Red clover (*Trifolium pratense*), and White clover (*Trifolium repens*).

	Revegetated road											
Forage species *(Grasses and Sedges)*	**P1R**	**P1L**	**P2**	**Kakagi**	**KakagiL**	**Sandhill**	**Stanbury**	**P5**	**P6**	**P7**	**P8**	**BrookR**
Blue-joint grass, *Calamagrostis canadensis**	4	15	6	15	7	2	3	21	25	34	19	34
Common hairgrass, *Deschampsia flexuosa**	1	1	1	1	0	0	7	4	11	5	5	5
False melic grass, *Schizachne purpurascens*	0	4	5	0	0	0	0	0	0	0	4	0
Poverty oat grass, *Danthonia spicata*	1	2	1	6	1	6	24	8	7	6	9	0
Rough mountain rice, *Oryzopsis asperifolia*	0	0	0	0	0	0	0	0	3	0	0	0
Timothy grass, *Phleum pratense*	0	1	0	1	0	0	12	0	3	0	2	0
Wheat grass, *Elymus smithii*	0	0	0	0	0	0	1	1	0	1	0	0
Sedge, *Carex spp.*[a]	18	17	2	8	4	15	0	0	1	0	0	1

[a]*Carex:* Brownish sedge (*Carex brunnescens*), Bladder sedge (*Carex intumescens*), and Beaked sedge (*Carex utriculata*).

Forage species *(Shrubs and Trees)*	Revegetated road											
	P1R	P1L	P2	Kakagi	KakagiL	Sandhill	Stanbury	P5	P6	P7	P8	BrookR
American mountain ash, *Sorbus americana*	0	0	0	1	0	0	0	0	0	0	0	0
Aspen, *Populus spp.**[a]	1	1	6	4	3	2	0	0	5	9	1	1
Balsam fir, *Abies balsamea*	0	0	0	0	1	0	0	0	0	0	0	0
Beaked hazel, *Corylus cornuta*	5	9	6	2	4	2	0	1	1	1	1	3
Black spruce, *Picea mariana*	0	1	0	0	0	0	0	0	0	0	0	0
Canada buffaloberry, *Shepherdia canadensis*	0	0	0	0	0	0	0	0	0	0	0	0
Cherry, *Prunus spp.*[b]	0	0	0	2	1	0	0	0	0	0	0	2
Common juniper, *Juniperus communis*	0	0	0	0	0	0	0	0	0	0	0	0
Downy arrow-wood, *Viburnum rafinesquianum*	0	1	0	0	0	0	0	0	0	0	0	0
Eastern white cedar, *Thuja occidentalis*	0	0	0	0	1	5	0	1	0	0	0	0
Elderberry, *Sambucus canadensis*	0	0	0	0	0	0	0	0	0	0	0	0
Green alder, *Alnus viridis*	8	2	0	1	5	0	0	0	0	1	0	0
Honeysuckle, *Lonicera spp.**[c]	21	5	6	10	17	6	1	0	1	2	2	6
Juneberry, *Amelanchier spp.*[d]	0	0	1	0	0	0	0	0	0	0	0	0
Maple, *Acer spp.*[e]	4	2	3	2	2	1	0	1	2	1	1	6
Paper birch, *Betula papyrifera*	7	5	1	6	6	3	1	0	0	0	0	3
Pine, *Pinus spp.*[f]	0	2	0	2	1	7	0	0	4	0	2	0
Prickly wild rose, *Rosa acicularis*	2	0	0	0	0	0	0	0	0	0	0	0
Raspberry, *Rubus spp.*[g]	27	26	14	16	17	3	7	8	7	11	11	12
Red oiser dogwood, *Cornus stolonifera*	5	7	1	1	2	0	0	0	0	0	1	1
Wild gooseberry, *Ribes hirtellum*	0	1	0	0	0	0	0	0	0	0	0	0
Wild red currant, *Ribes triste*	0	0	0	0	0	0	0	0	0	0	0	0
Willow, *Salix spp.*[h]	14	13	1	5	5	6	1	0	1	4	1	4

[a]*Populus:* Large-toothed aspen (*Populus grandidentata*) and Trembling aspen (*Populus tremuloides*).
[b]*Prunus:* Chokecherry (*Prunus virginiana*) and Pin cherry (*Prunus pensylvanica*).
[c]*Lonicera:* Bush honeysuckle (*Diervilla lonicera*), Bracted honeysuckle (*Lonicera involucrata*), and Glaucous honeysuckle (*Lonicera dioica*).
[d]*Amelanchier:* Mountain juneberry (*Amelanchier bartramiana*) and Red-twigged serviceberry (*Amelanchier sanguinea*).
[e]*Acer:* Red maple (*Acer rubrum*) and Mountain maple (*Acer spicatum*).
[f]*Pinus:* Eastern white pine (*Pinus strobus*), Jack pine (*Pinus banksiana*), and Red pine (*Pinus resinosa*).
[g]*Rubus:* Dwarf raspberry (*Rubus pubescens*) and Wild red raspberry (*Rubus idaeus*).
[h]*Salix:* Bebb's willow (*Salix bebbiana*) and White willow (*Salix alba*).
[*]Species marked with the ***** occurred in all 31 fecal samples.

Table 1.3. Summary of foraging patch size, distances among patches, and distances to the nearest primary road (Pipestone Rd).

		Distances (m)								
Foraging patches	**Sizes (ha)**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**Pipestone Rd**
P1	**0.1**		1399	8030	6937	7218	7802	**8248**	6519	**389**
P2	0.8			7793	6736	6981	7565	8005	6282	576
P3	0.5				1757	1507	2622	3062	2669	3030
P4	**48.4**					967	865	1305	1572	1937
P5	43.1						1832	2272	1847	2218
P6	0.5							**440**	2437	2802
P7	0.2								2877	**3242**
P8	2.9									1519

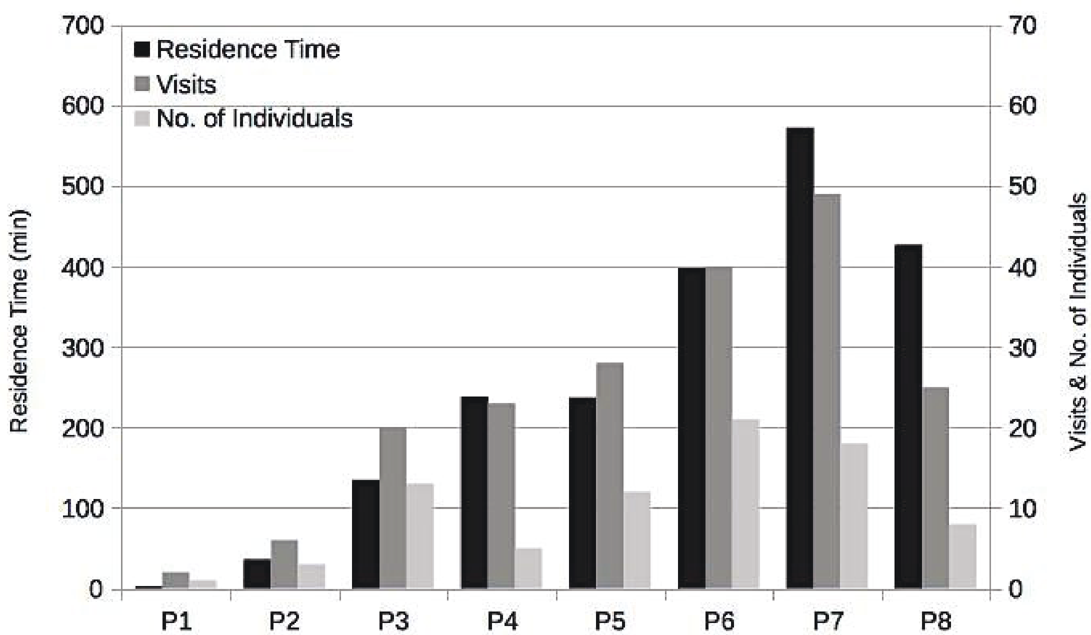


Figure 1.4. Residence time, visits, and number of individuals at foraging patches (P1 – P8) from May to September, 2014.

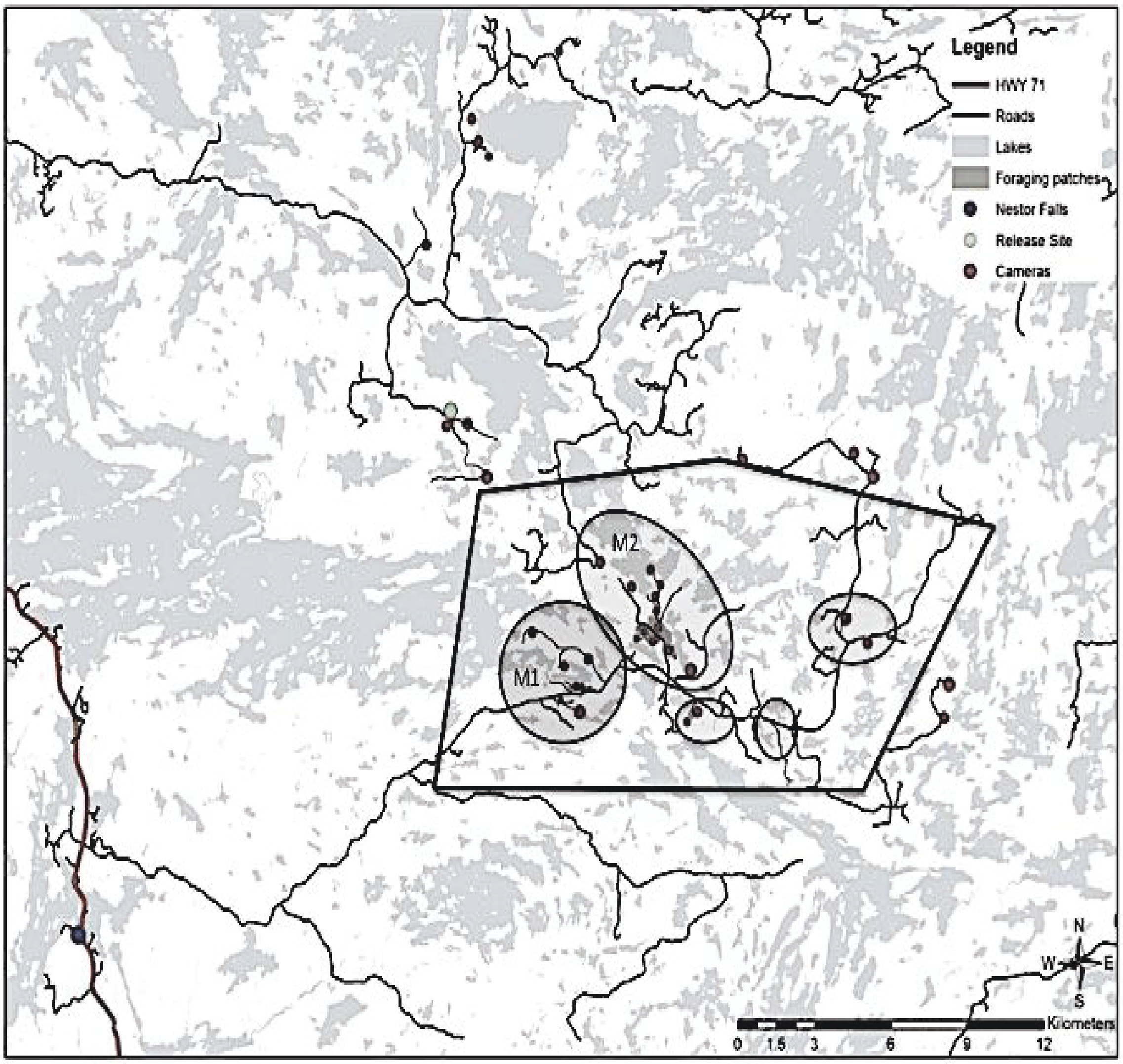


Figure 1.5a. Approximate summer home range (27,900 ha) of free-ranging elk in the LOW area, 2014. The *M1* and *M2* ellipses represent foraging patch aggregations (P1-P8). Home ranges and revegetated roads used by elk in the southern part of the LOW study area are also identified.

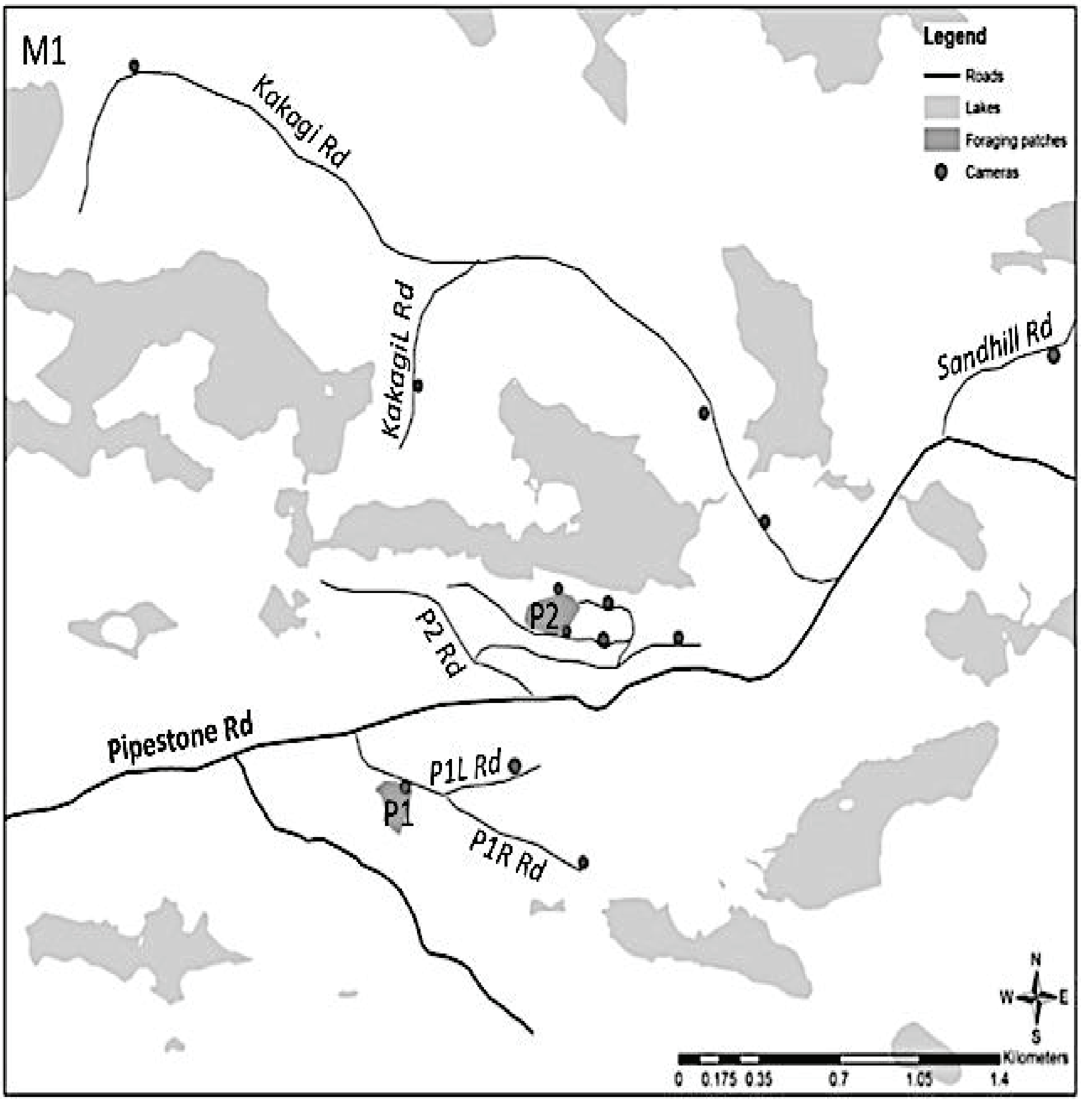


Figure 1.5b. Foraging patches (P1-P2) and revegetated primary and secondary road distribution in the southwestern part of the LOW study area.

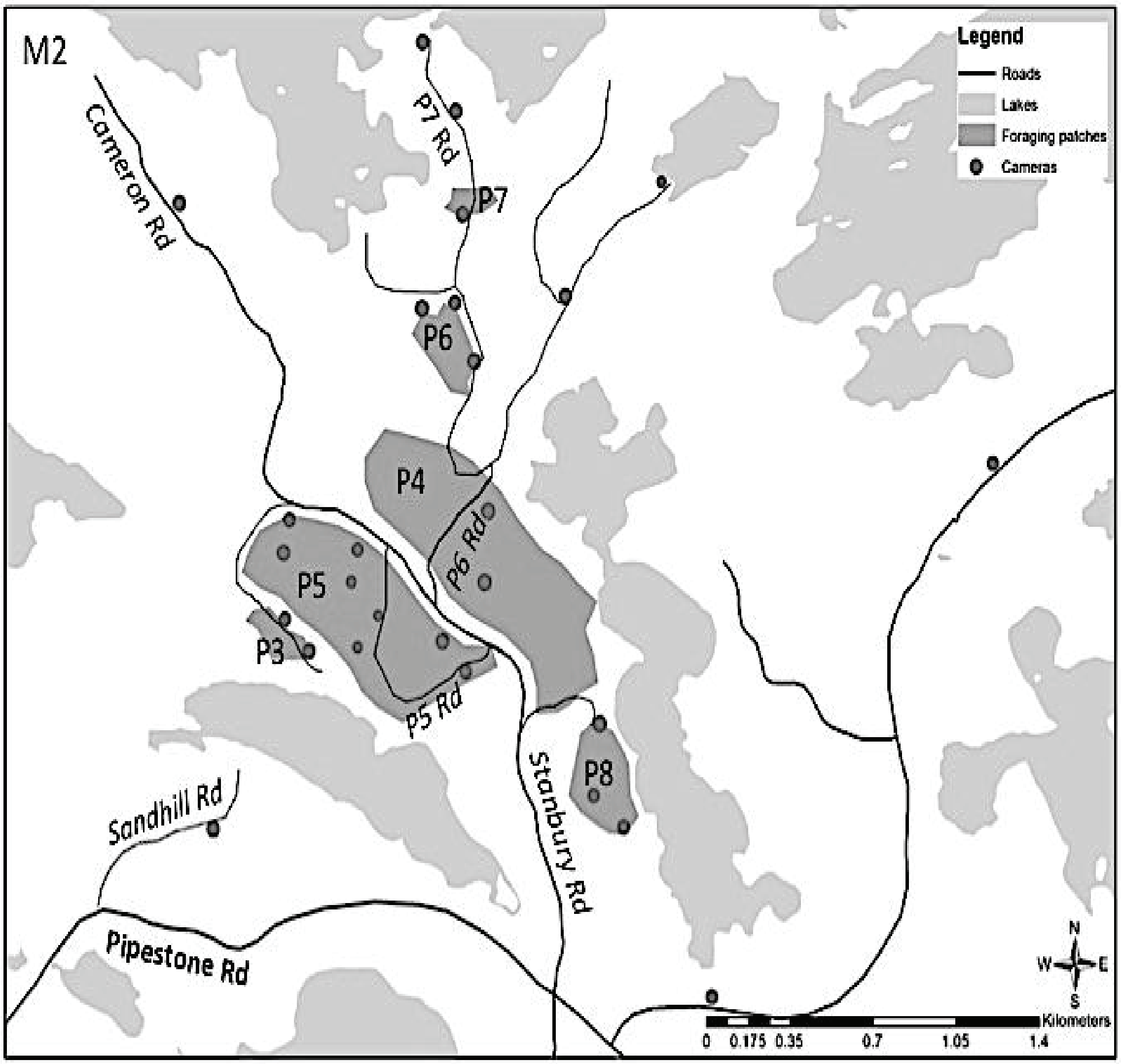


Figure 1.5c. Foraging patches (P3-P8) and revegetated primary and secondary road distribution in the southern part of the LOW study area.

Elk appeared to use smaller patches over large patches, which were more often occupied by moose, white-tailed deer and predators, such as bears and wolves (Figures 1.6 a, b). Elk fecal pellet density was higher in the smaller foraging patches (P6 and P7) and secondary roads that connect nearer foraging patches. The relative absence of pellet groups in other areas suggest that elk avoided areas close to primary roads and human disturbance (Figures 1.7, 1.8). Moose fecal pellet density was higher in the larger foraging patches (P4 and P5) and patches in close proximity to primary roads.

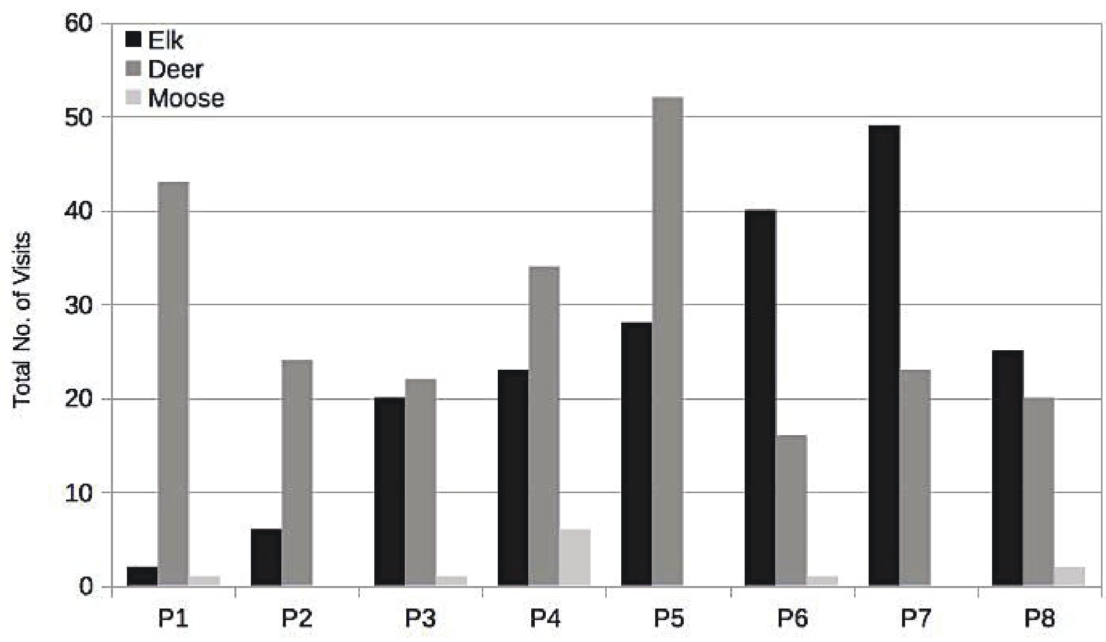


Figure 1.6a. Foraging patch use by elk, white-tailed deer and moose from May to September (2014).

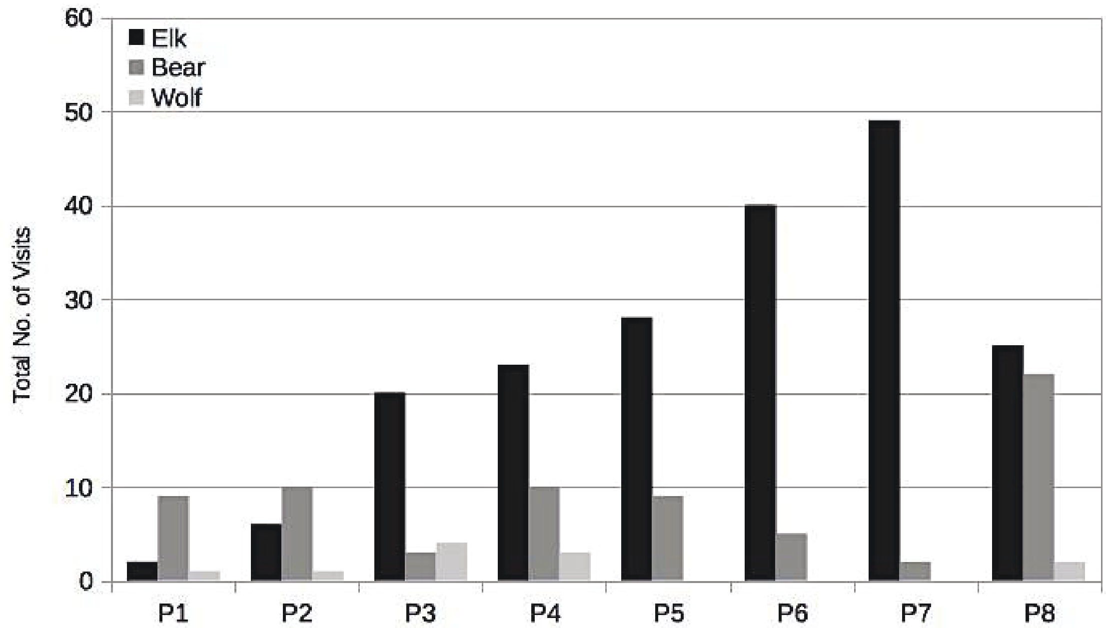


Figure 1.6b. Foraging patch use by elk, bears and wolves from May to September (2014).

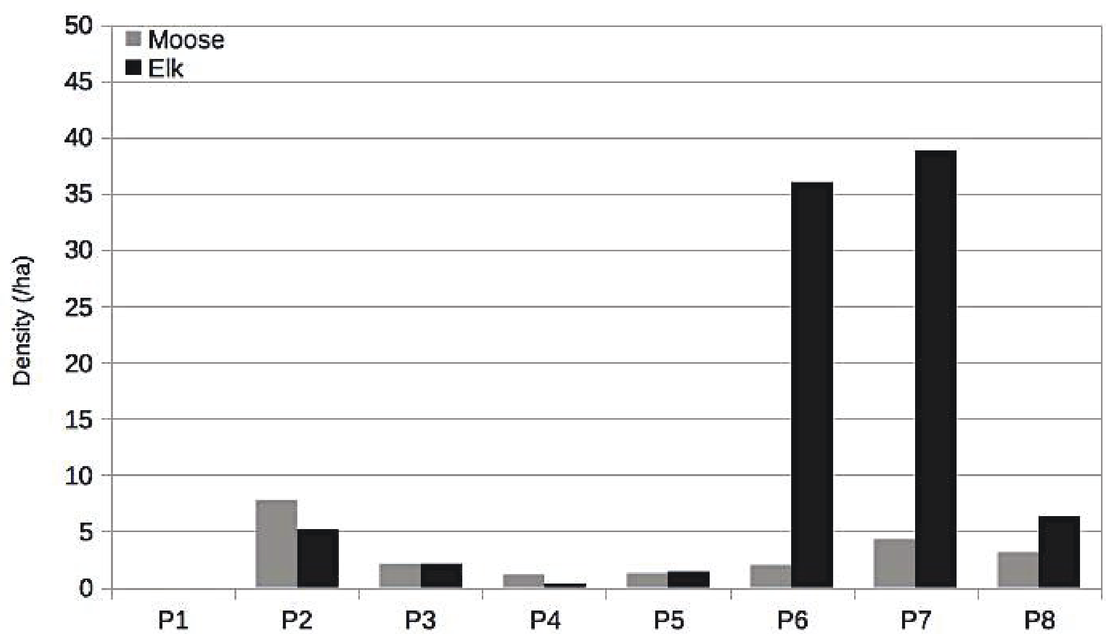


Figure 1.7. Moose and elk fecal pellet density in foraging patches in the LOW region. Moose pellets were more abundant in four of eight patches, while elk pellets were more abundant in three of eight patches.

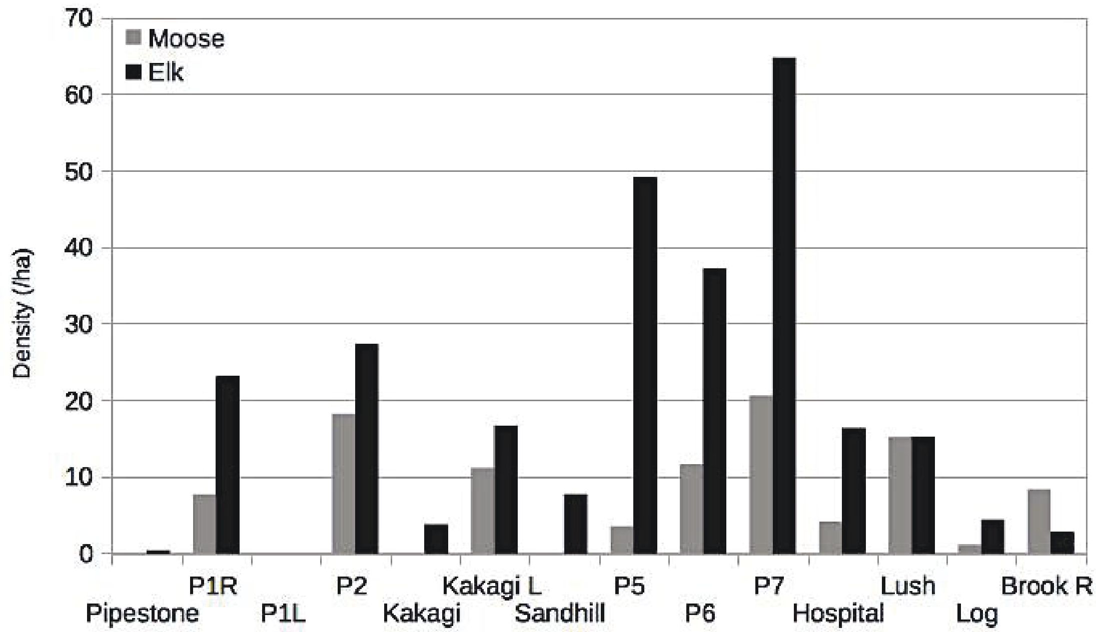


Figure 1.8. Moose and elk fecal pellet density on revegetated roads, in the LOW region.

No relationships were found between foraging patch size and elk residence time (r = 0.04), frequency of forage plant species and elk residence time (r = 0.35), or the number of visits by white-tailed deer (r = 0.42), moose (r < 0.01), wolves (r = 0.31), or bears with elk residence time (r = 0.01). In most areas where white-tailed deer, moose and elk overlapped, elk appeared to avoid large patches previously occupied by white-tailed deer and moose for several days (Figure 1.9). The co-occurrence of white-tailed deer or moose with elk on the same day was not common. Elk were more often by themselves in a foraging patch.

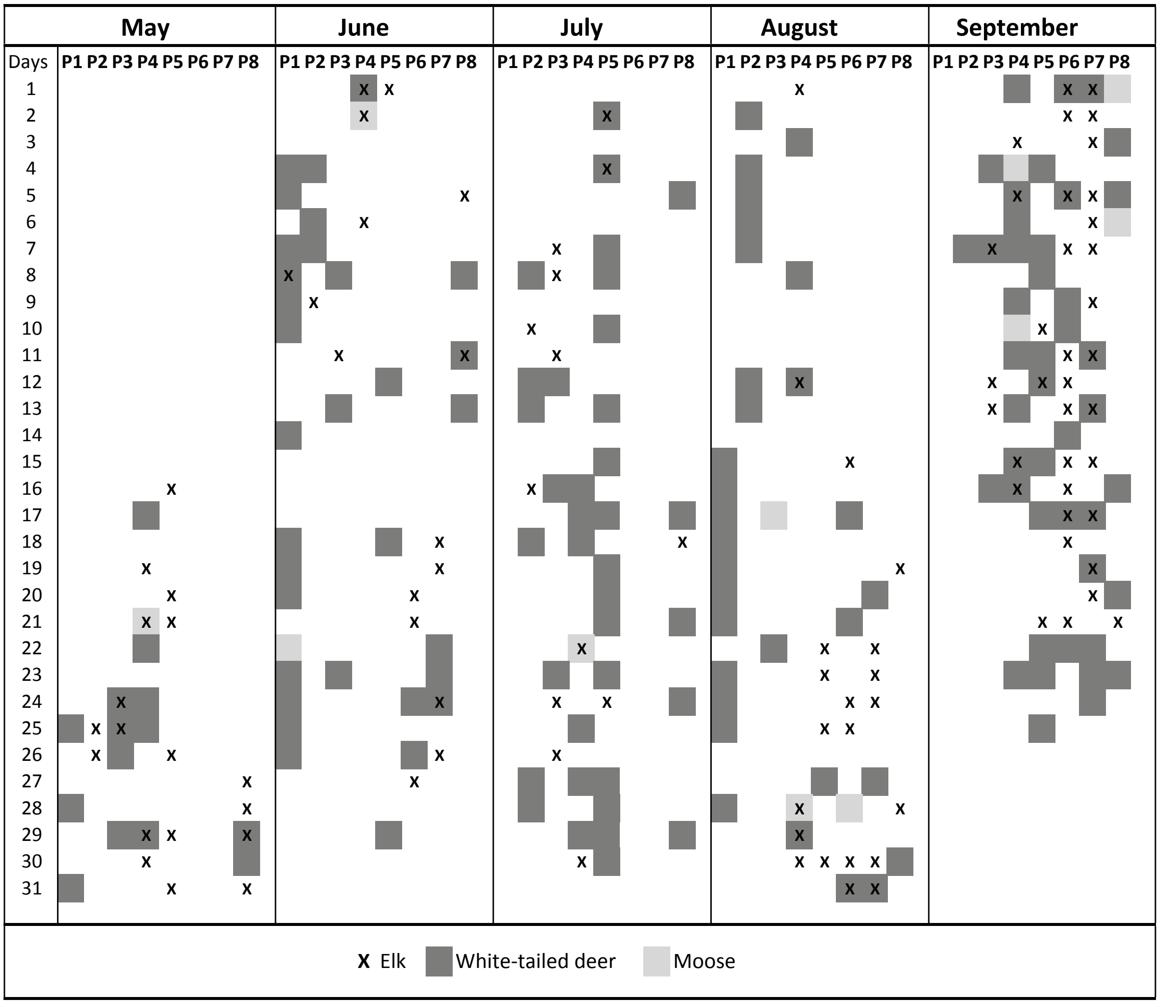


Figure 1.9. Summer foraging patch use by elk, white-tailed deer, and moose, in the LOW region between May-September (2014).

1.3.2. Seasonal activity patterns and identification of individuals

Weekly photo-capture frequency patterns varied from early May to late September. The highest number of daytime photo captures occurred in early June (Figure 1.10.). Afterwards, comparatively low frequency of photo-captures occurred overall during late June to early August, followed by a pronounced rise in nocturnal photo-captures from mid-August to late September. The highest number of photo-captures during crepuscular hours occurred in early June and late August.

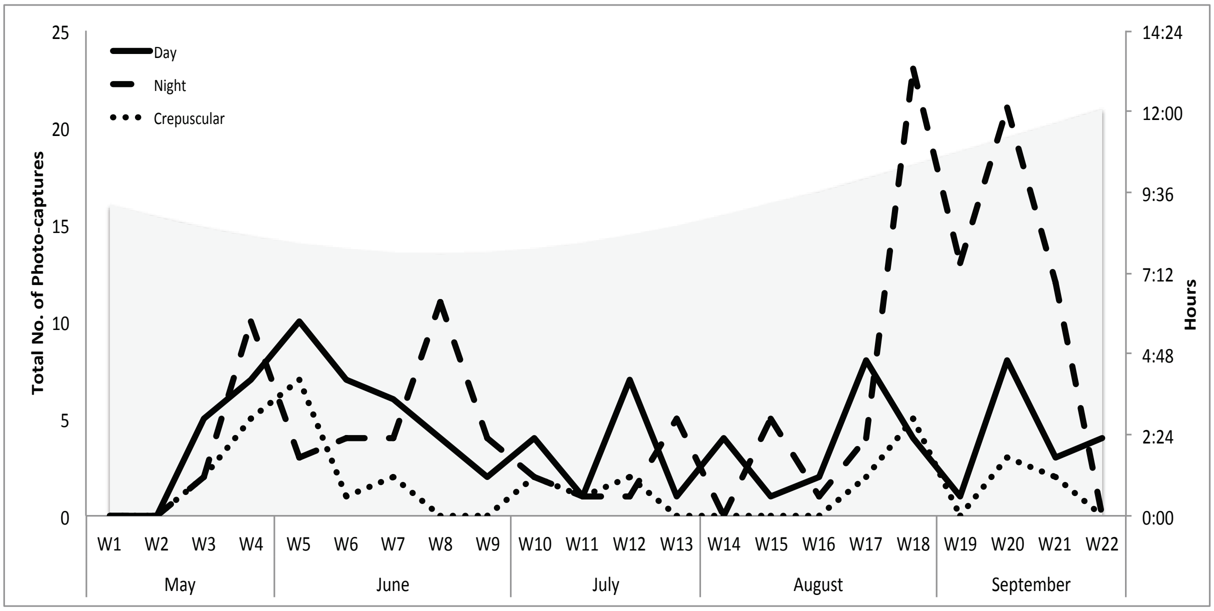


Figure 1.10. Weekly activity patterns and seasonal variation in the total number of unique elk photo-captured in the LOW region. The shaded area shows the seasonal distribution of night-time hours by calendar day; solid line represents the diurnal activity, dashed line represents the nocturnal activity, and the dotted line represents the crepuscular activity by all animals.

For all elk there was one significant variation from random activities based on the number of daytime, night-time and crepuscular hours. In September, elk increased significantly their use of night-time hours (χ^2 = 10.7, P < 0.01; Table 1.4). Photo-capture frequencies showed considerable variation among months, as well as among females and males. Elk were equally active during the day and night in May, July, and first half of August. They were more active during crepuscular hours than expected in May. Females were more active during the day, whereas males were more active during crepuscular hours. In June, elk were more active during the day than during the night. Females were more active during the night, whereas males were more active during the day. However, males also were more active during crepuscular hours than expected by chance in June. In July, the pattern of photo-captures was very similar to that in June. Elk were more active during the day, but their crepuscular activity was higher than expected. Animal activity showed great differences in the spring-summer months, from the beginning of May to late July. Thereafter, monthly activity was similar among all animals (Figure 1.10.).

There was a pronounced rise in nocturnal activity, in which the highest relative number of photo captures occurred from mid-August until late September. Subsequently, both females and males were less active during the day and during crepuscular hours than they were in May, June, and July. In late August, elk appeared to be more active during the night than during the day and both females and males were more active during night hours than expected by chance in August. In September, elk were significantly more active during the night than in previous months.

Photographs were categorized into three categories: females (30), males (105), and all 135 photos. Capture-mark-recapture model comparisons identified the null model (Mo) as the more parsimonious for females, whereas the time model (Mt) was a more reasonable fit for males (Table 1.5). For all animals, Mt was selected.

Table 1.4. Results of Chi-square tests of homogeneity comparing diurnal, nocturnal and crepuscular activity inferred from frequency of photo-captures to the null model of random photo-captures according to the relative length of each time period per month.

	May		June		July		August		September	
	Chi-sq	p-value	Chi-sq	p-value	Chi-sq	p-value	Chi-sq	p-value	Chi-sq	p-value
All elk	3.39	0.18	4.42	0.11	1.63	0.44	5.81	0.05	10.65	**0.00**
Female	0.54	0.76	3.66	0.16	0.74	0.69	1.43	0.49	3.76	0.15
Male	4.19	0.12	3.43	0.18	1.08	0.58	4.50	0.11	8.00	0.02

The capture-mark-recapture estimates by sex were 29 females (SE = 6.82, 95% CI = 21−51 individuals) and 19 males (SE = 0.36, 95% CI = 19 individuals). The population in the LOW region was estimated at a minimum of 39 elk (SE = 0.98, 95% CI = 39−46 individuals). Newly identified animals toward the end of the study period (August–September, 2014) were mostly females (Figure 1.11), and females fit the null model better because they were photo-captured throughout the study period. Males fit the time model better because most of them were photo-captured at the beginning of the study period.

Overall, direct observations and photography data demonstrated that elk did not avoid areas where cameras were set up. Several elk were photographed more than once during visits to camera stations. However, elk appeared generally wary of the camera systems, and photo-capture success rates increased with the number of sampling occasions.

Table 1.5. Results of tests using MARK for evaluating the fit of 2 capture-mark-recapture models and population estimation of elk in the LOW area (May-September 2014). *N*=Population estimate, *SE*=Standard error, *C.I.* = Confidence interval, and *AICc* = Akaike information criterion.

Model	Animals	AICc	AICc Weight	*N*	*SE*	*95% C.I.*
Mo	All	540.80	0.00	39	1.0	39-46
(null)	Females	120.13	0.22	29	6.8	21-51
	Males	396.70	0.00	19	0.3	19-19
Mt	All	520.97	0.00	39	0.9	39-46
(time)	Females	121.41	0.11	28	6.4	21-50
	Males	383.16	0.12	19	0.0	19-19

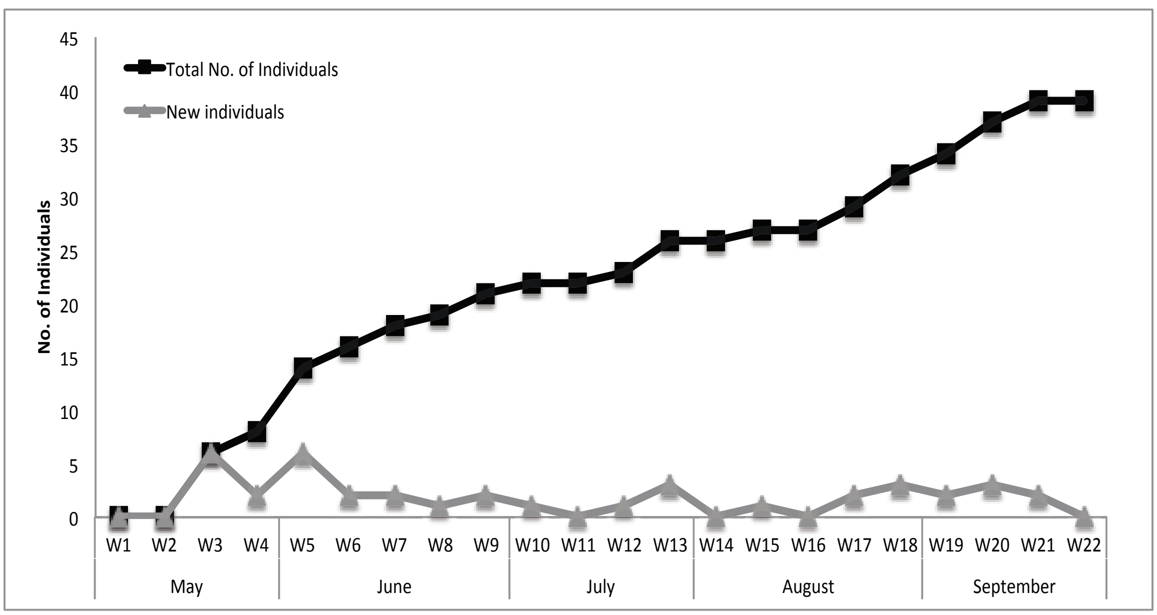


Figure 1.11. Cumulative number of individuals and number of new individuals photo-captured during each week over the course of camera trapping period (2014).

1.4. Discussion

Remote cameras with ongoing direct observations enabled description of habitat use, the total number of visits and residence time by elk in patchy habitats. Descriptions of seasonal activity patterns, and a population estimate using capture-mark-recapture models were also developed for the LOW elk population. Time-lapse photography is a valuable method, when animals occur frequently and activity occurs repeatedly. Courant and Fortin (2012) used a time-lapse photography method to evaluate group size and residency time in free ranging bison (*B. bison*). In contrast, an animal-triggered system was more appropriate for this study, where events occurred irregularly, relatively infrequently, and over a large area (Jackson et al., 2006; Gupta et al., 2009).

Elk in the LOW study area showed seasonal variation in movement and habitat selection, similar to elk populations elsewhere (Yamazaki et al., 2008; White et al., 2010; Sawyer and Kauffman, 2011). Elk increased their movements from early spring to early summer and movement peaked during late summer and autumn with the onset of rut. Generally, movements by elk peak during spring in response to increased forage availability and decrease during food shortages in the winter (Hanley, 1982; Hofmann, 1988). Seasonal activity patterns and movement by elk have been shown to be driven by local and seasonal food availability (Craighead, 1973; Collins, 1978).

Elk in the LOW area displayed a crepuscular and nocturnal activity pattern with more movements occurring at dusk and dawn. All elk showed differences in their weekly activity pattern throughout the study period, and activity patterns of males and females differed. The decrease in diurnal activities was partially compensated by increased activity at dusk and dawn and a significant increase in nocturnal activities as night-length increased. These changes were likely related to weather conditions and human activities. Late arrival of spring and snow accumulation are the main factors that can influence seasonal movements of Rocky Mountain elk and their foraging behaviour (Anderson, 1958; Picton, 1975).

Based on photographic evidence and direct observations, elk appeared to occupy certain areas at a particular time of the season because of human disturbance and hunting pressure. For example, elk appeared to increase their nocturnal activity and their home range by avoiding areas close to primary roads at the beginning of white-tailed deer (Sept. 1–Oct. 2) and moose (Sept. 19–Oct. 9) hunting seasons. Human disturbance can influence elk habitat use, causing individuals to move from foraging in preferred areas into more remote areas, away from primary roads, in order to seek cover and safety (Morgantini and Hudson, 1985). LOW elk avoided large foraging patches, which were more often occupied by other large herbivores, and areas close to primary roads. These results do not support the prediction that patch residence time increases with travel time, because elk in the study area used small foraging patches in close proximity to each other, connected by revegetated roads. Furthermore, as predicted, foraging patch use varied with the presence of other large herbivores, patch size and their distribution.

Several studies have shown that forest edge use by elk is more pronounced in large openings, but varies from year to year (Marcum, 1977; Tufto et al., 1996; Wirth et al., 2008). The influence of roads on space use by elk has been well studied (Lyon, 1979; Rowland et al., 2000). Current research shows that elk generally select habitats away from primary roads consistently throughout the spring and summer months apparently to minimize the effects of disturbance, but they use secondary and abandoned roads as travel corridors (Baasch et al., 2010; Montgomery et al., 2013).

This study supports the conclusion that photographic capture-mark-recapture sampling offers a useful tool for estimating the size of low-density elk populations. Various camera setup scenarios and settings were explored in different foraging patches and revegetated roads. The most reliable proved to be the use of multiple cameras in a few foraging patches set to motion detection, with a photographic interval of 3 seconds multi-shot. On revegetated roads, the most reliable proved to be 2 cameras oriented at 55^0 on either side of the road set at a height of 1.3 m. The capture-history data for all animals fits best with a closed capture-recapture time model (Mt) and only marginally fits the alternative model (Mo), which was the best fit for females. Effort required in terms of sampling occasions suggested that a minimum of 133 days were required to get a population estimate for elk in this study area.

1.5. Conclusions

The results supports the conclusion that motion-activated cameras with ongoing direct observation can be used to evaluate foraging patch use, residence time, activity patterns, and a minimum population estimate of a relatively low-density elk population. Foraging patch use and residence time by elk in the LOW area was less for larger patch sizes and for patches with larger distances between them. Furthermore, elk avoided large foraging patches, which were more often occupied by other large herbivores. LOW elk appeared to use secondary roads connecting nearer foraging patches more often, and to avoid areas close to primary roads. These results do not support the prediction that patch residence time increases with travel time. Elk in the LOW study area showed seasonal variation in movement and habitat selection, and displayed a strong crepuscular and nocturnal activity pattern with more movements occurring at dusk and dawn. This study supports the conclusion that photographic capture-mark-recapture sampling offers a useful tool for estimating the size of low-density elk populations.

Chapter 2. Foraging patch selection and identification of diet by microhistological analysis of elk fecal pellets

2.1. Introduction

It is essential in management of large herbivores to evaluate diet quality, preference for certain plants or plant parts, and diet composition. Elk diets vary seasonally and spatially, which makes area-specific recommendations for habitat modification difficult (Edge, 1988). In North America, elk occupy a broad range of habitats and have been classified as mixed feeders, capable of utilizing grasses, forbs and woody browse due to their adaptability to different environmental conditions (Hobbs, 1979; Kay, 1980). The foraging opportunities for elk are different in the LOW area from those in the western states and provinces of North America, where there are many open, grassy meadows. It appears that LOW elk are using areas with higher road densities, as roadsides can provide forage (Dewar, 2006) and major foraging areas for elk in the LOW area include recent clear-cuts and reforested stands (Chapter 1).

Diet consumption and selection are influenced by multiple interacting factors and determined by physical properties of forage, such as its fibre content (Forsyth et al., 2005; Pollock et al., 2007), and its availability (Danell and Ericson, 1986; Edenius, 2002). While the diet composition of elk has been analyzed in detail across North America (Jenkins and Starkey, 1993; Polziehn et al., 1998; Jost et al., 1999), very few quantitative studies have been published from environments where food patches are not part of a grassland biome. Studies of the Rocky Mountain elk, commonly found in mountain habitats, have indicated that woody browse and grasses are preferred forage items (Hobbs et al., 1983). In an attempt to obtain a more detailed understanding of forage use by elk in the LOW area, a diet composition study was conducted during the summer of 2014. The objectives were (1) to analyze the overall diet pattern of an elk population living in a new environment; and (2) to identify responses in diet choice and habitat use to pronounced seasonality in other behaviour patterns.

2.2. Materials and methods

2.2.1. Collection and preparation of reference plant fragments

Several techniques are available to evaluate diet composition in both domesticated and wild animals. One non-invasive technique is microhistological analysis, which has been utilized to determine diet composition of many animals, including cervids (Suter et al., 2004; Krojerová-Prokešová et al., 2010; Mátrai et al., 2013). This method is based on microscopic recognition of unique and identifiable undigested cellular structures from the cuticle layer of the plant leaf.

A total of 89 plant specimens were collected from June through August 2014, and 61 common forage plant species were selected according to their frequency in the study area (Chapter 1) and previous knowledge of elk use in other areas. Plant specimens were only collected from the south part of the study area. All plants were dried for transportation. In the laboratory, the epidermis (approx. 1 cm^2) of different plant parts (i.e., leaf tip, leaf blade and stem) was soaked in 20 ml of 6% sodium hypochlorite (NaClO; household bleach) for about 10−15 minutes, then rinsed with water and dried. Epidermal fragments were dispersed on microscope slides into a mixture of 0.1 ml 87% glycerine and 0.05 ml of 0.1% Toluidine-Blue (Johnson et al., 1983; Carrière, 2002; Katona and Altbacker, 2002), and viewed under a AmScope T120B-3M trinocular microscope at 160× magnification. Plant epidermal fragments were then photographed to create a reference atlas. A total of 651 photos were taken and used to identify the epidermal fragments from the fecal pellets (Figure 2.1).

2.2.2. Fecal pellet sampling and analysis

Fresh fecal pellets of elk were collected from during the study period (May–September 2014). Samples were primarily collected from foraging patches and revegetated roads in the south part of the study area, and from fresh heaps (10–15 pellets), visibly moist and soft to the touch. Fresh feces were oven-dried at 90^0C−100^0C for approximately 1 hour, placed in individual paper bags and a box containing naphthalene to avoid fungal and insect infestation (Litvaitis, 1994). Ten pellets were analyzed from each heap. The resulting pellet-heap sample sizes (spring, n = 7; early summer, n = 9; late summer, n = 15) varied slightly among seasons according to the number of visits by elk in foraging patches.

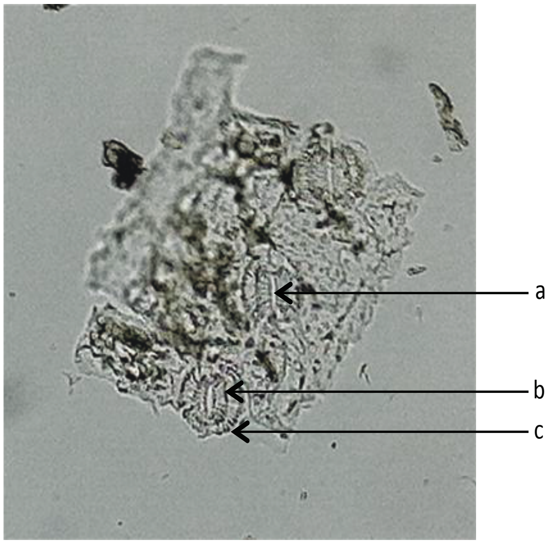
Microhistological analysis of the feces followed procedures described previously for plant fragments (Suter et al., 2004). In total, 310 pellets (n = 31 pellet-heaps) were fragmented in a blender and processed. To identify fecal constituents, each sample was divided randomly in 3 subsamples. Each subsample consisted of 0.1 g and was dispersed on a microscope slide into a mixture of 0.1 ml 87% glycerine and 0.05 ml of 0.1% Toluidine-Blue, covered with a 25 × 25 mm cover slip and viewed at 160× magnification. In each subsample, a minimum of 100 randomly chosen epidermis fragments were identified and categorized into four plant groups: forbs and ferns, grasses, sedges, and woody browse (shrubs and trees). The following organelles and their specific characteristics were most useful in forage plant species identifications: (1) stomata (size, shape, orientation and associated guard or subsidiary cells), (2) epidermal cells (size, shape and amount of undulations), (3) cork cells (size, shape, and bases for trichomes in some species), and (4) silica cells (presence, placement, shape and size; Figure 2.1).

Chi-squared tests of homogeneity were used to identify variation in diet composition and make comparisons among seasons. Pearson correlation coefficients were used to match the abundance of forage plant species among foraging patches and revegetated roads.

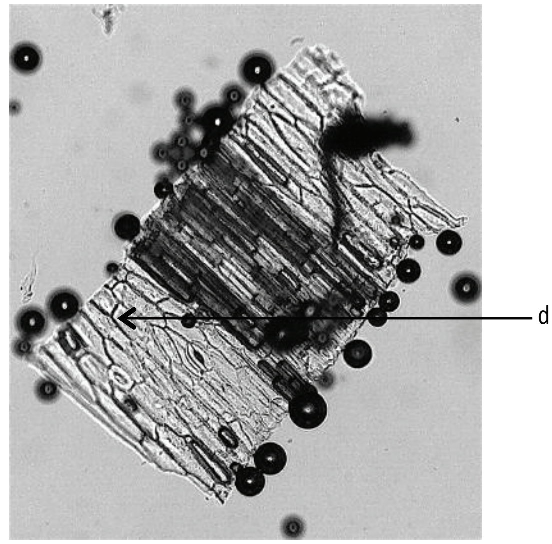
2.3. Results

Of the 9,300 epidermal fragments from 31 samples, 42% were identified as woody browse (8 genera and 15 species), 33% forbs and ferns (2 genera and 13 species), 22% grasses (7 species), and 3% sedges (3 species) and overall diet composition significantly differed among the three summer periods (Figure 2.2; χ^2 = 28.4, df = 6,

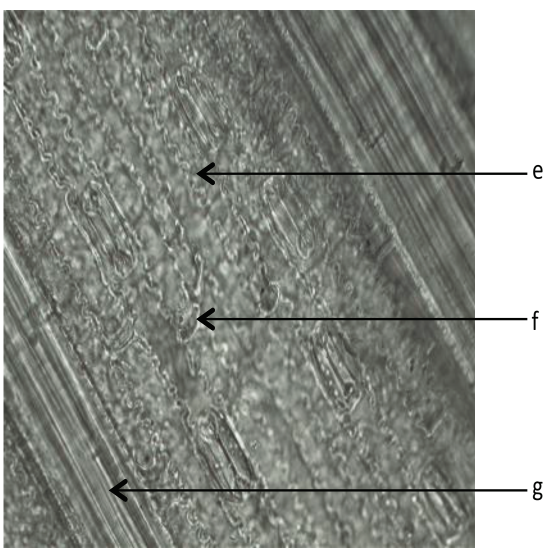
Field horsetail (*Equisetum arvense*)



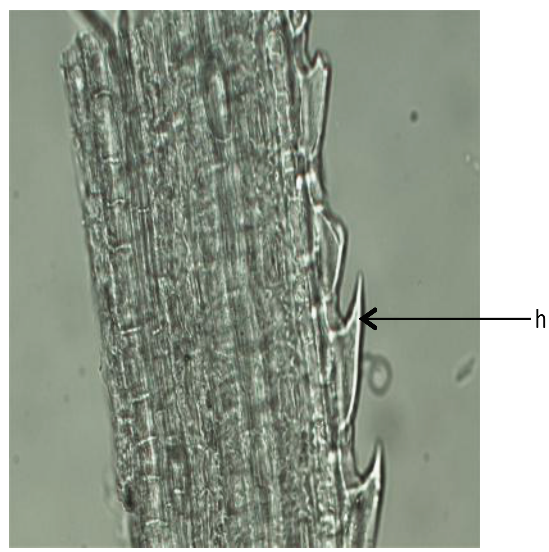
Hawkweed (*Hieracium caespitosum*)



Blue-joint grass (*Calamagrostis canadensis*)



Common hairgrass (*Deschampsia flexuosa*)



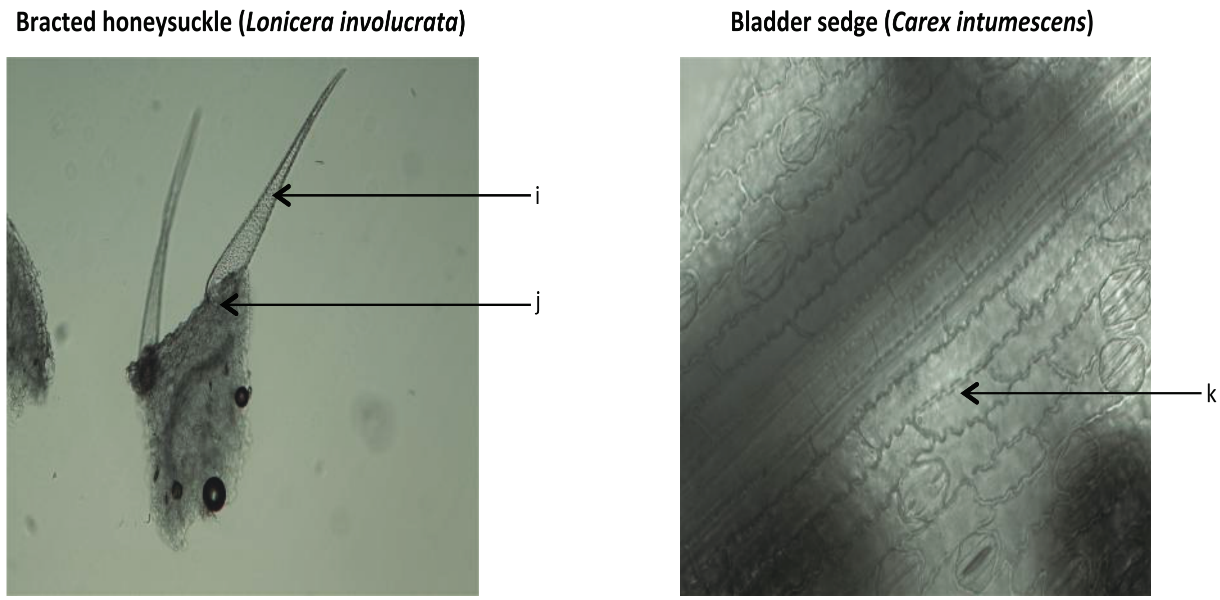


Figure 2.1. Epidermal features of forage plant species. (a) stomata; (b) guard cell; (c) subsidiary cell; (d) smooth cell wall; (e) thin, undulating, rope-like cell wall; (f) cork cell; (g) vein; (h) prickle hair; (i) trichome; (j) trichome base; (k) undulating cell wall (thick, double wall image).

$P < 0.01$). Elk consumed woody browse (53%) and forbs (25%) in spring, while their diet in early summer comprised a greater variety of forbs (42%) and grasses (30%; $\chi^2 = 26.6$, df = 3, $P < 0.01$). Late summer diet composition, when elk mainly consumed woody browse (44%), forbs (31%), also differed from early summer ($\chi^2 = 16.96$, df = 3, $P < 0.01$). However, there were no significant differences found between spring and late summer elk diet composition (Figure 2.3a−c).

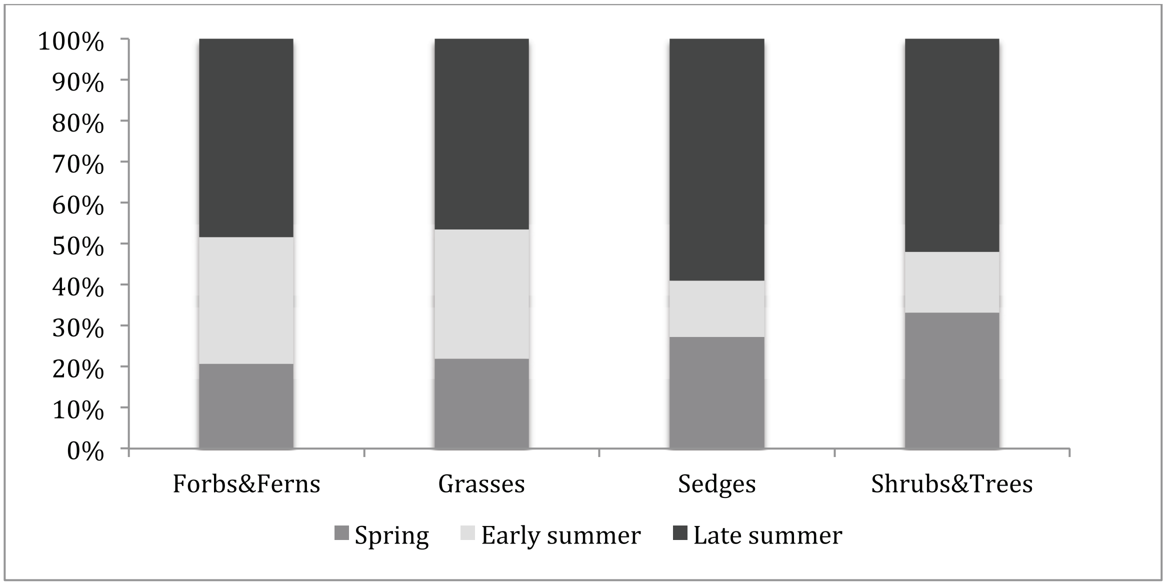
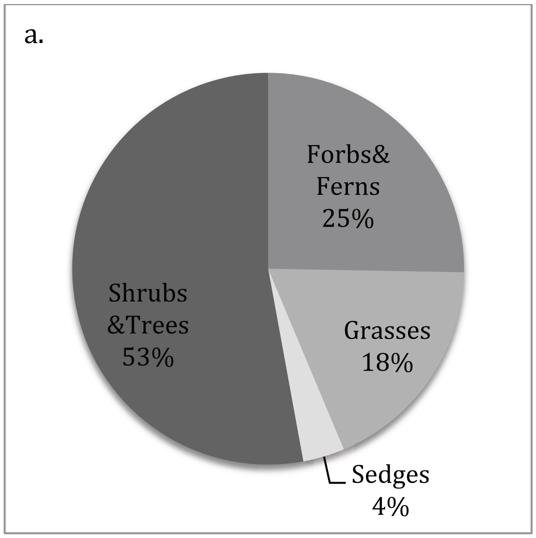
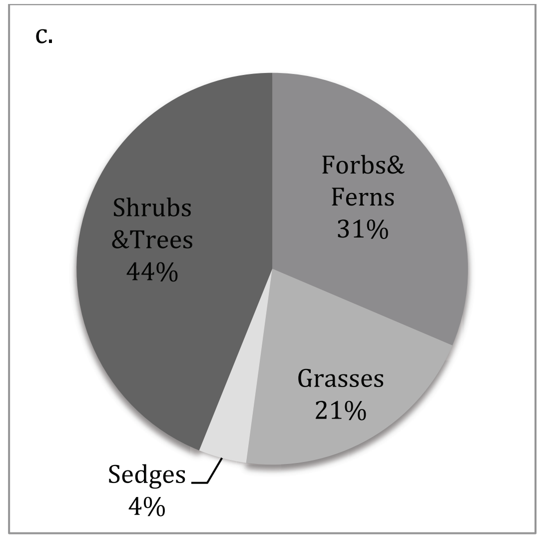


Figure 2.2. Variability in the seasonal diet composition (%) of four plant groups consumed by elk in the LOW area.

Of a total of 59 forage species used by elk, 33 were classified as woody browse species, 16 were classified as forbs and ferns, and 10 were graminoids. Woody browse species, included large-toothed aspen, trembling aspen, bush honeysuckle (*Diervilla lonicera*), bracted honeysuckle (*Lonicera involucrata*), and glaucous honeysuckle (*L. dioica*) and occurred in all 31 fecal samples (Table 2.1a). Canada buffaloberry (*Shepherdia canadensis*), chokecherry (*Prunus virginiana*), pin cherry (*P. pensylvanica*), common juniper (*Juniperus communis*), green alder (*Alnus viridis*), mountain juneberry (*Amelanchier bartramina*), red-twigged serviceberry (*A. sanguinea*), mountain maple, red maple, eastern white pine, jack pine, red pine, red-osier dogwood, wild gooseberry (*Ribes hirtellum*), Bebb's willow and white willow, occurred in at least 12 of 31 fecal samples collected.





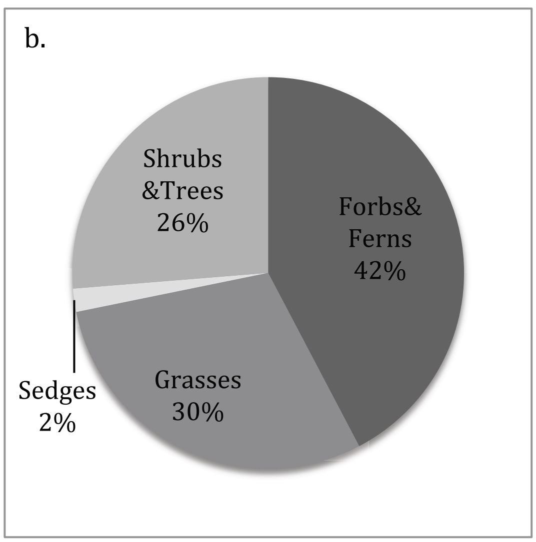


Figure 2.3a-c. Percentage of different plant groups consumed by elk in the LOW area. (a) spring, (b) early summer, and (c) late summer.

Forb species, included palmate hop-clover (*Trifolium aureum*), red clover (*T. pratense*) and white clover (*T. repens*), occurred in all 31 fecal samples (Table 2.1b), while bird's-foot trefoil (*Lotus corniculatus*), creamy pea-vine (*Lathyrus ochroleucus*), daisy fleabane (*Erigeron annuus*), dandelion (*Taraxacum officinale*), field horsetail (*Equisetum arvense*), hawkweed (*Hieracium caespitosum*), sweet clover (*Melilotus officinalis*) and wild geranium (*Garanium maculatum*), occurred in at least 12 of 31 fecal samples. Graminoid species, included blue-joint grass and common hair grass, occurred in all 31 samples (Table 2.1c), while false melic grass (*Schizachne purpurascens*), poverty oat grass (*Danthonia spicata*), rough mountain rice *(Oryzopsis asperifolia)*, Timothy grass (*Phleum pratense*), wheat grass (*Elymus smithii*), brownish sedge (*Carex brunnescens*), bladder sedge (*C. intumescens*), and beaked sedge (*C. utriculata*), occurred in at least 12 of 31 fecal samples collected during spring and late summer. There was a positive correlation between forage species availability in foraging patches and revegetated roads (r = 0.87; Figure 2.4).

2.4. Discussion

Elk are characterized as intermediate feeders, adapted to both forest and open plains, somewhat selective towards more nutritious plants, while still able to use coarse forage to a considerable degree (Hofmann, 1989; Gebert and Verheyden-Tixier, 2001; Storms et al., 2008). Elk in the LOW area used revegetated forest stands dominated by poplar and mixed hardwoods. These mixed-forest stands and revegetated clear-cuts are important to elk, as they provide a wide variety of desirable forage, including young poplar, white birch, mountain maple and red maple, as well as other common shrubs, such as honeysuckle and red-osier dogwood (Jost et al., 1999; Skovlin et al., 2002; Popp et al., 2013). The overall diet of the elk in the LOW was dominated by woody browse (42%) and forbs (33%) throughout the growing season.

Table 2.1a Forage plant species (shrubs and trees) identified in the fecal pellet samples of elk expressed by season.

Forage species *(Shrubs and Trees)*	**Number of samples**		
	Spring	**Early summer**	**Late summer**
American mountain ash, *Sorbus americana*	1	0	0
Aspen, *Populus spp.**[a]	7	9	15
Balsam fir, *Abies balsamea*	3	0	0
Beaked hazel, *Corylus cornuta*	2	0	0
Black spruce, *Picea mariana*	3	0	0
Canada buffaloberry, *Shepherdia canadensis*	3	1	8
Cherry, *Prunus spp.*[b]	7	4	2
Common juniper, *Juniperus communis*	1	6	10
Downy arrow-wood, *Viburnum rafinesquianum*	2	1	0
Eastern white cedar, *Thuja occidentalis*	5	2	4
Elderberry, *Sambucus canadensis*	2	0	0
Green alder, *Alnus viridis*	7	0	11
Honeysuckle, *Lonicera spp.**[c]	7	9	15
Juneberry, *Amelanchier spp.*[d]	3	3	9
Maple, *Acer spp.*[e]	7	0	15
Paper birch, *Betula papyrifera*	3	0	7
Pine, *Pinus spp.*[f]	6	0	11
Prickly wild rose, *Rosa acicularis*	1	0	0
Raspberry, *Rubus spp.*[g]	5	0	0
Red oiser dogwood, *Cornus stolonifera*	5	5	14
Wild gooseberry, *Ribes hirtellum*	3	0	9
Wild red currant, *Ribes triste*	3	0	0
Willow, *Salix spp.*[h]	6	1	14

[a]*Populus:* Large-toothed aspen (*Populus grandidentata*) and Trembling aspen (*Populus tremuloides*).
[b]*Prunus:* Chokecherry (*Prunus virginiana*) and Pin cherry (*Prunus pensylvanica*).
[c]*Lonicera:* Bush honeysuckle (*Diervilla lonicera*), Bracted honeysuckle (*Lonicera involucrata*), and Glaucous honeysuckle (*Lonicera dioica*).
[d]*Amelanchier:* Mountain juneberry (*Amelanchier bartramiana*) and Red-twigged serviceberry (*Amelanchier sanguinea*).
[e]*Acer:* Red maple (*Acer rubrum*) and Mountain maple (*Acer spicatum*).
[f]*Pinus:* Eastern white pine (*Pinus strobus*), Jack pine (*Pinus banksiana*), and Red pine (*Pinus resinosa*).
[g]*Rubus:* Dwarf raspberry (*Rubus pubescens*) and Wild red raspberry (*Rubus idaeus*).
[h]*Salix:* Bebb's willow (*Salix bebbiana*) and White willow (*Salix alba*).
[*]Species marked with the ***** occurred in all 31 fecal samples.

Table 2.1b Forage plant species (forbs and ferns) identified in the fecal pellet samples of elk expressed by summer period.

	Number of samples		
Forage species *(Forbs and Ferns)*	**Spring**	**Early summer**	**Late summer**
Birdsfoot trefoil, *Lotus corniculatus*	4	7	11
Bracken fern, *Pteridium aquilinum*	5	0	0
Clover, Trifolium spp.*[a]	7	9	15
Common evening-primrose, *Oenothera biennis*	0	0	4
Common strawberry, *Fragaria virginiana*	0	4	0
Creamy peavine, *Lathyrus ochroleucus*	4	7	11
Daisy fleabane, *Erigeron annuus*	3	1	9
Dandelion, *Taraxacum officinale*	2	7	4
Field horsetail, *Equisetum arvense*	4	8	15
Fireweed, *Camerion angustifolium*	1	0	9
Hawkweed, *Hieracium caespitosum*	6	7	7
Rough-fruited cinquefoil*, Potentilla recta*	1	2	4
Sweet clover, *Melilotus officinalis*	2	6	11
Wild geranium, *Garanium maculatum*	5	8	3

[a]*Trifolium:* Palmate hop-clover (*Trifolium aureum*), Red clover (*Trifolium pratense*), and White clover (*Trifolium repens*).
*Species marked with the ***** occurred in all 31 fecal samples.

Elk in the French River–Burwash regions of Ontario used ridge, mixed-forests, and grassland habitats for foraging (Jost et al., 1999). Mixed-forest habitats contained the largest number of browse species consumed by elk, and appeared to be an important habitat in the region. According to McIntosh (2003) and Dewar (2006), elk in the LOW area used habitats dominated by a diversity of age classes, and were often seen foraging in recent clear cuts and roadsides. In this study, elk selected smaller foraging patches connected by revegetated roads over large patches

Table 2.1c Forage plant species (grasses and sedges) identified in the fecal pellet samples of elk expressed by seasons.

Forage species *(Grasses and Sedges)*	**Number of samples**		
	Spring	**Early summer**	**Late summer**
Blue-joint grass, *Calamagrostis canadensis**	7	9	15
Common hairgrass, *Deschampsia flexuosa**	7	9	15
False melic grass, *Schizachne purpurascens*	2	7	5
Poverty oat grass, *Danthonia spicata*	6	6	10
Rough mountain rice, *Oryzopsis asperifolia*	3	7	9
Timothy grass, *Phleum pratense*	2	5	8
Wheat grass, *Elymus smithii*	5	3	6
Sedge, *Carex spp.*[a]	6	3	13

[a]*Carex:* Brownish sedge (*Carex brunnescens*), Bladder sedge (*Carex intumescens*), and Beaked sedge (*Carex utriculata*).
*Species marked with the * occurred in all 31 fecal samples.

in relatively close proximity. These secondary roads connect foraging patches and were used by elk as travel corridors and foraging opportunities. Roadsides can provide an abundance of forage biomass and a great diversity of forage species, and are often considered edges when in close proximity to cover (Tufto et al., 1996; McCorquodale, 2003; Wolff and Horn, 2003). Foraging patch use and residence time decreased with increased patch size and distribution over the landscape (Chapter 1). Moreover, residence time in foraging patches varied seasonally and was significantly higher than on revegetated roads (Chapter 1). Unsworth et al. (1998) found that elk in mixed-forest habitats with abundant roads had a pronounced preference for closed-canopy forest stands apparently to minimize human disturbance.

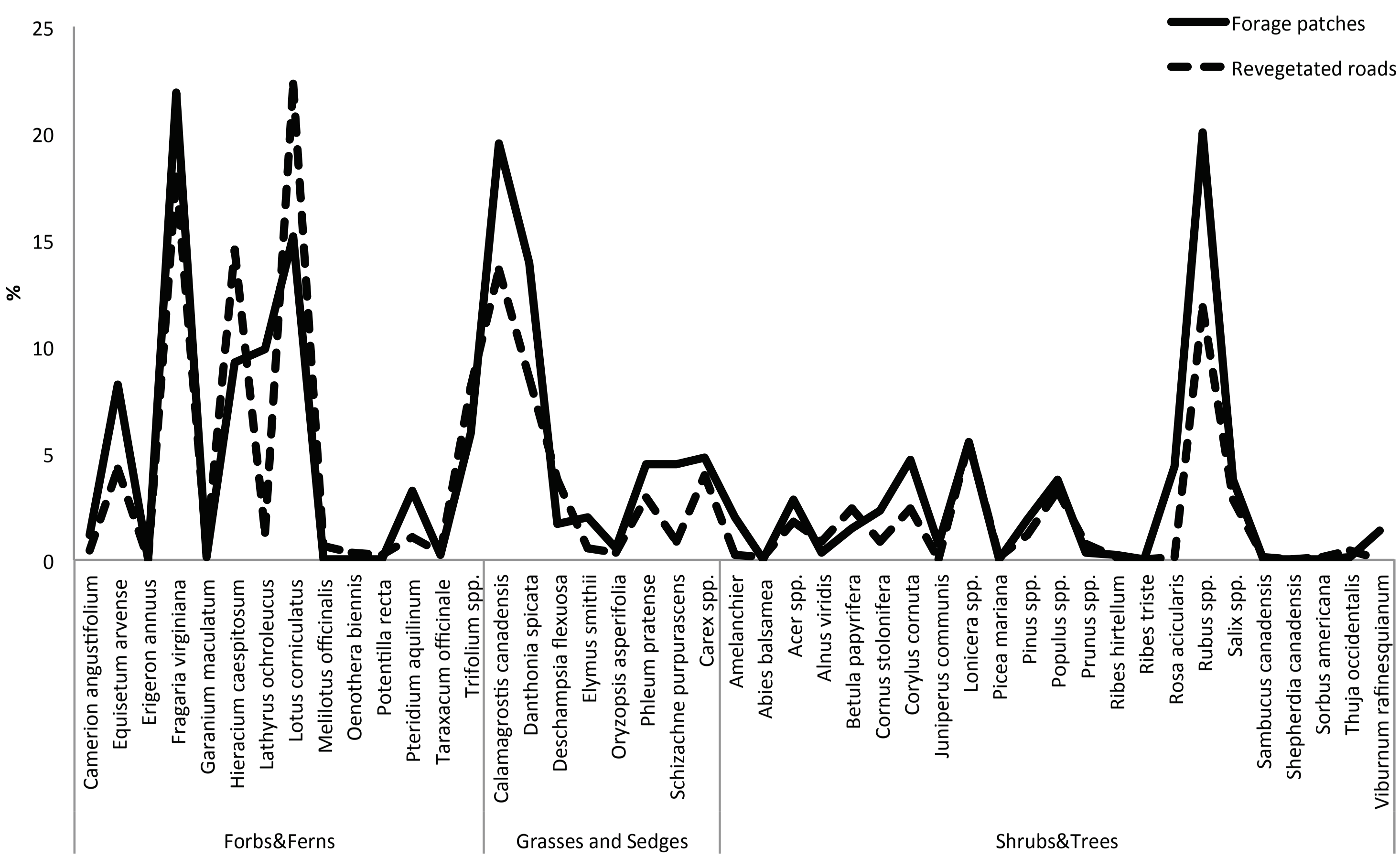


Figure 2.4. Common forage species used by elk and their abundance by plant groups in forage patches and revegetated roads.

2.5. Conclusions

These results support the conclusion that elk in the LOW area preferred various forage plants associated with smaller clear-cut openings and revegetated roads in forested habitats. Foraging patches that create the most suitable habitat in the study area contain food (early-successional plant communities) and cover (semi-mature and mature conifers) in relatively close proximity, usually remote from primary roads. Elk in the LOW area used habitats dominated by a diversity of age classes, including revegetated forest stands dominated by poplar and mixed hardwoods, and were often seen foraging in recent clear cuts and roadsides. Diet composition was dominated by woody browse (42%) and forbs (33%) throughout the growing season. The diet of re-introduced elk in the south part of the LOW area is similar in composition to the diet of elk using mixed-forest habitats in French River–Burwash region of Ontario.

Summary

The results of this study demonstrated that motion-activated cameras with ongoing direct observation, can be used to evaluate foraging patch use, residence time, seasonal activity patterns, and a minimum population estimate of a relatively low-density elk population. When not all individuals in a population are artificially or naturally marked and it is difficult to achieve sufficient sample sizes from camera surveys (due to a low population density or elusiveness of the focal species), investment in marking more animals and an independent non-camera survey could improve inference about seasonal habitat use and population size.

This study demonstrated that foraging patch use and residence time by elk in the LOW area was less for larger patch sizes and for patches with larger distances between them. Furthermore, LOW elk appeared to use secondary roads connecting nearer foraging patches more often, and to avoid areas close to primary roads associated with more human disturbance. Smaller patches were used more than large patches, which were also more often occupied by white-tailed deer and moose.

Elk in the LOW area exist in a complex mosaic of early successional foraging patches created by forest management. The arrangement and extent of suitable habitat types (foraging patches) vary between the northern and southern part of this study area. Foraging patches that create the most suitable habitat contained food (early-successional plant communities) and cover (semi-mature and mature conifers) in relatively close proximity. Availability of woody browse in winter may be a limiting factor for the LOW elk population, as their winter range often overlap with white-tailed deer and moose.

Elk are widely distributed throughout the study area and some individuals have been observed outside of the study area. In the past, evidence that elk were moving out of the study area shortly after the re-introduction was found, however, recent management studies recognize that the majority of elk are staying in the study area. As habitat management plans for elk should be different from management plans for moose and white-tailed deer, information of habitat use, foraging, seasonal distribution and separation on the landscape is important. To benefit elk in the LOW area, forest management should produce irregularly shaped clear-cuts in close proximity, within 200 m of shelter patches or other cover types of regenerating forest in these clear-cuts should have a high diversity of age classes and forage plants.

Elk in the LOW area preferred various forage plants associated with smaller clear-cut openings and revegetated roads in forested habitats. Diet composition during the growing season (May–September) was dominated by a variety of woody browse items, followed by forbs and graminoids in approximately equal amounts. The diet of reintroduced elk in the LOW area is similar to the diet of elk using mixed-forest habitats in French River–Burwash region of Ontario (Jost et al., 1999). Elk diet also varied seasonally, as well as spatially in this region. Further research into food availability, as well as an assessment of nutritional values of particular food sources, would help explain feeding patterns and seasonal habitat use by this forest-dwelling elk population. Forest management should continue to provide a high diversity of age classes and forage species that are necessary elements of good elk habitat in the LOW area.

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Appendix 1: Camera trapping effort, capture frequency and population estimate of unique individuals (females and calves) in the LOW area during May–September 2014.

					Capture/Individual (females and calves)																			
Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv.*	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	C1	C2
May	W1	1																						
		2																						
		3																						
		4																						
		5																						
		6																						
		7																						
	W2	8																						
		9																						
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		11																						
		12																						
		13																						
		14																						
	W3	15																						
		16																						
		17																						
		18																						
		19																						
		20	**P5**		**1**	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		21	**P5**		**1**	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W4	22																						
		23		**Kakagi***	0	**1***	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		24																						
		25		**Kakagi***	0	**1***	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		26																						
		27																						
		28																						
	W5	29																						
		30																						
		31		**Kakagi***	0	0	0	0	0	0	**1***	0	0	0	0	0	0	0	0	0	0	0	0	0

Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv*.	Capture/Individual (females and calves)																			
					F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	C1	C2
June	W5	1																						
		2																						
		3																						
		4																						
	W6	5																						
		6																						
		7																						
		8																						
		9																						
		10																						
		11																						
	W7	12																						
		13																						
		14																						
		15		**Kakagi***	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1***	0	0
		16																						
		17																						
		18	**P7**		0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W8	19																						
		20																						
		21	**P6**		0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		22																						
		23																						
		24	**P7**		**3**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		25																						
	W9	26	**P7**		**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0
		27	**P6**		0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		28																						
		29		**Kakagi***	**1***	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		30																						
		31																						
July		1																						

					Capture/Individual (females and calves)																			
Month	**Weeks**	**Days**	**Forage patch/Idv.**	**Revegetated road*/Idv.***	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**	**C1**	**C2**
July	W10	2																						
		3																						
		4																						
		5																						
		6																						
		7																						
		8																						
	W11	9																						
		10																						
		11	**P3**		**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		12																						
		13																						
		14																						
		15																						
	W12	16																						
		17																						
		18	**P8**		0	0	0	**2**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
		19																						
		20																						
		21																						
		22																						
	W13	23																						
		24																						
		25																						
		26																						
		27																						
		28																						
		29																						

					Capture/Individual (females and calves)																			
Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv.*	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	C1	C2
July	W14	30																						
		31																						
August		1																						
		2																						
		3																						
		4																						
		5																						
	W15	6																						
		7																						
		8		**Pipestone***	0	0	0	0	0	0	0	0	0	0	0	0	**1***	0	0	0	0	0	0	0
		9																						
		10																						
		11																						
		12																						
	W16	13																						
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	W17	20																						
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		22																						
		23																						
		24	**P6**		0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0
		25	**P6**		0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0
		26																						
	W18	27																						
		28																						
		29																						
		30	**P6/P7**		0	0	0	0	0	0	**1**	0	0	**1**	0	0	0	0	0	0	0	0	0	0
		31																						
September		1	**P6**		0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0
		2	**P6/P7/P6**		0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	0	0	0	0	**1**

Month	Weeks	Days	Forage patch/Idv.	Revegetated road/Idv.*	Capture/Individual (females and calves)																			
					F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	C1	C2
September	W19	3	P7		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		4																						
		5																						
		6																						
		7																						
		8																						
		9	P7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	W20	10																						
		11																						
		12	P3		0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
		13	P7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		14																						
		15																						
		16																						
	W21	17	P7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
		18																						
		19																						
		20																						
		21																						
		22																						
		23																						
	W22	24		Kakagi*	1*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		25																						
		26																						
		27																						
		28																						
		29																						
		30																						

Appendix 2: Camera trapping effort, capture frequency and population estimate of unique individuals (males) in the LOW area during May–September 2014.

					Capture/Individual (males)																		
Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv.*	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19
May	W1	1																					
		2																					
		3																					
		4																					
		5																					
		6																					
		7																					
	W2	8																					
		9																					
		10																					
		11																					
		12																					
		13																					
		14																					
	W3	15																					
		16	P5		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		17																					
		18																					
		19	P4		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		20																					
		21	P5/P5/P4		1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W4	22																					
		23		Kakagi*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	0	0
		24	P3		1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		25	P3/P2/P3/P3		1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		26	P5/P2/P5/P5		2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		27	P8		2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		28	P8		1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W5	29	P8/(P4/P5/P8)/P5		2	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		30	P4		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		31	P5/P8		0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv*.	Capture/Individual (males)																		
					M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19
June	W5	1	P4/P5/P5	Kakagi*/Kakagi*	0	1*	1	0	0	1*	0	1	1	0	0	0	0	0	0	0	0	0	0
		2	P4		0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
		3																					
		4		Sandhill*	0	0	2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W6	5	P8		0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		6	P4		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		7		Kakagi*	0	0	0	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0
		8	P1	Pipestone*/Kakagi*	0	1*	0	0	0	2/1*	0	0	0	0	0	0	0	0	0	0	0	0	0
		9	P2		0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		10		Pipestone*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	0
		11	P3	Kakagi*	0	0	1	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0
	W7	12	P8		1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		13																					
		14		Sandhill*/Kakagi L*/Pipestone*	0	0	1*	0	0	1*	0	0	0	0	0	0	0	0	0	0	1*	0	0
		15		Kakagi L*	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		16		(Kakagi L*/Kakagi*)/Kakagi*/Pipestone*	0	2*	0	0	0	1*	0	0	0	0	0	0	0	0	0	0	1*	0	0
		17																					
		18																					
	W8	19	P7	Kakagi*/Kakagi*	0	1*	1*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		20	P6	P1R*/P1L*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1*	0	0	0	0
		21		Lush*/Lush*/P1L	2*	0	2*	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0
		22																					
		23																					
		24																					
		25																					
	W9	26																					
		27		P1R*/Kakagi*	0	0	0	0	0	1*	0	0	0	0	0	0	0	0	1*	0	0	0	0
		28																					
		29		Kakagi*	0	0	0	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0
		30																					
		31																					
July		1																					

Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv.*	Capture/Individual (males)																		
					M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19
July	W10	2	P5		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		3																					
		4	P5	Brook R*	0	0	1	1*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		5																					
		6																					
		7	P3		0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
		8	P3	Brook R*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1*	0	0
	W11	9																					
		10	P2		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		11		Sandhill*	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		12																					
		13																					
		14																					
		15																					
	W12	16	P2		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		17																					
		18	P8	Pipestone*	0	0	2	0	0	0	0	0	0	0	0	0	1*	0	0	0	0	0	0
		19		Sandhill*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		20																					
		21		Sandhill*	0	0	1*	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0
		22	P4		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W13	23		Pipestone*	0	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		24	P5/P3/P5		0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0
		25		Brook R*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	0
		26	P3		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		27																					
		28																					
		29																					

Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv.*	Capture/Individual (males)																		
					M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19
July	W14	30	P4		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		31		Pipepstone*	1*	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August		1	P4		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2																					
		3																					
		4																					
		5																					
	W15	6																					
		7		Pipestone*	0	0	0	2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		8																					
		9																					
		10																					
		11																					
		12	P4		1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W16	13																					
		14																					
		15	P6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		16																					
		17																					
		18																					
		19	P8		1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W17	20																					
		21																					
		22	P7/P5/P7		0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0
		23	P5/P7/P7		0	0	2	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0
		24	P7		0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
		25	P5/P6		1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		26																					
	W18	27		Log*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	0
		28	P4/P8		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		29	P4		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		30	(P7/P6/P4)/(P6/P4)/P7/P7/(P6/P7)/P6/(P6/P5)/P6		3	0	2	0	0	1	2	0	0	0	0	0	3	2	3	0	1	0	0
		31	P6/P7/P7		0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0
September		1	P7		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2	P7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Month	Weeks	Days	Forage patch/Idv.	Revegetated road*/Idv.*	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19
					Capture/Individual (males)																		
September	W19	3	P7/P4		0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		4																					
		5	P7/P4/P6		0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
		6	P7		0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
		7	P7/P7/P3/P6		0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0
		8																					
		9	P7		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	W20	10	P5		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		11	P6/P6/P7		0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		12	(P5/P6)/P6/P3/P3/P6/P6		2	0	0	0	0	0	1	0	0	0	0	0	1	0	2	1	0	0	1
		13	P3/P7/P6		0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0
		14		Cameron*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	0	0	0
		15	(P7/P4)/P6/P6/P7/P7	Cameron*	2	0	2	0	0	2	1	0	0	0	0	0	1*	0	1	0	0	0	0
		16	(P6/P4)/P6	Cameron*	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1/1*	0	0	0	0
	W21	17	P6/P7(P6/P7)	Cameron*	0	0	2	1	0	0	0	0	0	0	0	0	2	1*	0	0	0	0	0
		18	P6		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		19	P7		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		20	P7	Cameron*	1*	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		21	(P5/P8)/(P6/P8)		2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		22																					
		23																					
	W22	24		Kakagi*/Sandhill*/Kakagi*	0	1*	0	0	0	1*	0	0	0	0	0	0	0	0	0	1*	0	0	0
		25																					
		26																					
		27																					
		28																					
		29																					
		30																					