THESIS

MOVEMENT PATTERNS, BEHAVIOR, AND HABITAT USE OF FEMALE MOOSE ON JOINT BASE ELMENDORF-RICHARDSON, AK

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2016

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ABSTRACT

MOVEMENT PATTERNS AND HABITAT USE OF FEMALE MOOSE ON JOINT BASE ELMENDORF-RICHARDSON, AK

Joint Base Elmendorf-Richardson (JBER), which is a combined United States Army/Air Force installation, and neighboring Anchorage, Alaska, support a population of moose *Alces alces* (Linnaeus, 1758) that inhabit a fragmented landscape of habitat types interspersed with human development. Because development plans in support of the military mission may have significant impacts on moose movement in the area, JBER and Alaska Department of Fish and Game (ADF&G) biologists began a study of moose habitat use and behavior on JBER. In order to help identify behaviors in wild radio-collared moose captured on JBER, we tested Telonics tri-axial accelerometers for accuracy in the detection of activity and the identification of behaviors in radio-collared moose. Direct observations of three captive animals fitted with radio collars containing accelerometers allowed us to calibrate activity readings to observed behaviors. We developed four datasets in order to test whether readings from this type of accelerometer could identify specific behaviors (browsing, grazing, walking, standing, lying), behavior categories (feeding, traveling, resting), or simply when moose were active or inactive. Multiple threshold criteria were tested in order to maximize correlation to observed behaviors. The highest overall accuracy was achieved when using threshold criteria to characterize behaviors as active (92.29% accuracy) or inactive (90.64% accuracy). A Fisher's Exact Test indicated that there was no significant difference between observed behaviors and those correctly classified using threshold criteria for either active ($p = .9728$) or inactive ($p = .9431$) behaviors, indicating that our threshold criteria is correctly classifying these behaviors. In the next phase of this study, we collected 244,957 GPS locations from 18 female moose captured on JBER and fitted with GPS collars equipped with the same model tri-axial accelerometer used in the captive trials. Data from the accelerometers were used to characterize moose behavior as active or inactive. GPS locations, along with behavior patterns and movement characteristics, were used to rank JBER habitat types. Turning angle and speed were calculated between successive locations for each animal across the animal's home range. Values were pooled for all animals and used to assess movement characteristics by season and habitat type. The highest velocity recorded for a 60 minute period was 1.50 m/s (5.40 kph), and 99.50% of all steps had velocities < 0.26 m/s (0.94 kph). Turning angle groups did not vary among either habitat types ($p = 1.00$) or seasons

($p = 0.99$). A new, intuitive home range estimation method, Dynamic Potential Path Area (dynPPA), was used to incorporate behavioral states into the delineation of animal home ranges. We delineated dynPPA home ranges by season for each moose, and used this technique in combination with Jacobs Index (which measures utilization in relation to availability) to determine habitat preference. Seasonal dynPPA home range sizes averaged 15.28 km^2 in summer ($SD = 6.43$) and 23.25 km^2 in winter ($SD = 7.97$). Habitat types most often used by moose on JBER included mixed deciduous/conifer (38.23% of summer locations and 30.03% of winter locations occurred within this habitat type), shrublands (15.04% of summer locations and 28.57% of winter locations), and deciduous forest (21.89% of summer locations and 19.08% of winter locations). While individual moose differed in habitat selection ($F = 1.73$, $df = 17$, $p < 0.01$), the most preferred habitat (according to Jacobs Index) on JBER in relation to its availability within the home range was shrublands.

ACKNOWLEDGMENTS

This has been a long road, and I owe thanks to a great many people. First I would like to thank the members of my committee. I initially asked Dr. Sean Farley of the Alaska Department of Fish and Game only for data from his study, but he insisted that I become an integral part of the project. His influence as my thesis advisor has made me a better biologist. Dr. Larry Rittenhouse encouraged me from the very beginning, and has always been there to listen and offer advice. At the last minute, Dr. Paul Meiman stepped in when I needed another committee member and provided valuable input into the final draft. Dr. Kraig Peel was always available, and like all the members of the committee, showed extraordinary patience. I thank each of you for all your encouragement, guidance and support.

Joe Welch, the other grad student on this project, needs a shout-out as well. We worked collaboratively on many aspects of our respective projects, and he’s a great guy to work with.

Thanks to Jed Long for creating the Dynamic Potential Path Area home range estimator.

I would like to express my appreciation for all the Fish and Game folks that were so essential to the success of this project. Rick Sinnott provided moose darting expertise. Liz Solomon’s help with GIS and databases was vital. Bill Collins was kind enough to let me use his captive moose for the accelerometer calibration, and Cory Stantorf was kind enough to help me collar said moose. Special thanks to Gino Del Frate for encouraging me to finish this thing up, and giving me the time to do so.

My two previous supervisors, Chris Garner and Jessy Coltrane, have become my lifelong friends. Chris was my supervisor when I was at JBER, giving me tremendous latitude to pursue my degree and to work on this project, as well as securing a large portion of the funding. Jessy not only led the team that hired me at Alaska Fish and Game, she encouraged me, believed in me, and provided opportunity to write, all while maintaining a sense of humor about my hillbilly ways.

I am indebted to the JBER Natural Resources crew. Rich Graham is a mentor, friend, moose-finding fool, and crotchety old curmudgeon. Chris McKee distracted me when I needed it with discussions on politics and theology. Herman Griese came up with the idea for this project in the first place. It would never have gotten started without him. Many JBER/CSU wildlife technicians put in many hours on field work, and this thesis would have suffered without their involvement. There are too many to name here, but they know who they are.

I could not have completed my thesis without the help of David Saalfeld. His expertise and advice on statistics and experimental design, and his willingness to take on extra work so I would have time to write, were absolutely invaluable.

There was never a more patient, understanding person than my wife, Beth. She provided tremendous amounts of practical assistance, including data management, thesis formatting, and the solving of technical issues, all while keeping me sane and lightening my load when I was feeling the crushing weight of the thesis pressing down. I am aware every day of how blessed I am to share my life with her.

Last but not least, I want to thank God for creating such a wondrous world full of wildlife and nature, especially *Alces alces*, to fascinate and intrigue us all. The intricacy of their design leaves me no doubt that He is the almighty creator.

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Chapter 1: Introduction

1.1 Why Study Movements and Habitat Use of Moose in Fragmented Landscapes?

Urban moose (*Alces alces*) must survive and reproduce in fragmented landscapes with many forms of disturbance. Human development such as the construction of roads, railroads, buildings, and paved areas has the negative effect of removing and fragmenting patches of habitat (Laurian et al. 2008, Olsson et al. 2008). However, the clearing of land for development may also inadvertently make high quality nutrition (in the form of shrublands) available along edges of roadways, power lines, railroads, and around buildings (Rea et al. 2010, Weixelman et al. 1998). This can attract moose into urban areas, leading to increased conflicts with humans. It is of utmost importance to understand how moose populations in these conditions will respond to changes in habitat.

Urban communities which contain large numbers of moose must find ways to deal with vehicle collisions, aggressive encounters, and damage to ornamental plants, vegetable gardens, and fruit trees (Child et al. 1991, Coltrane and Battle 2014, Dussault et al. 2007, Garrett and Conway 1999). Human activities can also affect moose behavior and movements, particularly if humans frequently approach moose on foot, skis, motorized vehicles, or aircraft (Andersen et al. 1996, Neumann et al. 2009, Støen et al. 2010).

The National Environmental Policy Act of 1969 (NEPA) requires federal agencies to consider potential environmental impacts before undertaking major construction projects. Fort Richardson Army Post and Elmendorf Air Force Base (EAFB) are US military installations located within the Municipality of Anchorage in Southcentral Alaska that combined in 2010 to create Joint Base Elmendorf-Richardson (JBER). The two parts of the installation are now referred to as JBER-Richardson and JBER-Elmendorf. Development plans in support of the JBER military mission are likely to have significant impacts on wildlife movement in both the Eagle River and Ship Creek drainages. These military lands comprise an important large-scale corridor for wildlife movement, already severely restricted by development outside the borders

Approximately 11,600 people live on JBER (Military Installations 2015) and 300,549 people (U.S. Census Bureau 2010) live in neighboring Anchorage Alaska. The moose population in the Anchorage area has increased over the past 70 years (Coltrane and Battle 2014) even though the human population has increased exponentially from 3,495 people (U.S. Census Bureau 1940) to over 300,000 people during the same period. Moose are valuable to the community for both hunting and wildlife viewing opportunities; however, moose also represent a substantial cost to the community in terms of vehicle collisions, bodily injury, property damage, and disruption of military operations (Northern Economics 2006). Moose often wander onto firing ranges and runways, causing disruption of military training.

In 2004, US Army Garrison Alaska (USAG-Alaska) completed an Environmental Assessment (EA) for fencing sections of the Fort Richardson boundary and housing area in order to deter both vehicle and pedestrian trespassers and allow soldiers to train safely and efficiently. The effect of the fencing on moose movements figured prominently in the assessment. The fence project was the subject of a great deal of commentary by the public and various state and federal agencies, much of which involved concerns about effects of the proposed fence on wildlife passage. Ultimately, chain link fence (with some one-way moose gates) was erected around the cantonment (housing) area and a pipe rail fence was built along sections of the Fort Richardson boundary. Mitigation identified in the EA required USAG-Alaska to monitor the effects of the fence on wildlife. Any barrier that impedes seasonal movement of wildlife has the potential to impact populations (Department of the Army 2004). As more habitat is developed on JBER there may be a profound effect on moose numbers and movement patterns.

There are a variety of factors that may affect how moose utilize the landscape, including distribution of food items, bedding cover, water, snow depth, presence of predators, fire history (as it relates to available nutrition and cover) and human activity (Peek 1997). Available literature contains conflicting results regarding the response of moose to habitat characteristics. High browse density has been correlated both with increased activity (Vivas and Saether 1987) and with decreased activity (Dussault et al. 2005). Low browse density has been correlated both with increased travel distance (Risenhoover 1987) and with decreased travel distance (Saether and Andersen 1990). High density moose populations are typically associated with post-fire habitats (Maier et al 2005, Davis and Franzmann 1979, Wolff 1978), but can also occur in locations where fire is infrequent (Peek 1997). Osko et al. (2004) found that moose preferences can vary among moose populations in different areas due to relative abundance of available habitat. This suggests that it is important to measure habitat preferences of specific populations in order to make management decisions.

1.2 Remote sensing of activity level

Measuring behavior and activity level is vital to gaining a more complete understanding of how animals are utilizing habitat. However, direct observation of free-ranging animals over long periods of time and large geographic areas is usually impossible. As radio collar technology has progressed from simple Very High Frequency

(VHF) signals into the use of collars that provide Global Positioning System (GPS) locations, an ever greater understanding of animal movement and activity is now possible. One technology that continues to advance is the use of various types of motion sensors mounted in radio collars to measure an animal's activity level, and in some cases even differentiate one behavior from another. This is providing researchers with a tool to remotely collect data on animal activity and behavior along with location data received from GPS collars.

Over the years, researchers have used a wide variety of motion sensors to attempt to remotely classify behaviors in both wild and domestic ungulate species in free-ranging situations. For example, Moen et al. (1996) used a dual axis sensor on moose. Both Adrados et al. (2003) and Löttker et al. (2009) used dual axis sensors on red deer (*Cervus elaphus*). Naylor and Kie (2004) used omnidirectional accelerometers on Rocky Mountain elk (*Cervus elaphus*). Coulombe et al. (2006) predicted white-tailed deer (*Odocoileus virginianus*) behaviors with VHF variable pulse sensors and GPS dual axis sensors. Blomberg (2011) used tri-axial accelerometers to monitor grazing behavior in cattle (*Bos taurus*). In any study involving the use of activity sensors to measure behavior, it is necessary to first correlate data from the specific type of sensor used with observed behavior for the species involved, as variations in motion and activity levels among species and individuals will affect readings. Data from trials on captive animals allow researchers to remotely classify behavioral states in wild radio-collared animals equipped with the same accelerometers.

1.3 Home Range, Movement Characteristics, and Habitat Use

One of the most basic requirements in the study of animals is an understanding of how the animal interacts with its environment. It can be assumed that animal habitat use is not random (Kauhala and Auttilla 2010). All animals prefer certain habitats to others (Samuel et al. 1985, Harris et al. 1990), and the analysis of particular movement characteristics (e.g., turning angle, velocity) may yield insight into these preferences. Moose movement characteristics and home range size can vary widely between seasons (Hundertmark 1997), and animals may vary the distance and direction (e.g., turning angles) of their movements based on varying temporal and spatial availability of resources (McClintic et al 2014, Getz and Saltz 2008). For instance, Graves et al. (2007) defined areas where brown bears exhibited high amounts of very directional, fast movement as highly functional travel corridors. Additionally, landscape features of fragmented urban environments (like those found on JBER) can affect animal movement. For example, Dussault et al. (2007) found that moose movement rates crossing a highway were an average of three times faster than steps preceding or following a crossing.

The analysis of home range is another method by which one can arrive at an improved understanding of an animal's interaction with its environment. Home range is an attempt to describe the spatial boundaries of an animal's movements. One early definition of home range was proposed by Burt (1943): "…that area normally traversed by the individual in its normal activities of food gathering, mating, and caring for young." Mitchell and Powell (2004) stated that home ranges of animals are associated with the spatial distribution of limiting resources on the landscape. Home ranges have been used to study habitat selection (Aebischer et al., 1993; Rhodes et al., 2005), territorial overlap (Fieberg and Kochanny, 2005; Kjaer et al., 2008), impacts of various factors on space use (Smulders, 2006; Lynch et al., 2008), and the vulnerability of species to extinction (Waldron, et al., 2006).

Many methods have been devised to estimate home ranges, all of which have strengths and weaknesses. Two of the most common techniques are minimum convex polygon (MCP) and kernel density estimation (KDE). MCP is still widely used in wildlife research because of its comparability to past studies (Nilsen et al., 2008), and possibly because of the ease of implementation in common Geographic Information System (GIS) programs (Long and Nelson, 2012). However, this technique has often been criticized because of several drawbacks, including a high sensitivity to sample size and outliers, and convex assumption (White and Garrott, 1990; Laver and Kelly, 2008; Nilsen et al., 2008). While KDE is generally considered more representative of an animal's true home range than MCP (Borger et al., 2006), its use is also sometimes debated, primarily based on difficulty in selecting appropriate bandwidth values (Gitzen and Millspaugh, 2003). KDE home ranges can also be misleading when used for animals occupying a fragmented distribution of habitat patches (Mitchell and Powell, 2008).

Most existing home range techniques do not take temporal characteristics into account. Potential Path Area (PPA) (Long and Nelson 2012) is a new method for delineating a home range using concepts from time geography (Hägerstrand 1970). PPA uses an animal's beginning and ending locations, the time elapsed between these two locations, and the animal's presumed maximum velocity to calculate the area the animal could feasibly have been in during that time. This results in an ellipse drawn around the two points. The series of ellipses for an entire dataset comprise a PPA home range. Since the technique was first developed, a dynamic component has been added to include behavioral states into the demarcation of a home range (Long and Nelson 2015). This is termed the Dynamic Potential Path Area (dynPPA).

Analysis of home range has often been used to study habitat use (e.g., Aebischer et al. 1993, Rhodes et al. 2005). In order to answer research questions involving habitat needs of a particular species in a particular area, it is necessary to first measure how each habitat type is used and what proportion of time is spent in each habitat type available to the animal.

1.4 Study Objectives

While some research has been done on the effect of topographic variables on moose (e.g., Poole and Stuart-Smith 2006) little has been done on habitat selection by urban moose in the JBER/Anchorage area. Objectives for this thesis were to determine: 1) what types of behaviors can be remotely classified using data from tri-axial accelerometers embedded in Telonics radio collars worn by moose; 2) whether specific behaviors are strongly associated with discrete habitat types; 3) whether movement characteristics such as turning angle and velocity vary according to season or habitat type; and 4) the utility of a relatively new home range estimator, the dynamic Potential Path Area, in investigating habitat use in relation to availability. Results will allow JBER decision makers to increase or decrease moose numbers in various sections of JBER through the careful management of habitat.

In Chapter Two, we address the question: what types of behaviors can be identified using Telonics tri-axial accelerometers embedded in radio collars? To accomplish this, radio collars were mounted on three captive moose at an Alaska Department of Fish and Game (ADF&G) facility in Palmer, Alaska. These moose were followed for three consecutive days during daylight hours, employing focal animal sampling methodology, and observed behaviors were correlated to accelerometer readings. Four datasets were developed in order to test whether readings from this type of accelerometer could identify specific behaviors (browsing, grazing, walking, standing, lying), behavior categories (feeding, traveling, resting), or simply when moose were active or inactive. Multiple threshold criteria were tested in order to maximize correlation to observed behaviors. These results can be used by researchers using Telonics radio collars equipped with tri-axial accelerometers to remotely classify moose behaviors.

In Chapter Three, the relationship between habitat type and movement of moose is examined. Results from Chapter Two were used to remotely classify behaviors from wild moose collared on JBER. Chapter Three also investigates the utility of the dynPPA home range estimator. Jacob's Index (which measures utilization in relation to availability) was used in conjunction with dynPPA to determine which habitats on JBER were preferred by moose and which were avoided. In addition, kernel density maps are used to identify areas and travel corridors that were frequently used by collared moose.

This thesis examines how moose move and the behaviors they exhibit through a mosaic of habitats and manmade landscape features. These results can be used to increase the accuracy of home range estimation, study habitat selection, and help remediate conflicts between moose and humans.

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Chapter 2: Identifying Moose Behavior with Tri-axial Accelerometers

2.1 Introduction

Direct observation of free-ranging animals over long periods of time and large geographic areas is often impractical. As radio collar technology has progressed from simple VHF signals into the use of collars that provide GPS locations, an ever greater understanding of animal movement and activity has become possible. One technology that continues to advance is the use of various types of motion sensors mounted in radio collars to get a measure of an animal's activity level, and in some cases even differentiate one behavior from another. This has provided researchers with a tool to remotely collect data on animal activity and behavior along with the location data received from the collars.

A variety of activity sensors have been used to estimate animal activity in free ranging situations. In the 1980s, variable pulse emitters and tip switches were mounted in VHF collars (Garshelis et al., 1982, Gillingham and Bunnel, 1985, Beier and McCullogh, 1988). These systems were found to be accurate in many situations, but did have some technical issues. Gillingham and Bunnel (1985) found that slight head movements prevented conventional tip switch collars from transmitting an inactive pulse signal, causing misclassification of behaviors, and that higher rates of activity do not necessarily result in higher pulse rates with variable pulse emitters. These systems were improved upon in the 1990s by the addition of tilt switch (Rumble et al., 2001) and dual axis sensors (Moen et al., 1996, Adrados et al., 2003, Yamazaki et al., 2008). Tilt switch sensors detected head up/down movement. Dual axis sensors detected both head up/down and side-to-side movement. Early versions of dual axis sensors combined the up/down and side-to-side movements into one count. Later versions summed these counts separately, which improved accuracy (Coulombe et al., 2006).

Activity sensors have been used with humans for some time, primarily for activity assessment after medical procedures (e.g., Bussmann et al. 1998, Foerster et al. 1999). Accelerometers have been used with domestic or livestock animals (e.g., Watanabe et al., 2005 in cats (*Felis catus*), Cornou et al., 2011 in pigs (*Sus scrofa*), Blomberg, 2011 in cattle (*Bos Taurus*), and Moreau et al., 2009 in goats (*Capra hircus*)) and on wildlife species (e.g., Arai et al., 2000 on Andelie penguins (*Pygoscelis adeliae*), Okuyama et al., 2004 on Hawksbill turtles (*Eretmochelys imbricate*), and Yamazaki et al., 2008 on Japanese black bears (*Ursus thibetanus japonicas*)).

In recent years, researchers have used a variety of types of motion sensors to attempt to remotely classify behaviors in wild ungulate species. Löttker et al. (2009) used a dual axis sensor on red deer. Coulombe et al. (2006) predicted white-tailed deer (*Odocoileus virginianus*) behaviors with VHF variable pulse sensors and GPS dual axis sensors. Naylor and Kie (2004) used omnidirectional accelerometers on Rocky Mountain elk (*Cervus elaphus nelsonii*). Adrados et al. (2003) used GPS dual axis sensors on red deer (*Cervus elaphus*). Moen et al. (1996) used a dual axis sensor on moose.

The sensor used in this study to measure activity data is a Telonics tri-axial accelerometer designed to detect activity in three planes of motion (front/back, side/side, up/down). This type of sensor has largely supplanted the tip switches and dual axis sensors used in previous generations of GPS systems, as the measurement of motion along three axes has been found to allow for greater accuracy in the detection of activity (Ware et al., 2015).

In any study involving the use of activity sensors to measure behavior, it is necessary to correlate data from the specific type of sensor used with observed behavior for the species involved, as variations in motion and activity levels among species and individuals will affect readings. Calibration of accelerometer data with activity levels and behaviors of captive radio-collared moose was undertaken in order to remotely identify behaviors in wild radio-collared moose involved in a study on moose movements on Joint Base Elmendorf-Richardson, Alaska. These data will be used to rank habitat by activity patterns. In addition, we present our findings on using several possible methods to analyze output from the accelerometer used by Telonics in their Generation 4 collars.

2.2 Methods

2.2.1 Collars

Collars used were Telonics Generation 4 GPS Store-On-Board radio collars. The sensor used to measure activity data in these collars is a tri-axial accelerometer designed to detect changes in acceleration in any one, or a combination of, the three planes of motion. The sensor detects acceleration and tilt relative to gravity. The system compares the level of acceleration detected from one second to the next. If the system detects a change in acceleration or a change in the position of the animal relative to gravity (or "tilt") this second is classified as an "active second" to indicate that some activity has occurred during that second. Data are presented in "active seconds per minute" (Telonics, 2009). Unlike some other systems using tri-axial accelerometers, the Telonics accelerometer does not record data for the different axes separately.

2.2.2 Observations

The accuracy of the accelerometers in the correct identification of behaviors was tested on three captive moose in an 8-hectare holding pen at an ADF&G captive facility in Palmer, AK. Vegetation in the pen was mostly deciduous forest, consisting primarily of *Betula neoalaskana* Sarg (Alaska birch), *Populus balsamifera* L. (Balsam poplar), and *Populus tremuloides* Michx (quaking aspen). There was also a small grassy field on one edge of the pen, and in certain areas *Picea mariana* (Mill.) Britton, Sterns & Poggenburg (black spruce) and *Picea glauca* (Moench) Voss (white spruce) were mixed with the deciduous forest. The three moose used were Blue (a 437-kg adult female), Red (an 383-kg adult female), and Diana (a 354-kg adult female). Adult females were used because all the research animals in the JBER Movement Corridor Study are adult females. Other moose present in the pen were a female calf (born May 2010), two castrated adult males, and a one-and-one-half-year old female. Also present were a caribou female and two calves.

The data collection period took place October 17-19, 2010. Mean temperature for the three days was 6° (C). Weather conditions were overcast with no precipitation and no snow cover. The observer followed the moose for those three consecutive days during daylight hours, employing focal animal sampling methodology. Sampling periods lasted a minimum of five minutes, but did not have a maximum time limit, as we were not interested in activity budgets of captive animals, but rather in calibrating activity readings to observed behaviors. Instead, the observer focused on the research animal which was exhibiting the most consistent behaviors at any particular time. If the focal animal was displaying consistent behavior, sampling periods often lasted considerably longer than five minutes. In order to maintain consistency, all observations were conducted by one observer, from distances ranging approximately 3 to 30 meters. When focusing on each individual, all behaviors lasting longer than two seconds were noted. Data were recorded on Zire 31 palmOne™ personal digital assistants (PDAs), using a data entry program custom designed for this project by Dr James Ha of the University of Washington. PDAs were synchronized with the collar time.

Placement and removal of the collars was accomplished without chemical immobilization, as the moose were raised in captivity.

2.2.3 Behavior Analysis

Specific behaviors recorded included browsing, grazing, feeding-other (most often used for drinking from a trough), standing, lying, walking, and running. See Appendix A on page 29 for a detailed definition for each behavior. Observed behavior data was then compared to the one-minute collar accelerometer readings for the same time periods. In order to determine how best to correlate readings to observed behavior, four datasets (one of which consists of two subgroups) were developed. In order to ensure that only one behavior was causing accelerometer readings, all minutes in which more than one behavior occurred were removed from analysis in three datasets. This allows for the most consistent readings possible, but limits the sample size in some cases, particularly with traveling behaviors. For instance, it was very rare to see the moose walk for a full minute, so there were only two minutes of walking behavior included in these datasets. The two data subgroups under "Partial Minutes: Behavior Categories" explored methods of classifying minutes in which more than one behavior was observed, primarily in an attempt to expand the sample size for traveling behavior. The datasets are listed below:

1) **Specific Behaviors.** The first dataset correlated activity readings with the exact behaviors observed (browsing, grazing, feed-other, standing, lying, walking, and running) for each full minute.
2) **Behavior Categories.** For the second dataset, we determined the behavior category for each full minute. Browsing and grazing behaviors were placed in the feeding category. Lying and standing behaviors were placed in the resting category. Walking (the only traveling behavior that was observed to last a full minute) was placed in the traveling category. This allowed for a slightly larger sample size, as (for example), if an animal was browsing then halfway through a minute switched to grazing, the entire minute was characterized as feeding and could be included in analysis. This dataset did not include minutes which contained more than one behavior category (e.g., feeding for 30 seconds, then traveling for 30 seconds).
3) **Partial Minutes: Behavior Categories.** The following two subgroups of data were developed as an attempt to expand the sample size for traveling behavior by determining the dominant behavior category for each minute of data collection.
    a. **Behavior Categories: 40 Seconds.** In this subgroup, if there were at least 40 seconds of one behavior category (feeding, resting, traveling) in a one-minute period, the full minute was classified as that category. These "partial minutes" were then added to the minutes in which one behavior category lasted a full 60 seconds.
    b. **Behavior Categories: 30 Seconds.** In this subgroup, if there were at least 30 seconds of one behavior category (feeding, resting, traveling) in a one-minute period, the full minute was

classified as that category. These “partial minutes” were then added to the minutes in which one behavior category lasted a full 60 seconds.

4) **Active/Inactive.** In the last dataset, we characterized each full minute of observation as simply active or inactive. Resting behaviors were characterized as inactive, while feeding and traveling behaviors were characterized as active.

Feeding-Other was excluded from all datasets, as feeding from a trough is not a behavior exhibited by wild moose.

2.2.4 Results

In order to test homogeneity of variance, Levene’s Test for Equality of Variances ($p = 0.029$) was used to test mean accelerometer readings, and the Brown-Forsythe test ($p = 0.043$) was used to test median readings.

Activity readings did not follow a normal distribution, even after log transformation (see Figure 2.1). In order to ascertain whether activity readings are normally distributed, a Shapiro-Wilk Normality Test ($p < 0.01$) was conducted.

Since this data is not normally distributed, log transformation did not improve normality, and the variances are not statistically equal, we used nonparametric tests.

2.2.5 Specific Behaviors

The first dataset consists of accelerometer readings for the specific behaviors observed during data collection, taken only from minutes during which one behavior lasted the entire 60 seconds. Summary statistics for this dataset are in Table 2.1. This dataset yielded a total of 751 minutes (Table 2.2). While a Kruskal-Wallis Analysis of Variance (ANOVA) indicated there were statistically significant differences in accelerometer readings between some behaviors ($p < 0.01$), there were not significant differences between other behaviors, and there was too much overlap in readings in this dataset to be able to differentiate some behaviors from others with any degree of accuracy.

2.2.6 Behavior Categories

Table 2.3 illustrates summary statistics for the Behavior Categories dataset. When observations from all three moose were combined, there were 422 minutes of feeding, 342 minutes of resting, and two minutes of traveling (Table 2.4). The mean activity count for feeding behaviors was 4.075 and the mean activity count for resting behaviors was 0.183. There were only two minutes in the entire three days of data collection during which a moose being observed walked for a full minute. While it seems there may be clear differences in activity counts for traveling (the mean activity count for the two minutes of traveling behavior was ten active seconds/minute), the captive moose being observed very rarely walked for a full minute without stopping and standing for a few seconds, resulting in a very small sample size.

Although a Kruskal-Wallis test indicated that there was a significant difference (see Table 2.5; $p < 0.01$) between accelerometer readings for feeding and resting behaviors, threshold values were not applied to this dataset since there was not a large enough sample size of traveling behavior to be useful. It is possible that if sample size could be increased for traveling behavior, we would be able to differentiate between feeding, traveling, and resting behaviors.

2.2.7 Partial Minutes: Behavior Categories

These two subgroups of data, which add "partial minutes" (those minutes in which one behavior lasted 40-59 seconds or 30-59 seconds) to those with one behavior category lasting a full minute, were developed in an attempt to expand the sample size for traveling behaviors and enable us to differentiate feeding, traveling, and resting. Tables 2.6 and 2.7 list summary statistics for these two subgroups. Figures 2.2 and 2.3 show mean active seconds per minute within each behavior category for each moose for these two subgroups. This approach did not expand the sample size (Tables 2.8 and 2.9) enough to enable us to differentiate traveling from feeding with any degree of confidence, but it can be seen that traveling behaviors will generally have higher counts than feeding or resting behaviors (Tables 2.10 and 2.11). However, including activity counts from partial minutes may bias the identification of resting behaviors. Since resting behaviors which last a full minute most often result in a reading of zero active seconds per minute, any traveling or feeding behavior which occurs during that same one minute period will likely result in higher activity readings. In fact, a reading of zero was found in only 13% of those minutes in which resting behavior was found to account for between 30 and 59 seconds. This could cause resting behavior to be mistaken for another behavior (most likely feeding). However, since minutes that contain both resting and some other behavior category occur rarely, and most often when an animal is transitioning from one behavior to another (e.g., a moose has been bedded, then rises to start feeding), this type of misclassification may not greatly affect accuracy. Figures 2.4 and 2.5 illustrate the percent of behavior categories found within specific activity ranges for each of these subgroups.

2.2.8 Active/Inactive

Table 2.12 lists summary statistics for the Active/Inactive dataset, and Table 2.13 lists sample size for each behavior, by research animal. Applying threshold criteria to this dataset (0 active seconds/minute = “inactive”; >0 active seconds/minute = “active”) resulted in an overall accuracy of 92.04% (93.16% for active behaviors, and 90.64% for inactive behaviors). See Table 2.14 for details on accuracy for each research animal. Multiple threshold criteria were tested in order to maximize correlation to observed behaviors. A Fisher’s Exact Test indicated that there was no statistically significant difference between observed behaviors and those correctly classified using threshold criteria for either active (p = .9728) or inactive (p = .9431) behaviors, indicating that our threshold criteria is correctly classifying these behaviors.

2.3 Discussion

There was some individual variation in activity readings among the three moose. Most notably, Diana consistently had lower readings than the other two when engaged in the same behaviors. For instance, Diana’s mean activity reading for feeding behaviors (when looking at the “Full Minutes” dataset) was 3.538, compared to Blue’s 5.270 and Red’s 5.183. This may have been due to differences in collar fit, sample size, individual behavior (Diana seems to be the dominant animal in the pen, and so may be more relaxed in her movements), age (Diana is several years older than Blue and Red) or a combination of factors.

There was a disparity in sample size among the three moose—for example, more feeding behavior was collected from Diana than from the other two. This is primarily due to behavioral differences among the study moose. Diana exhibited very little reaction to the observer, resulting in long, uninterrupted feeding bouts. Both Blue and Red had a tendency to stop and stare at the observer for periods of time, even during feeding bouts. Once a moose exhibited standing behavior for at least two seconds, this was noted by the observer. This resulted in their feeding behavior more often being interspersed with standing behavior. Feeding behaviors exhibited by Blue and Red were more often removed from the analysis, since it was less common for these behaviors to last for a full minute.

The data collection period took place in mid-October, at a time when the bulk of feeding behavior consisted of “grazing” fallen leaves from the forest floor (see appendix on page 29 for behavior definitions). Some browsing behavior was observed, but this primarily consisted of chewing bark. During other seasons, feeding behavior may result in different accelerometer readings. For instance, during the summer, when moose are stripping leaves off limbs, higher readings may be recorded.

2.3.1 Characterizing Accelerometer Data from Research Collars

Out of the datasets we developed, the highest accuracy was achieved by applying threshold criteria to the active/inactive dataset. Using a threshold of zero (0=Inactive, >0=Active), while there was some individual variation among research subjects, the accelerometers were found to correctly classify active behavior 93.16% of the time, and inactive behavior 90.64% of the time. This level of accuracy compares well to other studies involving the use of activity sensors to predict ungulate behavior. Blomberg (2011) used HOBO® and IceTag™ tri-axial accelerometers to monitor grazing behavior in cattle (*Bos Taurus*), achieving an overall accuracy of 84.2% when the two accelerometers were used in conjunction. Löttker et al. (2009) found an accuracy of 93% with a Vectronic dual axis sensor on red deer. Coulombe et al. (2006) were able to accurately predict white-tailed deer (*Odocoileus virginianus*) behaviors 87% of the time with a VHF variable pulse sensor, and 92% of the time with a GPS dual axis sensor. Naylor and Kie (2004) found an accuracy of 87% using Actiwatch omnidirectional accelerometers mounted in LORAN-C radio collars on Rocky Mountain elk (*Cervus elaphus nelsonii*). Adrados et al. (2003) found an overall accuracy rate of 88% with a Lotek GPS dual axis sensor on red deer (*Cervus elaphus*). Moen et al. (1996) found a 75% accuracy rate with a Lotek dual axis sensor on moose. In both the Coulombe (2006) and the Löttker (2009) studies, the dual axis sensors were more accurate in predicting behavior with one axis than with the other. The Telonics accelerometer detects activity on three axes, but the only output is a simple count of active seconds per minute. Improved accuracy would likely be achieved if the data were reported separately for each axis, allowing researchers to examine output from each plane of motion separately.

Based on these results, data recovered from the collars in the JBER Movement Corridor Study were characterized as active or inactive in 15 minute bouts around the GPS locations (the minute of location, and seven minutes on either side). Active seconds from the 15 minutes were summed. Those bouts with ≥15 active seconds were classified as active; those with <15 active seconds were classified as inactive. This method should account for very short behaviors which may throw off interpretations of accelerometer readings (e.g., vigorous head shaking which would produce high readings in an otherwise inactive period). This follows the method used by Moen (1996), in which the activity readings of minutes neighboring a focal minute are taken into account when classifying the behavior of the focal minute, in order to increase accuracy.

2.3.2 Further Analysis

Experimenting with other data analysis techniques may increase the accuracy of interpretation of accelerometer readings. Most notably, further variations on the method used by Moen (1996) should be investigated. The design of our data collection on captive moose did not lend itself to the investigation of how much this might increase accuracy, but future data collection periods may be redesigned to allow for this, and we believe it is still a useful technique in characterizing activity periods with data recovered from collars involved in the Movement Corridor Study.

2.4 Tables

Table 2.1. Summary statistics (all moose combined) on activity counts for specific behaviors.

	Browsing	Grazing	Standing	Lying	Walking
Mean	6.96	3.46	1.05	0.09	10.00
Median	6.00	3.00	0.00	0.00	10.00
St Dev	4.15	2.31	1.79	0.44	4.24
Min	0.00	0.00	0.00	0.00	7.00
Max	16.00	12.00	8.00	4.00	13.00

Table 2.2. Total number of minutes included in analysis for each specific behavior.

	Browsing	Grazing	Standing	Lying	Walking	Total
Blue	15	47	12	161		**235**
Diana	23	245	20	14	2	**304**
Red	39	53	24	113		**229**
Total	**77**	**334**	**50**	**288**	**2**	**751**

Table 2.3. Summary statistics (all moose combined) on activity counts for behavior categories.

	Feeding	Traveling	Resting
Mean	4.075	10.000	0.183
Median	4.000	10.000	0.000
St Dev	3.027	4.243	0.690
Range	16	6	5
Min	0	7	0
Max	16	13	7

Table 2.4. Total number of minutes included in analysis for each behavior category.

	Feeding	Traveling	Resting	Total
Blue	63	0	175	**238**
Diana	277	2	28	**307**
Red	82	0	139	**221**
Total	**422**	**2**	**342**	**766**

Table 2.5. Mean active seconds per minute, (Standard Error), and Letter indicating groups with significant differences. Behavior categories in the same row with the same letter designation are not statistically different from one another according to a Kruskal-Wallis ANOVA multiple comparison test ($p < 0.05$). All comparisons are across rows.

	Feeding	Traveling	Resting
Blue	5.270 (0.444) A		0.206 (0.053) B
Diana	3.538 (0.153) A	10.000 (3.000) A	0.000 (0.000) B
Red	5.183 (0.392) A		0.281 (0.084) B
Total	**4.116 (0.147) A**	**10.0 (3.000) A**	**0.219 (0.044) B**

Table 2.6. Summary Statistics (all moose combined) on activity counts for minutes with one behavior lasting 40-60 seconds (full and partial minutes combined).

	Feeding	**Traveling**	**Resting**
Mean	4.138	14.429	0.534
Median	4.000	13.000	0.000
St Dev	3.043	9.554	1.414
Range	16	29	9
Min	0	3	0
Max	16	32	9

Table 2.7. Summary statistics (all moose combined) on activity counts for minutes lasting 30-60 seconds (full and partial minutes combined).

	Feeding	**Traveling**	**Resting**
Mean	4.127	16.000	0.731
Median	4.000	14.000	0.000
St Dev	3.024	9.535	1.969
Min	0.000	3.000	0.000
Max	16.000	32.000	16.000

Table 2.8. Total number of minutes included in analysis with one behavior lasting 40-60 seconds (full and partial minutes combined).

	Feeding	**Traveling**	**Resting**	**Total**
Blue	70	2	186	**258**
Diana	291	4	38	**333**
Red	94	1	160	**255**
Total	**455**	**7**	**384**	**846**

Table 2.9. Total number of minutes included in analysis with one behavior lasting 30-60 seconds (full and partial minutes combined).

	Feeding	**Traveling**	**Resting**	**Total**
Blue	71	2	189	**262**
Diana	297	5	39	**341**
Red	98	5	166	**269**
Total	**466**	**12**	**394**	**872**

Table 2.10. Mean activity count for minutes with one behavior lasting 40-59 seconds (partial minutes only).

	Feeding	**Traveling**	**Resting**
Blue	5.333	22.000	4.364
Red	4.222	21.000	3.048
Diana	5.143	8.000	1.800

Table 2.11. Mean activity count for minutes with one behavior lasting 30-59 seconds (partial minutes only).

	Feeding	**Traveling**	**Resting**
Blue	4.714	22.000	4.571
Diana	4.950	6.667	2.180
Red	3.846	21.600	4.630

Table 2.12. Summary statistics (all moose combined) on activity counts for active/inactive behaviors.

	Active	**Inactive**
Mean	4.144	0.219
Median	4.000	0.000
St Dev	3.051	0.811
Range	16	7
Min	0	0
Max	16	7

Table 2.13. Total number of minutes included in analysis for active/inactive behaviors.

	Active	**Inactive**	**Total**
Blue	63	175	**238**
Diana	279	28	**307**
Red	82	139	**221**
Total	**424**	**342**	**766**

Table 2.14. Percentage of active/inactive behaviors correctly classified using a threshold of 0.

	# of minutes		**# correctly classified**		**% correctly classified**	
	Active	**Inactive**	**Active**	**Inactive**	**Active**	**Inactive**
Blue	63	175	60	157	95.24%	89.71%
Diana	279	28	254	28	91.04%	100.00%
Red	82	139	81	125	98.78%	89.93%
Total	**424**	**342**	**395**	**310**	**93.16%**	**90.64%**

2.5 Figures

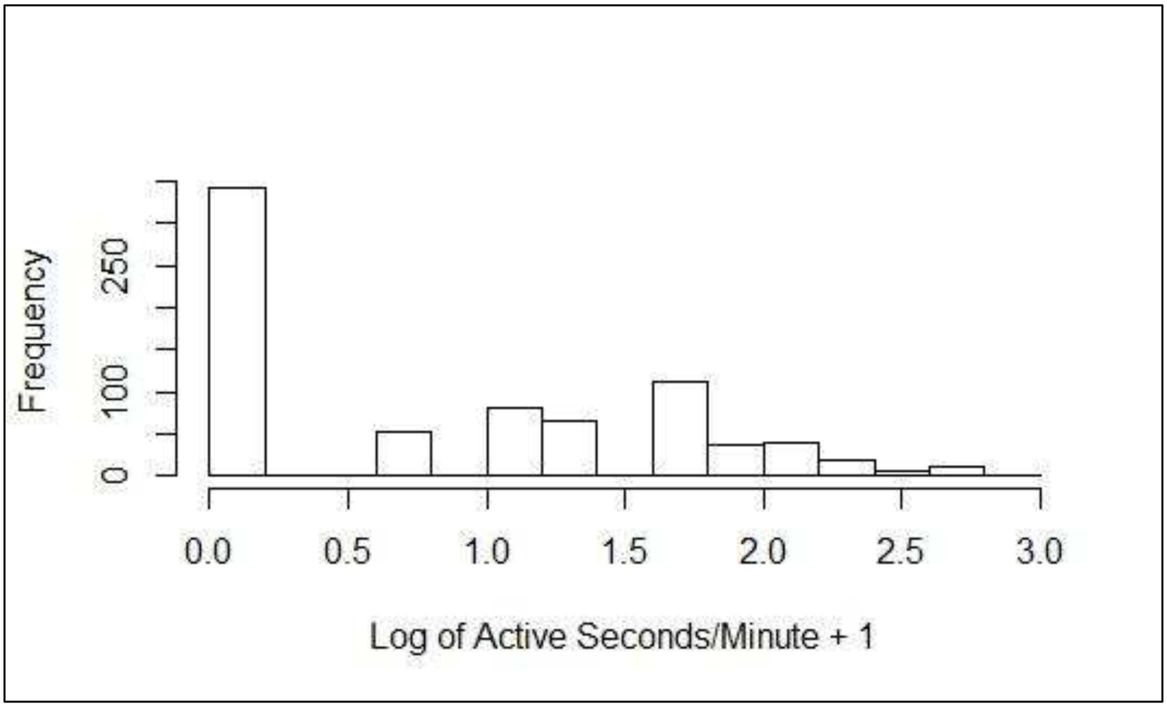

Figure 2.1. Distribution of log transformation of accelerometer readings (active seconds per minute) + 1.

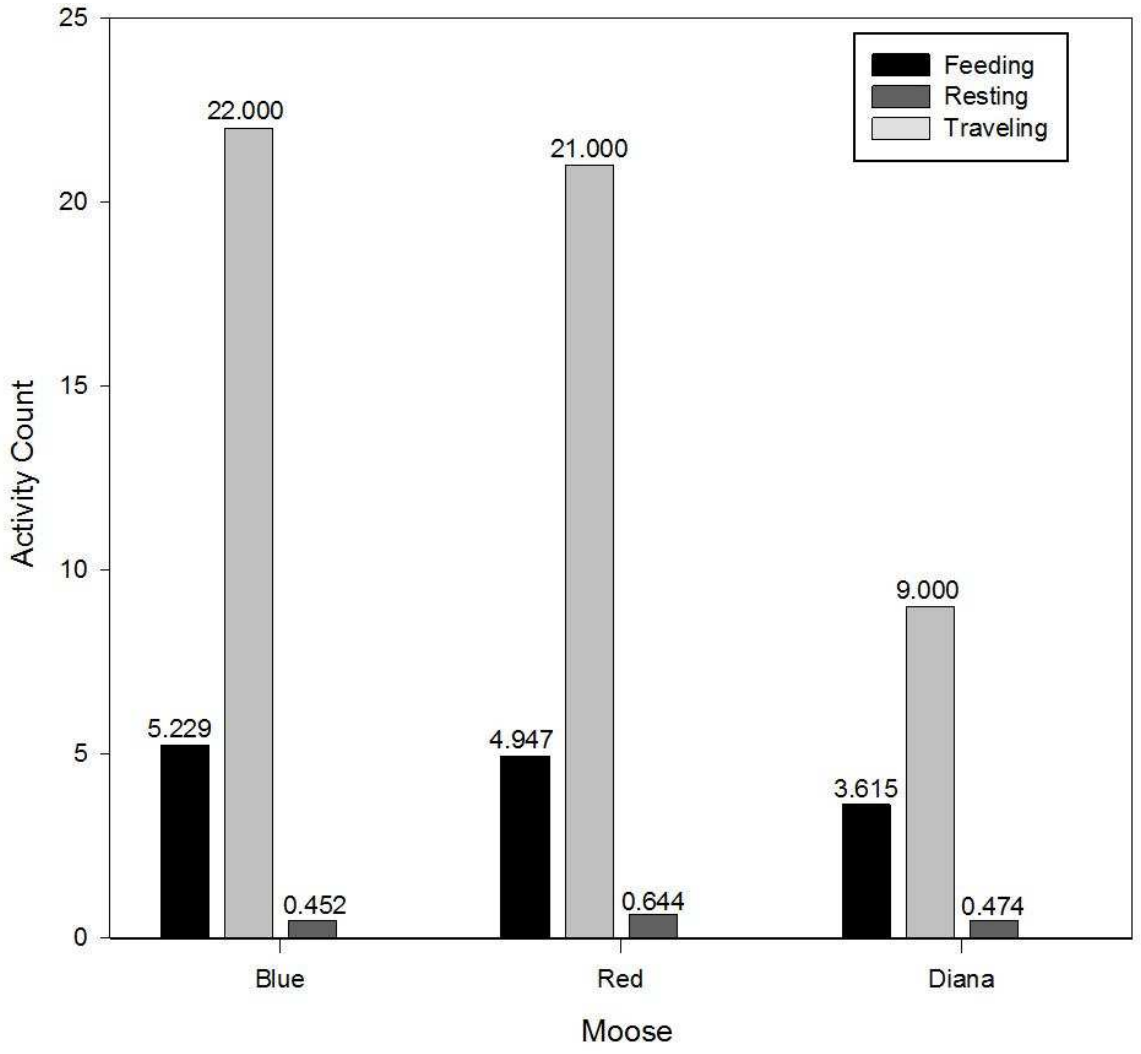

Figure 2.2. Mean activity counts within each behavior category for each moose, for minutes with one behavior lasting 40-60 seconds (full and partial minutes combined).

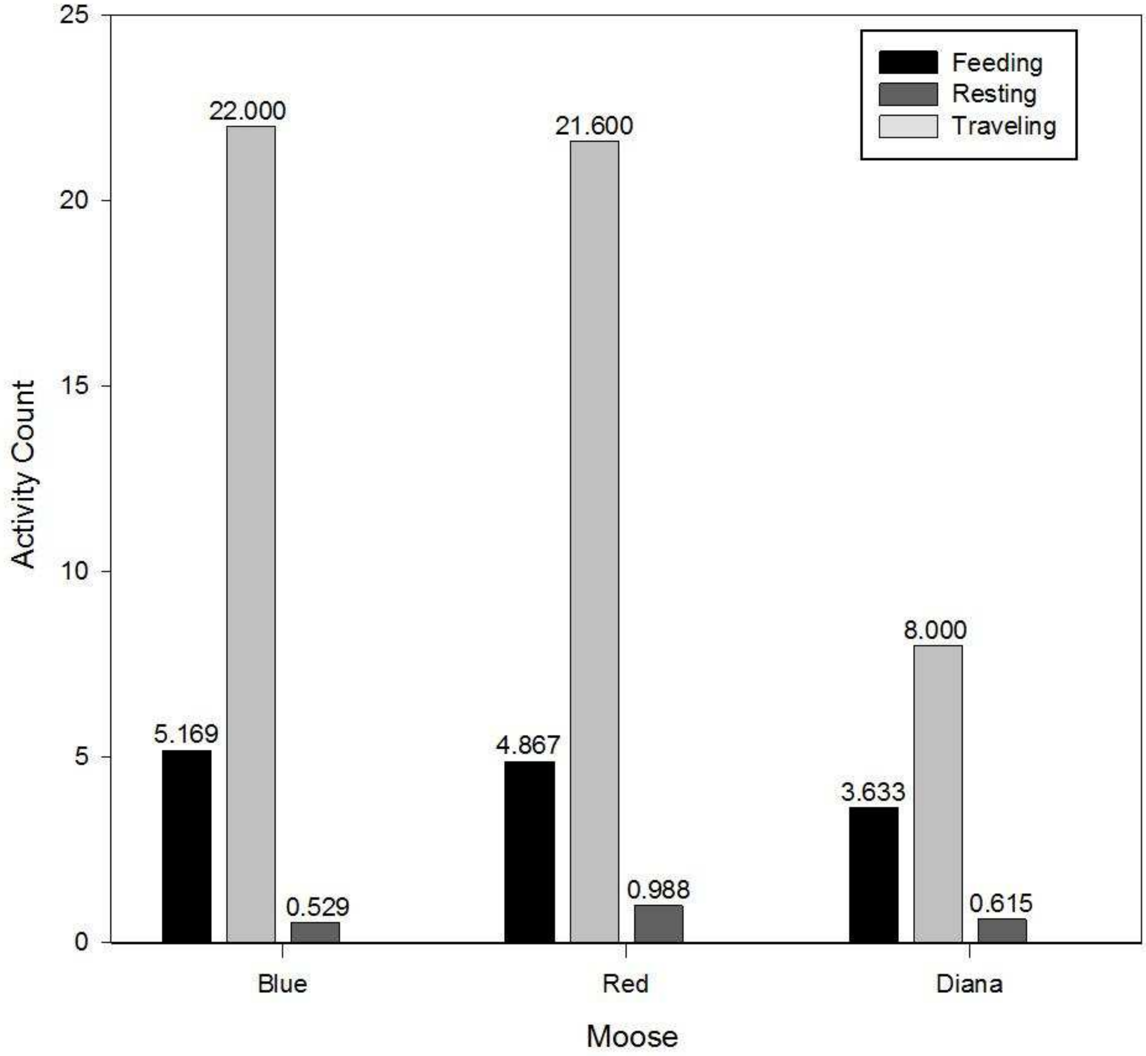

Figure 2.3. Mean activity counts for each moose, for minutes with one behavior lasting 30-60 seconds (full and partial minutes combined).

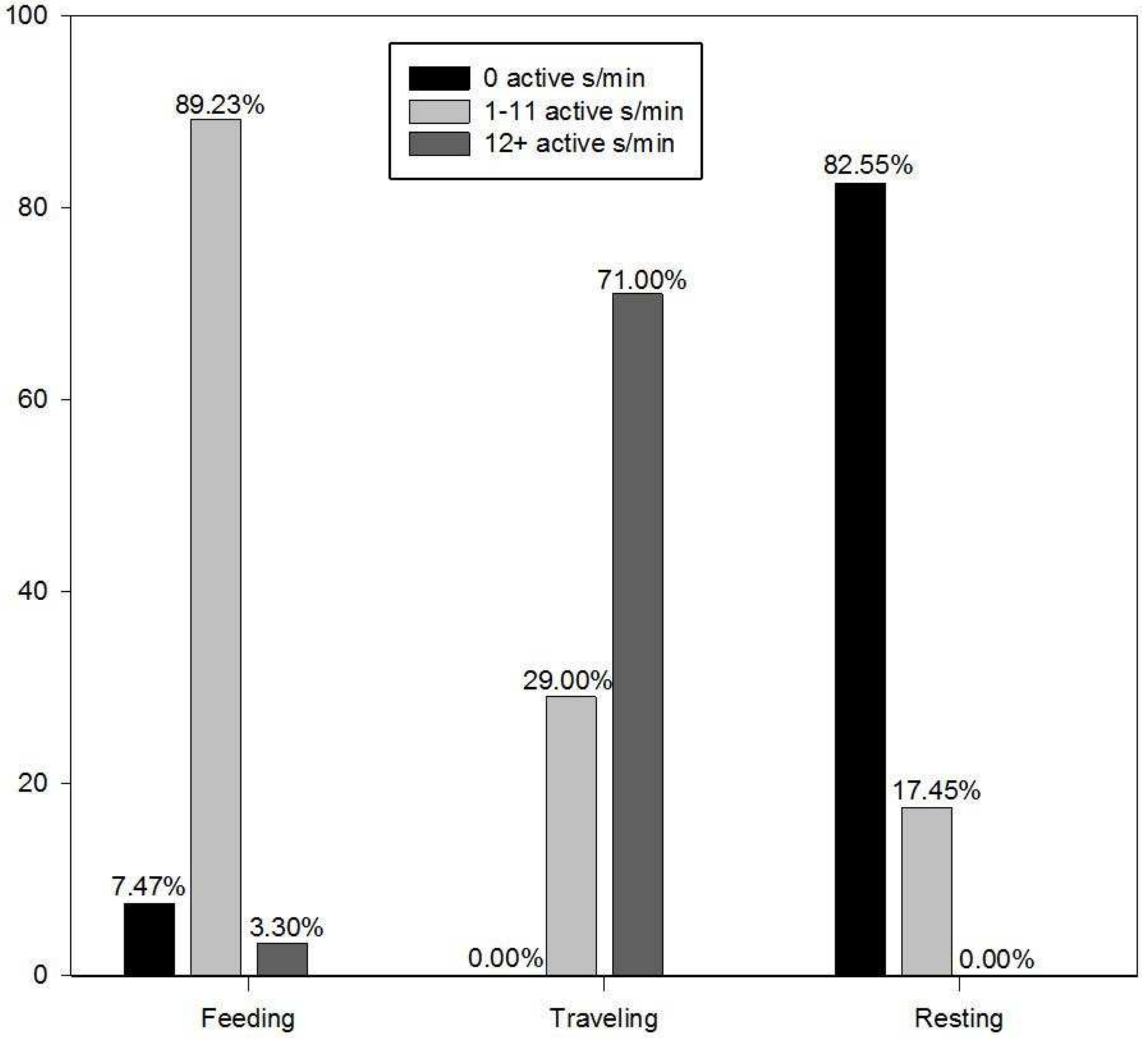

Figure 2.4. Percent of behavior categories found within specific activity ranges for minutes in which one behavior accounted for 40-60 seconds (full and partial minutes combined).

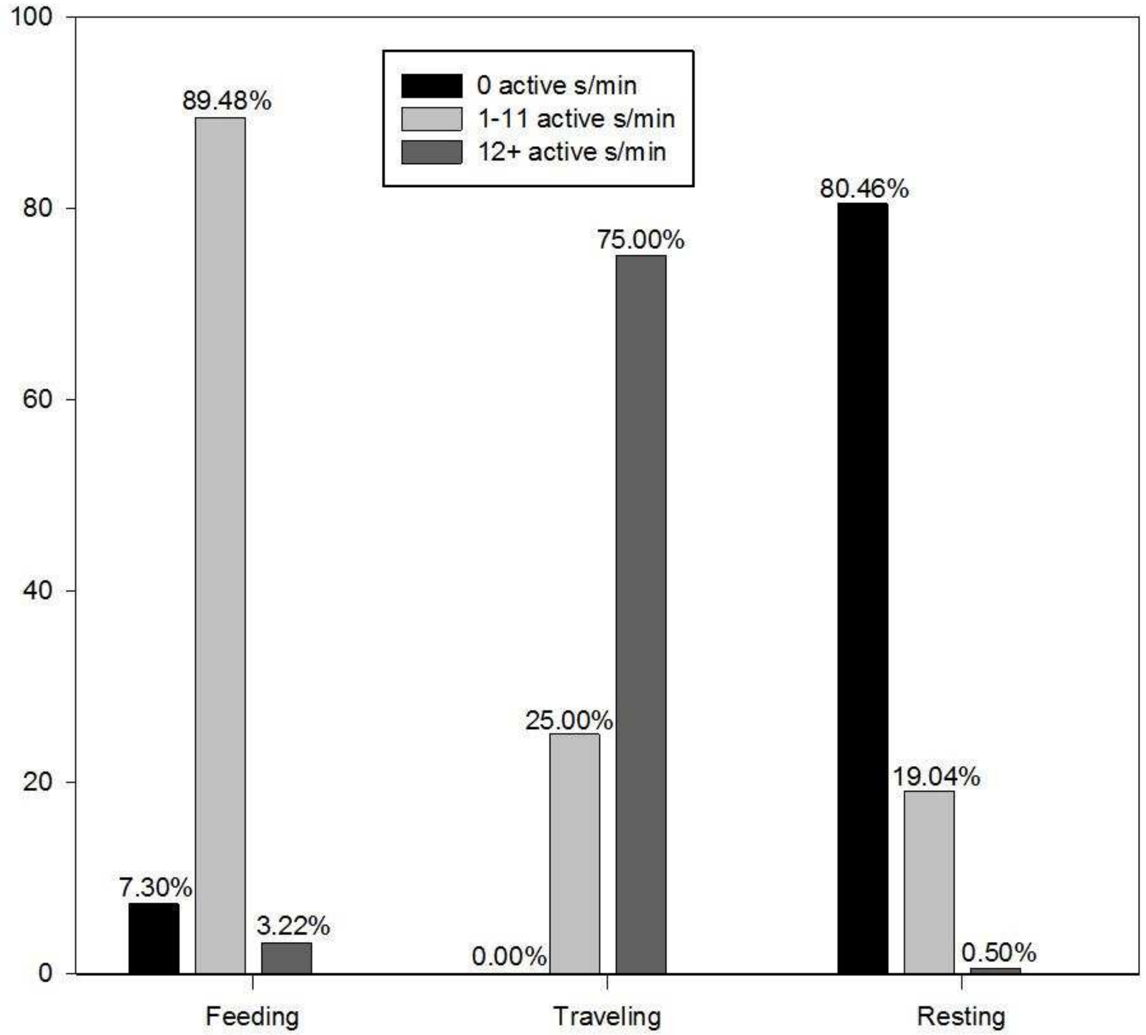

Figure 2.5. Percent of behavior categories found within specific activity ranges for minutes in which one behavior accounted for 30-60 seconds (full and partial minutes combined).

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Chapter 3: Movement Characteristics, Habitat Use, and Home Range

3.1 Introduction

In Alaska, moose (*Alces alces*) are managed for a variety of uses, including recreational hunting, subsistence hunting, and wildlife viewing. While moose are valuable to communities for both hunting and wildlife viewing opportunities, moose-vehicle collisions represent a substantial cost to the community (Northern Economics, 2006). Increasing human development is likely to reduce and alter the distribution of resources for moose. Such changes in habitat availability or disturbance could decrease nutritional condition and fitness of individuals and reduce or alter the number or distribution of moose on the landscape (Neumann et al., 2011; Andersen et al., 1996). Thus, understanding moose use of space upon the landscape is critical for effective management of moose populations.

The National Environmental Policy Act of 1969 (NEPA) requires federal agencies to consider potential environmental impacts before undertaking major construction projects. Fort Richardson Army Post and Elmendorf Air Force Base (EAFB) are United States (US) military installations within the Municipality of Anchorage in Southcentral Alaska. These two military installations were combined in 2010 and renamed Joint Base Elmendorf-Richardson (JBER). Development plans in support of the JBER mission may have significant impacts on moose movement. These military lands comprise an important large-scale corridor for wildlife movement, already severely restricted by development outside the borders (Farley et al., 2008; Farley et al. 2012). A 2005-2007 brown bear (*Ursus arctos*) study provided insight into important movement corridors within military lands, but small sample size and species-specific behavioral patterns may have failed to identify all primary large animal movement patterns (ADF&G, 2008).

The analysis of movement characteristics such as velocity, turning angle, and density of locations within habitat types, and how these characteristics differ according to an animal’s utilization of habitat, may be used to better understand use of space. For example, if a particular area contains few resources, an animal may travel rapidly through in a linear manner (low angular deviation) in order to minimize the time spent within that habitat type. If an area contains valuable resources (food, cover, etc.), the animal may slow down because it is stopping to eat or rest, and turn frequently because it is searching for food (Fryxell et al, 2008; Johnson et al, 2002; Graves et al, 2007).

Potential Path Area (PPA;Long and Nelson, 2012) uses time geography concepts (Hägerstrand, 1970) to delineate animal home ranges by taking temporal constraints in animal movement into account. This technique uses an animal's beginning and ending locations, the time elapsed between these two locations, and the animal's maximum velocity, to delineate the locations accessible to the animal during the time elapsed. This results in an ellipse drawn around the two points. The series of ellipses around each two consecutive points for an entire dataset of an animal's locations comprise a PPA home range. The current version of the technique, dynamic potential path area (dynPPA), includes a dynamic component, incorporating behavioral states into the estimation of a home range (Long, 2014).

Home range analysis can be used to study habitat selection, however it is necessary to quantify how habitat is used and what proportion of time is spent in each available habitat type. Johnson (1980) defined the availability of a component (e.g., a habitat type) as its accessibility to the consumer, and habitat selection as a process in which an animal actually chooses a resource or habitat. Johnson separated habitat selection into four orderings. First order selection is the selection of the geographical range of a species. Second order selection is the choice of a home range by an individual within the geographical range of the species. Third order selection addresses the use of habitat types within the home range. Fourth order selection is the finest scale and identifies the actual procurement of different food items within each habitat type.

Determining habitat preference is a critical element in the study of habitat selection. Jacobs Index (Jacobs, 1974) calculates an absolute preference value for each habitat type by calculating the amount of time spent in each habitat in proportion to its availability. A habitat type is considered to be preferred if it is selected in a greater proportion than availability; if it is selected in a lower proportion to availability it is considered to be avoided.

In addition to determining habitat selection of collared moose on JBER, one goal for this study was to provide JBER biologists and land managers information on which specific areas of JBER saw the highest use by collared moose, particularly within and in close proximity to, the Cantonment Area. This can help guide future decisions on the location of buildings, ranges, and recreational areas. One way to accomplish this is through the use of density maps which serve as graphical representations of amount of use by collared moose of various areas on the installation.

Moose movement rates and home range size can vary widely between seasons (Hundertmark, 1997). Additionally, landscape features of fragmented urban environments (like that found on JBER and in Anchorage) can affect animal movement (Dussault et. al, 2007). Accordingly, the objectives for this study were to 1) measure differences in behavior, turning angle and velocity among individuals, seasons, and habitat types; 2) utilize the dynPPA home range estimator to measure habitat utilization on JBER at the levels of second and third order selection; 3) utilize Jacobs Index to determine which habitats are preferred, avoided, or selected at a level corresponding with their availability; and 4) provide JBER biologists and land managers with specific information on which areas of the installation were used most intensively by collared moose through the use of kernel density estimation maps.

3.2 Study Area

JBER is a 74,641-acre military base located within the Municipality of Anchorage in southcentral Alaska (Figure 3.1). JBER is located within the Cook Inlet-Susitna Lowlands, a physiographic province within the Pacific Mountain System. Elevations range from sea level to over 5,000 feet. The climate is transitional between the northern continental climate of the Alaskan interior and the maritime climate of the Gulf of Alaska. Average monthly high temperatures range from -6 to 18° C, with the highest monthly average occurring in July. Average monthly low temperatures range from -26 to -12° C, with the lowest monthly average occurring in January (US Air Force Alaska, 2012). The predominant habitat types within the study area are mixed deciduous/coniferous forest, barrens, deciduous forest, and shrubland. Other habitat types that occur at lower proportions include grassland, coniferous forest, vegetated wetland, and water.

3.3 Methods

3.3.1 Animal Captures

We captured animals under approved Alaska Department of Fish and Game protocols (#90-05) for animal care and assurance. Moose were darted with a mixture of 3.0 to 3.9 mg carfentanil (carfentanil-citrate, Wildlife Pharmaceuticals, Fort Collins, CO) and 90 to 175 mg xylazine (xylazine-hydrochloride, Wildlife Pharmaceuticals, Fort Collins, CO). Dart wounds were cleaned with a 0.1% providone-iodine solution and filled with antibiotic ointment (0.2% nitrofurazone, Squire Laboratories, Inc., Revere, MA). In addition, a prophylactic dose of 4,000 to 7,000 mg oxytetracycline (Oxytet, Norbrook, Lenexa, NJ) was administered intramuscularly. We placed moose in sternal recumbency to monitor anesthesia, collect samples, and attach radio collars. Anesthesia was reversed within 30 minutes of darting by administering 400 mg Naltrexone (naltrexone-hydrochloride, Wildlife Pharmaceuticals, Fort Collins, CO) and 800 mg Tolazoline (tolazoline-hydrochloride, Wildlife Pharmaceuticals, Fort Collins, CO).

3.3.2 Radio Collars and Relocations

We equipped 24 moose with Telonics Generation IV Global Positioning System (GPS) store-on-board radio collars (Telonics, Inc. Mesa, AZ) programmed to collect locations every 30 minutes or every 60 minutes. Collars were equipped with very high frequency (VHF) transmitters, tri-axial accelerometers (to permit remote classification of behavior), and were marked with highly visible numbers to permit visual identification of individual animals from a distance (Figure 3.2). Collars deployed in March 2012 were equipped with CR-2a autonomous collar release mechanisms (Telonics, Inc. Mesa, AZ) programmed to automatically drop off in October 2012. All other collars were retrieved through recapture or death of study animals, and data downloaded. During the annual calving period (May 15 - 30), we attempted to locate females each day to determine whether a parturition event had occurred. We attempted to monitor calves at least twice a month through August for survival. Throughout the rest of the year, we located collared animals at least monthly by ground and/or air in order to assess health, functionality of the radio collar, and presence/absence of calves.

3.3.3 Movement Characteristics

Velocity and turning angle were calculated for each moose, across their dynPPA home ranges, allowing us to rank habitat according to movement characteristics. Turning angle was calculated using the movement path metrics function in Geospatial Modeling Environment (Beyer, 2012), as the angle at time t formed as the moose moved between locations t - 1, t, and t + 1 (-180º to 180º). In order to calculate turning angle distributions, all angles were made positive by taking their absolute value with the abs function in R (version 3.0.2; R Development Core Team 2013). Velocity (m/s) was calculated using R (version 3.0.2; R Development Core Team 2013) as

$$vi = di / ti$$

where di= distance (step length) and ti = time between consecutive GPS locations.

3.3.4 Potential Path Area

The equation for the basic PPA method can be expressed as:

$$Dmax = vmax * T$$

where Dmax is the maximum distance the animal could have traveled, vmax is the maximum velocity of the animal, and T is the time difference between two successive points. Geometrically, the PPA is an ellipse around the beginning and ending points (Long and Nelson, 2012), representing the set of all locations available to an animal between those two known locations in space and time, given the assumed maximum velocity of the animal and the time difference between the beginning and ending points. A PPA home range is computed by generating a series of PPA ellipses for a set of consecutive GPS locations.

Since the spatial and temporal locations of the starting and ending points are known, PPA requires only a single input parameter, vmax. Maximum velocity is determined either from knowledge of the capabilities of the animal or estimated directly from the data. Long and Nelson (2012) give a range of statistical procedures based on estimating the bounds of a distribution that can be used for estimating the vmax parameter for a dataset. The vmax parameter could be derived from the actual maximum velocity of an animal. Moose have been known to achieve speeds of 56 kph, (Cottam and Williams, 1943), but they typically only do so for very short periods, and only when displaying a stress reaction such as fleeing a predator or a defensive charge. It is more reasonable to estimate normal (unstressed) movement speed by using a telemetry dataset to calculate the upper bound of a distribution of speeds recorded during the time between GPS fix intervals and thereby derive a value for the vmax parameter.

For this project, we used the van der Watt method (1980) of estimating vmax, suggested by Long and Nelson (2012), which considers the ordered set of vi (velocity) such that $v1<v2<v3\ldots<vm-1<vm$ and $m=n-1$. This method can be described by the formula:

$$vmax=(k+2/k+1)vm - (1/k+1)vm - k$$

where $1<k<m$ represents the kth ordered value of vi.

While the basic method for delineating PPA home ranges requires only the vmax parameter, the technique has been enhanced by adding a dynamic component (Long, 2014), using the animal’s behavior to vary the calculation of available area according to activity level.

3.3.5 Dynamic Potential Path Area

Commission and omission errors are important factors to consider in home range estimation. An omission error can be defined as an area that an animal utilizes, but is not included in the home range; a commission error can be defined as an area that an animal does not utilize, but is included within the home range (Long and Nelson, 2012). Since a PPA home range should include all locations that were available to the animal, it can be thought of as the largest spatial unit that does not include omission errors. When used for organisms that exhibit highly variable activity levels (typically related to different behaviors), the basic PPA method will overestimate vmax for periods of low mobility, leading to increased errors of commission (Long and Nelson, 2015). Incorporating a dynamic approach should reduce commission errors by reducing overestimation of area available to an animal between locations during periods of low mobility by utilizing remotely sensed data to differentiate low mobility (resting) periods from high mobility (feeding, traveling) periods.

Dynamic vmax is defined by the formula:

$$vmaxP = F(viP)$$

where vmaxP is the estimate for vmax for the Pth dynamic phase of a subset of a telemetry dataset, and F(viP) is a statistical technique used for determining the upper bounds of a distribution applied to the vi in phase P.

3.3.5.1 Activity

Behavior was remotely estimated as active (feeding, traveling) or inactive (bedded) based on accelerometer readings calibrated to observed behavior of captive moose and incorporated into the estimation of dynPPA home ranges. Based on results documented in Chapter 2 of this thesis, we characterized data recovered from the collars in the JBER Movement Corridor Study as active or inactive in 15 minute intervals around the GPS locations (the minute of location, and 7 minutes on either side). Active seconds per minute from the 15 minutes were averaged. Those bouts with an average ≥ 1 active seconds per minute were classified as active; those with an average < 1 active seconds per minute were classified as inactive.

3.3.5.2 Parameters

Dynamic PPA home ranges were calculated and plotted for each moose using the R package dynPPAHR (version 0.1; Long, 2014), then imported into ArcGIS 10 (ESRI Inc, Redlands, CA). We used the "class.col" option within the dynPPAHR package to specify behavior classes. Using the active/inactive classifications for each 15 minute period around the GPS location, the dynamic PPA code calculated separate velocity distributions for steps preceding active and inactive points, resulting in separate vmax values for active and inactive steps for each animal. The vmax parameter was then set for active and inactive points separately, based on each distribution.

The dynamic approach allows for the setting of additional parameters, which assist in more accurately describing the animal's use of space and in correcting for some issues inherent to the PPA technique. PPA ellipses are based on both time and distance between fixes. When the time between two fixes is much larger than normal (because one or more fixes are missing due to irregular sampling schedules or to the GPS unit failing to engage satellites), the vmax parameter for calculating the ellipse drawn around those two points (and for contributing to the generation of the overall PPA home range) is overestimated, and the size of the ellipse for that segment becomes large, dominating the home range calculation. The tol parameter is used to filter out segments for which the time between fixes is overly long. Use of this parameter dictates that segments greater than the value for the tol parameter will not be used in the calculation of the home range (Long 2014). Our fix interval was 3600 seconds (60 minutes). Occasionally the GPS system embedded in the radio collars takes several minutes to collect a location, so this parameter was set at 4000 seconds so as to only filter out segments which were at least double the standard fix interval.

The vmaxtrunc parameter sets the maximum velocity that is used for calculating velocity distribution and for the drawing of ellipses used in the dynPPA home range. We set vmaxtrunc at 0.26 m/s, excluding the top 0.5% of outliers. These outliers are included in the home range (ellipses around these outliers are drawn using 1.05 * vi), but are not included in the calculations for computing vmax.

Areas that fell within dynPPA home ranges but were not utilized due to inaccessibility (fenced and marine areas) were removed from home range calculations. We calculated dynPPA home ranges for summer, defined as 6 Jun —26 Aug, and winter, defined as 8 Nov —14 Mar, in order to examine moose movements for seasonal differences.

3.3.6 Habitat Selection and Preference

Jorgenson et al (2003) conducted an ecological survey of Fort Richardson and used vegetation data from 231 survey plots to classify ecotypes and delineate 54 vegetation classes. Welch (2012) grouped the original 54 vegetation classes into seven habitat types. Forested habitat types were those with >25% tree cover, and consisted of: deciduous forests (dominated by deciduous trees), conifer forests (dominated by conifer trees), and mixed forests (co-dominated by deciduous and conifer trees). Non-forested habitat types consisted of: barrens (alpine tundra, pavement, floodplains, mudflats, landscaping, sites with <30% ground cover, and open water), shrublands (*Salix spp*. L. [willow], *Alnus spp*. Mill. [alder], and seral scrub communities), vegetated wetlands (bogs and wetlands generally containing an understory of *Myrica gale* L. [sweetgale], willow, and *Betula spp*. L. [birch]), and grasslands (wetland and upland graminoid communities lacking a shrub overstory). Open black spruce vegetation classes were classified as either vegetated wetlands or conifer forests depending on habitat characteristics: stands with a boggy substrate with a large shrub component were classified as vegetated wetlands, and stands with a non-boggy substrate in upland zones were classified as conifer forests. For purposes of this study, we separated open water from the barrens habitat type into its own type, as movement characteristics for moose moving through open water may be very different from alpine tundra, pavement, etc. This resulted in eight habitat types: deciduous, mixed deciduous/conifer, conifer, barrens, shrublands, vegetated wetlands, grasslands, and water.

Habitat analysis was performed at the scales of second and third order selection. We used Jacobs index (index D in Jacobs, 1974) to study habitat preferences (Revilla et al.,2000; Drygala et al., 2008; Kauhala and Auttila, 2010). This is calculated as

$$D = (r - p)/(r + p - 2rp)$$

where r is the proportion of habitat used and p is the proportion of habitat available. We used this index to measure both second order selection (r = proportion of habitat type within each home range; p = proportion of habitat type within the study area) and third order selection (r = proportion of locations within each habitat type; p = proportion of habitat type within the home range). Values range from -1 (indicating avoidance) to +1 (indicating preference). Values near 0 indicate that habitat is selected in proportion to its availability. Although habitat use among animals varied, we combined data from all individuals in each season in order to obtain an overall picture of seasonal habitat use (White and Garrott, 1990).

3.3.7 High Use Areas/Travel Corridors

In an effort to provide JBER biologists and land managers with specific information on areas of high moose use on the installation (particularly about travel corridors within the Cantonment Area), all GPS locations for moose that were collared for all of calendar year 2010 (selected because this is the year the highest number of moose were collared) were pooled and the kernel density tool in the Spatial Analyst toolbox for ArcGIS 10.3 was used to construct a map showing density of moose locations (Figure 3.3; n = 10). In addition, in order to determine seasonal areas of higher use, density maps were created for these ten moose for summer 2010 (Figure 3.4) and for winter 2010/2011 (Figure 3.5). Cell size was set for ten meters. In order to only illustrate areas that saw the highest use, those areas in which less than one-fourth of the GPS locations occurred were removed from the density surface. Values generated are for locations per square kilometer.

3.3.8 Statistical Analysis

Statistical analysis was performed using R (version 3.0.2; R Development Core Team 2013). If > 5% of an animal’s locations, or 5% of area within the animal’s home range were outside the boundaries of the JBER study area (for which habitat information is available), that animal was removed from home range analysis. Home range sizes were tested for homogeneity of variance using Levene and Brown-Forsythe tests, and tested for normality of distribution with a Shapiro-Wilks Normality Test. Amount of area within each habitat type in home ranges were first transformed into percentages, then analyzed using Multivariate Analysis of Variance (MANOVA). A Shapiro-Wilks test was used in order to determine whether Jacobs Index values (JIV) were normally distributed, then a Kruskal-Wallis one-way analysis of variance was used to determine if JIV varied by season for each habitat type. Velocities for individual moose were not normally distributed, so a Mann-Whitney U test was used to assess differences in velocities between active and inactive steps. Kruskal-Wallis one-way analysis of variance was used to test for differences in velocity distributions between habitat types. In order to determine the effect of season and habitat type on turning angle distributions, count data for turning angle groups were transformed into proportions, then a chi square test was used. A chi square test followed by post hoc analysis with a Bonferonni correction was used to examine associations of habitat types with active vs. inactive behaviors. An alpha level of 0.05 was used to detect significance for each analysis.

3.4 Results

3.4.1 Animal Captures

Twenty-four adult female moose were captured a total of 62 times between March 2009 – March 2012 (Figure 3.6). Moose captured from 2009 – 2011 were darted from the ground, typically within 0.5 km of roads, often in or adjacent to the cantonment (central developed) area of JBER. Moose captures in 2012 were conducted from a helicopter, and took place north of Eagle River, in the "backcountry" of JBER.

3.4.2 Radio Collars and Relocations

Collars were programmed to collect locations every 30 minutes or every 60 minutes, however only 60 minute locations were used for analysis. In order to rank habitat types found in JBER moose home ranges by behavior patterns and movement characteristics, we collected 244,957 locations from 18 female moose fitted with GPS collars equipped with tri-axial accelerometers.

3.4.3 Movement Characteristics

While moose may be capable of achieving high speeds, they rarely do. The highest velocity we observed being sustained over a 60 minute period was 1.5 m/s (5.4 kph), and 99.5% of all steps had a velocity $\leq$ 0.26 m/s (0.94 kph). Out of 244,933 GPS locations recorded among the 18 moose, velocities greater than 0.9 m/s (3.24 kph) were recorded in only eight steps. As expected, inactive steps typically had much lower recorded velocities than active steps. A Mann-Whitney U Test indicated significant differences between mean velocities of active and inactive steps ($p < 0.01$) and between mean velocities by season ($p < 0.01$). Mean active velocity = 0.03 m/s (0.11 kph); mean inactive velocity = 0.01 m/s (0.04 kph). A Kruskal-Wallis one way analysis of variance indicated that velocity distributions varied between habitat types ($H = 1298.38$, $p < .001$; Table 3.2). A chi square test was used to determine that turning angle groups (Figures 3.7 and 3.8) did not deviate significantly from expected among habitat types ($x^2 = 1.652$, df = 48, $p = 1.000$) or seasons ($x^2 = 0.406$, df = 8, $p = 0.999$).

3.4.4 Dynamic Potential Path Area

We analyzed 19 summer home ranges and 14 winter home ranges from 18 of the 24 moose. Seasonal dynPPA home range sizes averaged 15.28 km^2 in summer (SD = 6.43) and 23.25 km^2 in winter (SD = 7.97). Seasonal home range size was tested for homogeneity of variance using Levene's test for the mean ($p = 0.369$) and Brown-Forsythe for the median ($p = 0.346$). Seasonal home range size variances were equal, and home range size followed a normal distribution ($W = 0.95$, $p = 0.140$).

3.4.5 Habitat Selection and Preference

Table 3.1 illustrates proportion of habitat types occurring on JBER, as well as utilization by moose. A MANOVA indicated that proportion of habitat type within each home range varied across individuals ($F_{17,15} = 1.73$, $p = 0.001$) and seasons ($F_{1,31} = 2.59$, $p = 0.039$). A chi square test indicated that activity level varied by habitat ($x^2 = 2039.194$, df = 7, $p < 0.01$). Adjusted p value from post hoc analysis with Bonferonni correction indicated that the only habitat types which did not differ significantly according to activity level were deciduous and mixed deciduous/conifer (adjusted $p = 0.917$). Measurement of habitat preference via Jacobs Index at the level of second order selection on JBER indicated a deviation from availability, particularly in the case of shrublands. In regard to JIV (Figure 3.9), selection of a particular habitat type was considered to be "neutral" (selection was proportional to availability) if the value 0 was within the 95% confidence interval of the mean JIV for that habitat. JIV indicated that moose on JBER select home ranges which contain high proportions of conifer (summer JIV = 0.22; winter JIV = 0.16). While mixed deciduous/conifer forest was the most utilized habitat type in the study area, it was selected in proportion to its availability in both seasons (summer JIV = 0.01; winter JIV = -0.01). Shrubland was selected against (avoided) in the summer but selected for (preferred) during the winter (summer JIV = -0.19; winter JIV = 0.11). In contrast, results of Kruskal-Wallis one-way analysis of variance indicated that deciduous forest ($p = 0.020$), shrubland ($p = 0.010$), and vegetated wetland ($p = 0.010$) were the only habitat types for which JIV varied by season.

JIV measured at the level of third order selection on JBER also indicated a deviation from availability. Third order selection JIV (Figure 3.10) indicated a definite preference for shrubland in proportion to its availability within the home range. This preference was much more pronounced during winter (JIV = 0.38) than summer (JIV = 0.14). While more locations were recorded in mixed deciduous/conifer in both summer and winter than for any other habitat type, moose preferred this habitat during summer (JIV = 0.14) but were neutral in winter (JIV = 0.01). Moose tended to select home ranges which have some degree of conifer component, but they actually avoided conifer within the home range during winter (JIV = -0.14) and were neutral during summer (JIV = 0.00). Results of Kruskal-Wallis one way analysis of variance indicated that grassland ($p = 0.019$) and shrubland ($p = 0.044$) were the only habitat types for which JIV varied by season.

The most utilized habitat on JBER in both seasons (Figures 3.11 and 3.12) was mixed deciduous/conifer (38.23% of summer locations and 30.03% of winter locations occurred within mixed deciduous/conifer). Shrublands were second most utilized during the winter (28.57%) but third most utilized during the summer (15.04%). Conversely, deciduous forest was second most utilized in the summer (21.89%), but third in the winter (19.08%). Conifer was fourth most utilized in both summer (12.98%) and winter (7.77%). Barrens, grassland, vegetated wetland, and water each saw an average utilization of less than 6% of locations, although certain individuals differed from the norm and spent more time in barrens and vegetated wetland.

3.4.6 High Use Areas/Travel Corridors

When interpreting the maps of high use areas on JBER, it is important to note that these maps only reflect areas used by collared moose. Areas where low or no use from collared moose was documented during this study may or may not have been used (at unknown levels of intensity) by other moose in the area. In most cases, the highest use areas represented locations from five or fewer moose. In some cases only two or three moose were responsible for most locations in high value areas, likely indicating that certain individuals often restrict movements to one small area (where all habitat requirements are being met) more than do others. However, in no case was one moose responsible for all locations in a high use area.

The density maps shown in Figures 3.3 – 3.5 demonstrate that the greenbelt around Ship Creek constitutes an important travel corridor for moose on JBER during all seasons. There is also a corridor in the Cantonment Area which was highly utilized by collared moose (particularly during the winter), stretching from the wooded area around Grady Highway, north through the Richardson Antenna Fields and the area between Ammo Area A and

Warehouse Loop. This is not surprising, as this is the largest expanse of woodlands between the Elmendorf Airfield and the Glenn Highway, and is the primary route from the wooded areas of North Post down to Ship Creek. Any additional development in this corridor will likely cut moose off from large patches of habitat. While other habitat types are present, there is a substantial amount of shrublands in this corridor due to anthropogenic disturbance, reinforcing other findings demonstrating how important shrublands are to moose. During the winter, this corridor extends east to the large patch of shrublands just to the west of the south end of Poleline Road (number nine in the list of habitat patches in Appendix B), but that area was not visited at all by these ten collared moose during the summer. Appendix B lists and shows the locations of important patches of habitat for moose contributing to the high use areas and corridors within and in close proximity to the Cantonment Area.

3.5 Discussion

3.5.1 Movement Characteristics

Almost all moose had more turning angles in the 160-180 degree range than in any other grouping, indicating they reversed direction often. This is true across all habitat types and both seasons. However, overall, moose turning angle distributions were more uniform than those for some other ungulate species. Boulanger and Gunn (2002) found that, while there are some seasonal differences, caribou (*Rangifer tarandus*) tend to move in a forward (low turning angle) trajectory the majority of the time. Bruggeman et al. (2007) found that bison (*Bison bison*) tend to move in a forward trajectory most of the time. In contrast with these other ungulates, moose seem to have little variation in turning angles, most likely indicating that they spend much of their time moving in a meandering fashion, foraging (foraging behavior tends to result in slow, tortuous movement patterns (Sawyer, et. al, 2009)). This may be because caribou and bison migrate over long distances, whereas moose tend to confine their movements to a smaller home range.

Mean velocities were higher in summer than in winter in all habitat types. Presumably, this is because during much of the winter, deep snow makes travel more difficult. Velocities through habitats with less nutrition (barrens, water) were higher than others, as moose likely weren’t feeding, they were just moving through those areas. Velocities in open habitats such as barrens may also have been affected by increased disturbance (such as military training and vehicle traffic) in those areas. However, this assumption is not reinforced by turning angle distributions, which were not found to differ significantly by habitat.

3.5.2 Dynamic Potential Path Area

The winter period used in this study was longer than the summer period, so contained more GPS locations. Odum and Kuensler (1955) found that home range size will typically increase asymptotically as the number of locations increases. An increased number of GPS locations are likely to capture excursions outside the core area, increasing the area of the home range. The fact that winter periods in this study contained more locations than summer periods may have caused larger winter home ranges, but a review of past studies indicates that the size of seasonal home ranges varies. Doerr (1983) documented winter home ranges larger than summer home ranges in migratory moose in Southeast Alaska. Lynch and Morgantini (1984) documented winter home ranges significantly larger than summer home ranges in Northwestern Alberta. They attributed this to the limited availability of browse species in their study area. Schwartz (1992) found that in general, spring and summer foods are 1.5 to 3 times more nutritious than winter foods. There is ample nutrition available to moose on JBER and surrounding areas during summer months, but many wintering areas are overbrowsed (Davis and Gibson, 2006). It is possible the larger winter home ranges in this study were caused by a need to range further to find sufficient nutrition.

Many of the ellipses produced by dynPPA calculations in this study are almost round (Figure 3.13). This is most likely because moose have a tendency to travel to a habitat patch, then stay in a relatively small area for a period of time, feeding and resting. Since the dynPPA includes all paths the animal could reasonably have traveled given its maximum velocity, when two consecutive locations are close together, the ellipse drawn around the two points is close to a perfect circle, and likely covers a considerably larger area than the animal actually traveled between locations.

The seasonal home range for JB42 in summer 2010 (Figure 3.13) was the only dynPPA generated that consisted of two separate polygons. In this case, the polygons are not connected because this moose had a missing fix followed by an abnormally long step length when it traveled to a new area. The tol parameter (which filters out steps where the time between fixes is larger than the parameter value) removed the ellipse drawn for this step. When the moose traveled back to the original area, the exact same thing happened—an abnormally long step, immediately preceded by a missing fix, so the tol parameter removed this ellipse as well. This resulted in two separate unconnected polygons. It is likely that this occurred in other places in dynPPA home ranges generated for this project, but in most cases it is not obvious, since most missing sections would occur within the core area of activity and be covered by the rest of the home range. This reflects a possible issue with setting the tol parameter to filter anything other than consecutive fixes, but as this primarily results from outliers we believe this is still the best approach and will prevent overly large ellipses (which would increase errors of commission).

The vmaxtrunc parameter (which removes outliers) was set at 0.26 m/sec for the purpose of generating all dynPPAs in this project. Referring again to Figure 3.13, the summer 2010 home range generated for JB42, it can be seen that a fenced area cuts off one point (labeled 8/4/2010 4:00 PM) from the rest of the home range. As the dynPPA does not show a pathway taken by the moose around the fence, the natural assumption might be that the vmaxtrunc parameter is set too low, but this parameter is based on a speed distribution of the dataset rather than an actual maximum speed. There will generally be outliers in any dataset, when the animal was moving faster than normal.

Long and Nelson (2012) suggest that due to the need for temporally close GPS locations, PPA (or dynPPA) home ranges should not be used with telemetry datasets with long fix intervals. While the addition of the dynamic component and the ability to set the tol and vmaxtrunc parameters have greatly improved the utility of this home range estimator, increased time between fixes will also increase uncertainty of the path taken by the animal, resulting in drastically enlarged home range size and errors of commission. Datasets with a large number of missing GPS fixes will also have this effect unless the tol parameter is used to filter out locations that are far apart temporally, or the vmax parameter for those segments is input manually. It is likely that some species are more suited to the use of dynPPA than others. Due to certain details of moose behavior and anatomy (they are tall so the transmitter is high off the ground, and their movements are generally slow and unhurried), most GPS fix attempts made by their radio collars are successful, so moose datasets tend to have very few missing fixes. It would be much more difficult to use PPA or dynPPA with datasets from animals which, due to smaller size, more rapid movement, and tendency to inhabit denser cover, have a larger number of unsuccessful fix attempts (e.g., bears, wolves).

While averaging accelerometer readings over 15 minutes is one method by which to assign behavioral states and calculate velocity distributions, 5% of inactive steps had step lengths in excess of 144 meters. This was likely due to a period of activity earlier in the step, after which the animal was bedded during the 15 minute classification period. Remote classification of behavior may be improved by experimenting with assigning behavior classes for drawing dynamic PPAs by utilizing different methods for analyzing accelerometer readings (e.g., averaging accelerometer readings over longer periods of time), using a combination of accelerometer and step length, or simply using step length for behavior classification.

The home range is a commonly used concept for the study of space use in wildlife conservation. The Dynamic Potential Path Area home range estimator is a simple, intuitive, technique based on concepts from time geography that can be used as a stand-alone method to study movement and habitat use. Because it explicitly considers the space accessible to an animal given distance and time, it can be used to refine measurements of use of space, can be used in conjunction with other home range estimators to study errors of omission and commission, and may be particularly applicable in habitat use versus availability studies. It is best used with datasets containing temporally close locations, with few missing fixes. If used with datasets with many missing fixes, careful setting of parameters (e.g., vmaxtrunc, tol) should be considered.

3.5.3 Habitat Selection and Preference

Peek (1997) stated that moose select habitat primarily for the most abundant and highest quality forage. Welch (2012) found that the shrubland habitat type could support 11 to 81 times more moose than any other habitat on JBER. However, the majority of collared moose did not spend the highest proportion of their time in shrub habitats. The mixed conifer/deciduous habitat type was the most utilized, but that was also the most common habitat on JBER, and JIV indicated a strong preference for shrubland in proportion to its availability, particularly during the winter. It can be seen that moose spend a disproportionate amount of time within certain areas of their home range. Most notably, moose that resided close to the Cantonment Area (the housing area) of JBER had home ranges containing a large percentage (as much as 28.9%) of barrens. However, no moose had more than 13.6% of locations occurring within barrens, and most had considerably less (mean summer JIV = -0.59; mean winter JIV = -0.51). This is not surprising, as the barrens habitat type includes paved areas, but there is a disparity between available barrens, grasslands, vegetated wetlands, and water within home ranges and proportion of locations actually located within those habitat types. It can be argued that this is partially due to commission errors in home range analysis. This is not unique to the dynPPA method, but is true to some extent of all home range methods. Some areas that animals did not actually visit are bound to be included in any home range. Minimum Convex Polygon is one method known to be very prone to this drawback, but it may be impossible to completely purge commission errors from any home range estimation technique until technology allows for minute-by-minute monitoring. However, it is also true that animals value certain areas more than others. On JBER, the habitat types most utilized by moose were (in descending order) mixed deciduous/conifer, shrublands, and deciduous forest. Most moose had more locations within the mixed deciduous/conifer habitat type, but this was not true of all individuals. There was a high amount of variability in habitat selection. Overall, JIV indicated that shrublands were most strongly selected in disproportionate amount to their availability on the landscape, and this habitat type was utilized substantially more during the winter than during the summer.

Moose on JBER selected home ranges with a conifer component, but selected against conifer within the home range. The selection of home ranges containing conifer may simply be due to the fact that coniferous forest occurs within close proximity to habitat types which moose do prefer, such as shrubland and mixed deciduous/coniferous forest. It is also possible that coniferous forest is a needed habitat component, but it is not necessary for moose to spend large amounts of time there. Conifers are likely used more for rest periods or for traveling between habitat patches than for foraging. A common assumption among researchers is that the presence of an animal in a habitat type indicates selection of that habitat type; however, the proportion of time an animal spends in a habitat is not necessarily an indication of the value of that habitat to the animal (Beyer et. al, 2010). Time spent in a habitat is often the only variable that we can measure to obtain a sense of the value of the habitat to the animal, but it is possible that animals are obtaining high amounts of nutrition in a short time in some habitats.

While it is true that there was a tremendous amount of variety in habitat selection among individuals, no moose selected for (third order selection) the barrens habitat type in either season, and all moose selected for shrublands during winter. Vegetated wetland was also avoided by almost all moose during both seasons, however this habitat type was selected for very strongly by JB987 during the winters of 2009 (JIV = .76) and 2010 (JIV = .80), and by JB234 during the summer of 2010 (JIV = .71). Water was avoided by most moose during both seasons (i.e., there were few GPS locations within the water habitat type; moose are known to follow river corridors and feed within and in close proximity to water, but most moose in this study evidently did not spend much time actually in water). In fact, nine seasonal home ranges contained no locations at all within water. However, JB367 selected for this habitat strongly during the winter of 2010 (JIV = .60) and JB991 selected for water during the summer of 2010 (JIV = .52). There were even a few moose that selected against shrublands (though not during winter), which was the most preferred habitat type, and the one that has been found to yield the most nutrition (Welch, 2012). These examples merely serve to exhibit the diversity in habitat selection demonstrated by moose on JBER.

3.5.4 High Use Areas/Travel Corridors

The summer 2009 home range of moose JB373 (Figure 3.14) illustrates a typical pattern for this population of urban moose. This moose followed the narrow corridors of woodland through the Cantonment Area, where movements are constrained by barriers such as fenced areas, roads, and buildings, then its locations “fan out” when the moose reached larger patches of habitat such as the Antenna Fields or north of Warehouse Loop. Contrast this with the summer 2012 home range for JB282 (Figure 3.14), a moose that lived exclusively in the contiguous forest on North Post. This moose had a much more centralized home range, without the excursions through narrow pathways which characterized home ranges of collared moose inhabiting urban areas. This illustrates the importance of maintaining connecting pathways for moose that have home ranges which include parts of the Cantonment Area. Wilson et. al (2015) found that moose on the Kenai Peninsula, where habitat is not strongly bisected by roads, have home ranges roughly twice the size of moose in Anchorage and on JBER. Constraint by barriers may contribute to the smaller home ranges of Anchorage moose, or it may be that the greater amount of early and mid-successional plant communities created by disturbance for anthropogenic development enable moose to meet habitat requirements without traveling as far.

The density maps were primarily constructed to give JBER biologists and land managers a picture of where collared moose moved within the Cantonment Area. While it is difficult to quantify the location of needed travel corridors on JBER, one could make the argument that the “lighter colors” (signifying lower to middle densities of locations) on the density maps between areas seeing higher use could represent needed connections between important patches of habitat.

3.5.5 Management Implications

Moose movements and home range must be considered as anthropogenic development on JBER increases. Construction of physical barriers such as fences may block traditional movement routes, causing disruption of population dynamics and even impedance of gene flow. For instance, Wilson et. al (2015) found that the Glenn Highway (and associated fencing), which bisects JBER and serves as the principal road access to Anchorage, constitutes a barrier to moose movements. While some collared moose occasionally crossed the Glenn Highway during this study, it was very uncommon. Some study moose never crossed, and of those that did cross, the movement typically consisted of a single excursion in which the moose crossed the highway, stayed a few days, then crossed back into the main part of their home range. The barrier effect of the Glenn Highway has resulted in a genetic subdivision of the local moose population. Any development in the main route between Ship Creek and North Post (the wooded area stretching from the Richardson Antenna Fields north between Ammo Area A and

Warehouse Loop) is likely to further fragment natural areas on the installation and impede movements of moose between habitat patches.

There was a very high degree of variability in habitat selection among research animals in this study, but all moose selected for shrublands during the winter. Other habitat types strongly utilized in both seasons included deciduous, conifer, and mixed deciduous conifer. Shrubland areas are found throughout JBER, but there is a large quantity of shrubland along roadways and fences within the Cantonment Area and in the Small Arms Complex on South Post. If conducting habitat management to benefit moose, increasing the proportion of early successional shrubland habitats (particularly willow) through the introduction of disturbance such as controlled burns (probably not practical on JBER due to the proximity to buildings and housing areas), cutting mature woodlots, or mechanical crushing of vegetation, would likely be the most effective use of resources and provide the most benefit. However, as shrubby areas along roadways and in developed areas can attract moose and increase the likelihood of vehicle collisions and other conflicts (Danks and Porter 2010), we recommend that when possible, shrublands should be located away from major roads, ranges, and populated areas, in order to reduce conflicts with humans and minimize interruptions to training.

Any wildlife management program should contain a set of clear objectives designed to achieve desired population characteristics at the scale with which the wildlife manager is concerned. The population of moose on JBER is a part of the larger population in Game Management Unit (GMU) 14C. At the landscape scale, moose management activities on JBER contribute to objectives established for GMU 14C by ADF&G, and JBER Natural Resources staff have a long history of working cooperatively with ADF&G. When habitat on JBER is manipulated, whether land is being cleared for firing ranges, new buildings or roads are being constructed, or wildlife plots are installed, land managers should take into consideration whether the new mix of habitats will be sufficient to meet moose resource needs. For instance, moose winter home ranges contained an average of 3.4 km^2 of shrubland (an average of approximately 15% of the total home range area, usually spread through the home range in a mosaic of cut areas and road edges). On average, moose spent almost 30% of their time during the winter in shrublands. Particular care should be taken to provide enough shrublands, but land managers should take the same care in examining the habitat makeup of the entire area, comparing figures for habitat utilization with the Jacobs preference index and Welch’s findings on nutrition available in each habitat type, and provide for all needed resources within the area that is accessible to moose.

While habitat management on the installation will affect overall moose abundance to some extent, another important reason to conduct habitat management on JBER may be to affect moose distribution. JBER land and wildlife managers should decide where on the installation higher moose densities are preferable as well as where lower moose densities would be more appropriate, taking into account factors such as intensity of training, placement of recreation areas and firing ranges, and frequency of moose-vehicle collisions, and utilize the information contained within this thesis and other studies to design a landscape accordingly.

3.6 Tables

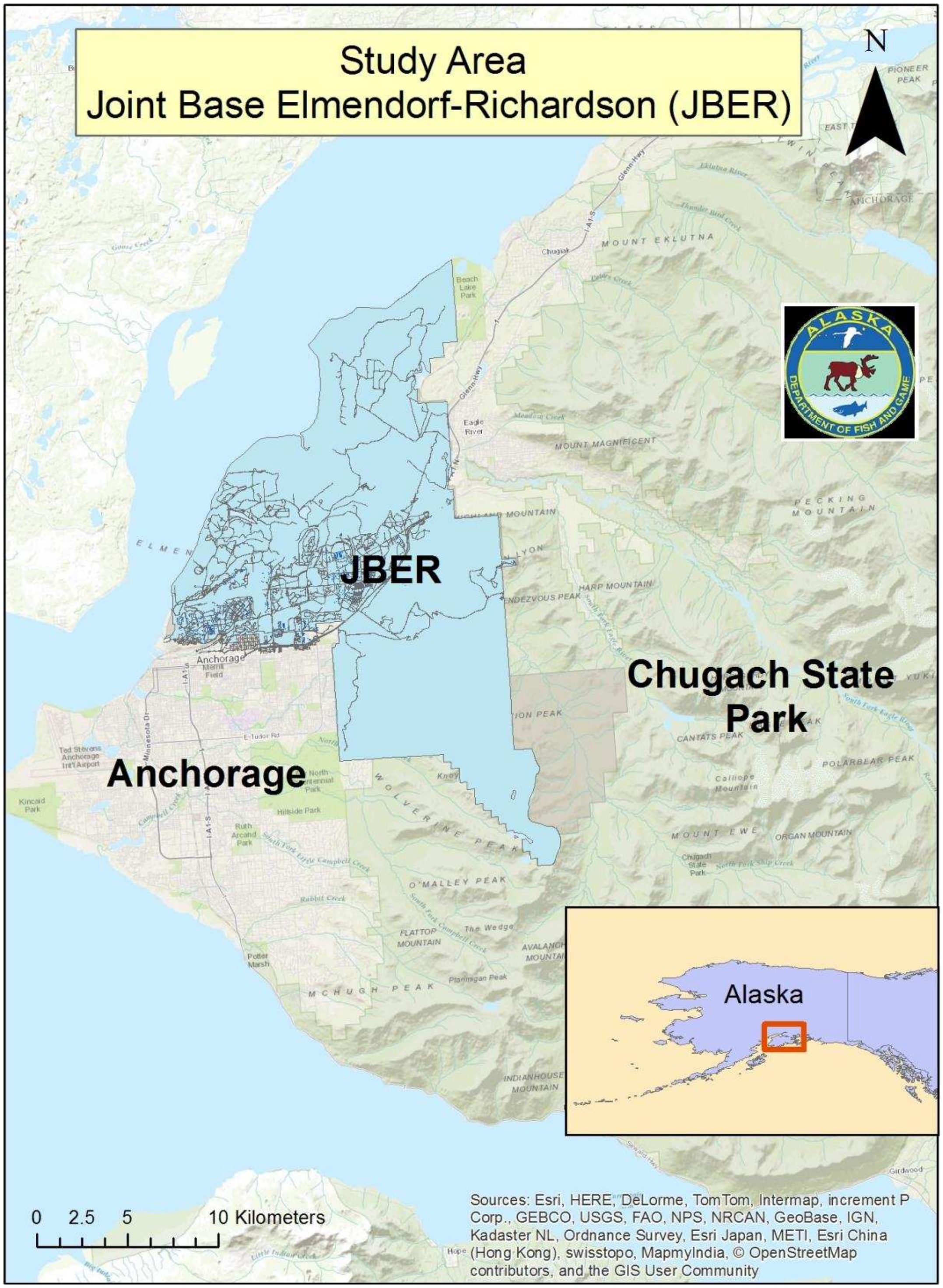
Table 3.1. Joint Base Elmendorf-Richardson study area by habitat type and percent of pooled moose locations within each habitat type for summer and winter for 18 female moose (March 2009 – October 2012).

Habitat Type	Area (km^2)	% of Area	% Summer Locations	% Winter Locations
Barrens	55.69	19.15%	2.40%	5.37%
Coniferous	17.74	6.10%	12.98%	7.77%
Deciduous	54.99	18.91%	21.89%	19.08%
Grassland	23.32	8.02%	5.60%	5.74%
Mixed Deciduous/Conifer	87.11	29.95%	38.23%	30.03%
Shrub	35.12	12.08%	15.04%	28.57%
Veg Wetland	1.31	4.50%	3.26%	3.01%
Water	3.73	1.28%	0.59%	0.43%

Table 3.2. Mean velocity in kph (Standard Error) Letter indicating groups with significant differences. Habitats in the same row with the same letter designation are not statistically different ($p < 0.05$) from one another (Dunn's test with Bonferroni correction). All comparisons are across rows.

Season	Barrens	Coniferous	Deciduous	Grassland	Mixed Decid/Conifer	Shrub	Vegetated Wetland	Water
Summer	0.14 (0.0018) A	0.09 (0.0006) B	0.10 (0.0005) C	0.13 (0.0012) C	0.09 (0.0003) D	0.11 (0.0008) D	0.14 (0.0019) C	0.22 (0.0082) E
Winter	0.09 (0.0008) AE	0.07 (0.0004) B	0.06 (0.0003) C	0.08 (0.0007) A	0.06 (0.0002) B	0.05 (0.0002) D	0.05 (0.0009) D	0.08 (0.0025) E
Combined	0.10 (0.0007) A	0.08 (0.0004) BE	0.08 (0.0003) C	0.10 (0.0006) A	0.07 (0.0002) B	0.07 (0.0003) D	0.09 (0.0009) E	0.12 (0.0029) F

3.7 Figures



Study Area
Joint Base Elmendorf-Richardson (JBER)

Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3.1. Location of the study area, Joint Base Elmendorf-Richardson, Alaska.

Figure 3.2. Moose fitted with radio collar bearing highly visible numbers to permit visual identification of individual animals from a distance or on remote cameras mounted on one-way “moose gates” along the Glenn Highway.

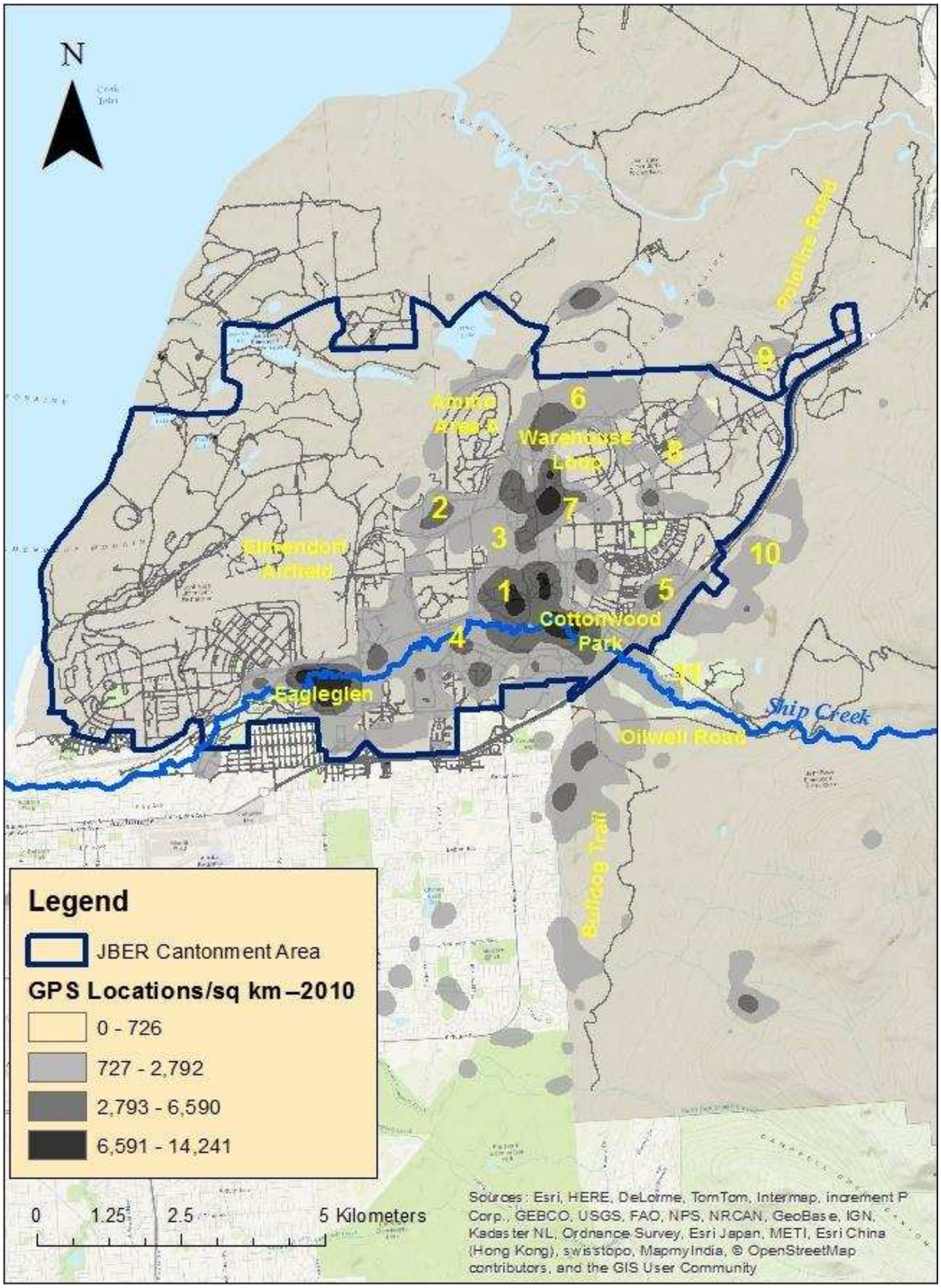


Figure 3.3. Kernel density map for 10 female moose (Alces alces) for the period 1 January 2010 – 31 December 2010 within the Cantonment Area on Joint Base Elmendorf-Richardson, Alaska (all moose locations pooled). Numbers on map correspond to habitat patches described in Appendix B.

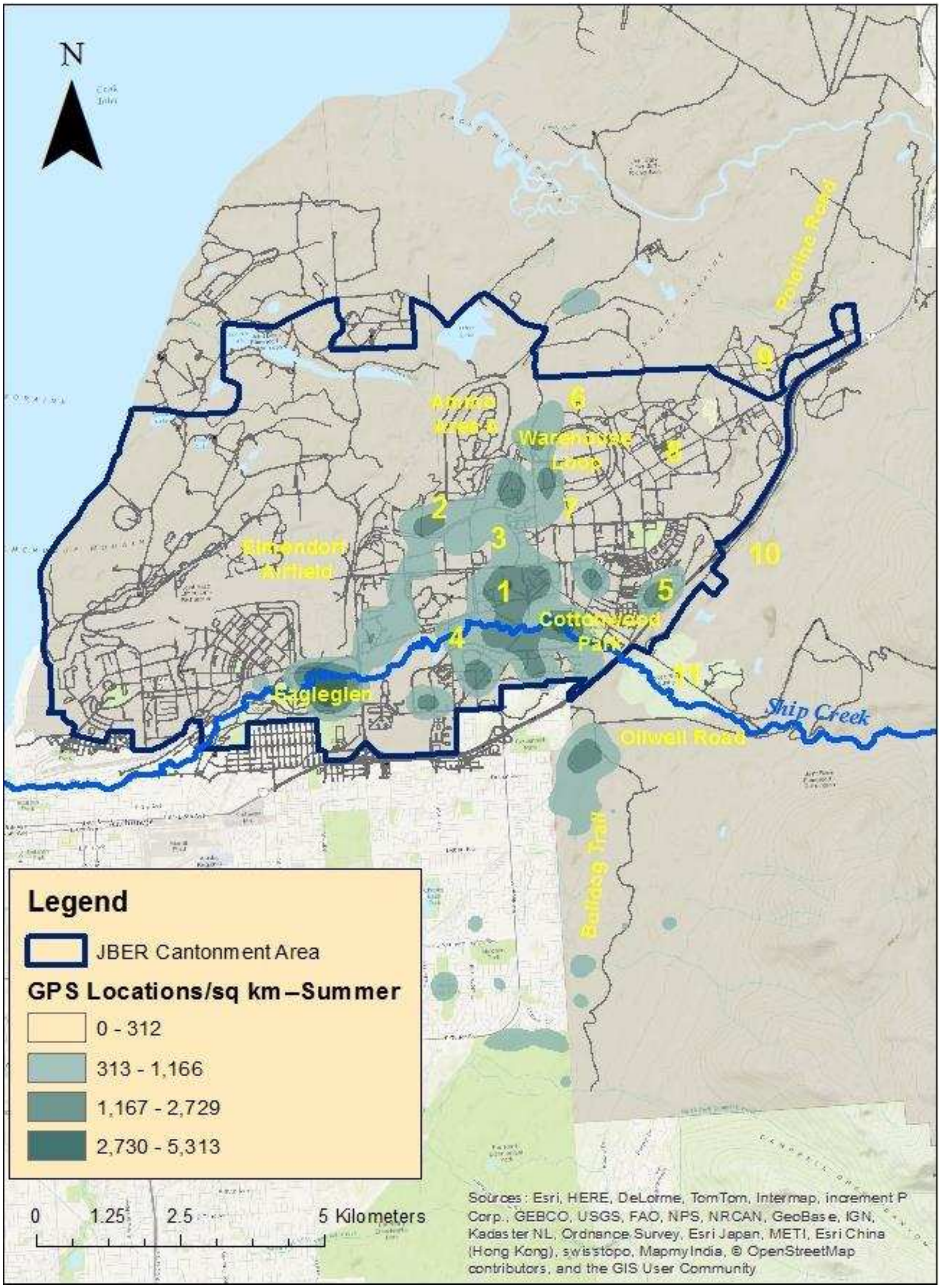


Figure 3.4. Kernel density map for 10 female moose (Alces alces) for the period 6 June 2010 – 26 August 2010 within the Cantonment Area on Joint Base Elmendorf-Richardson, Alaska (all moose locations pooled). Numbers on map correspond to habitat patches described in Appendix B.

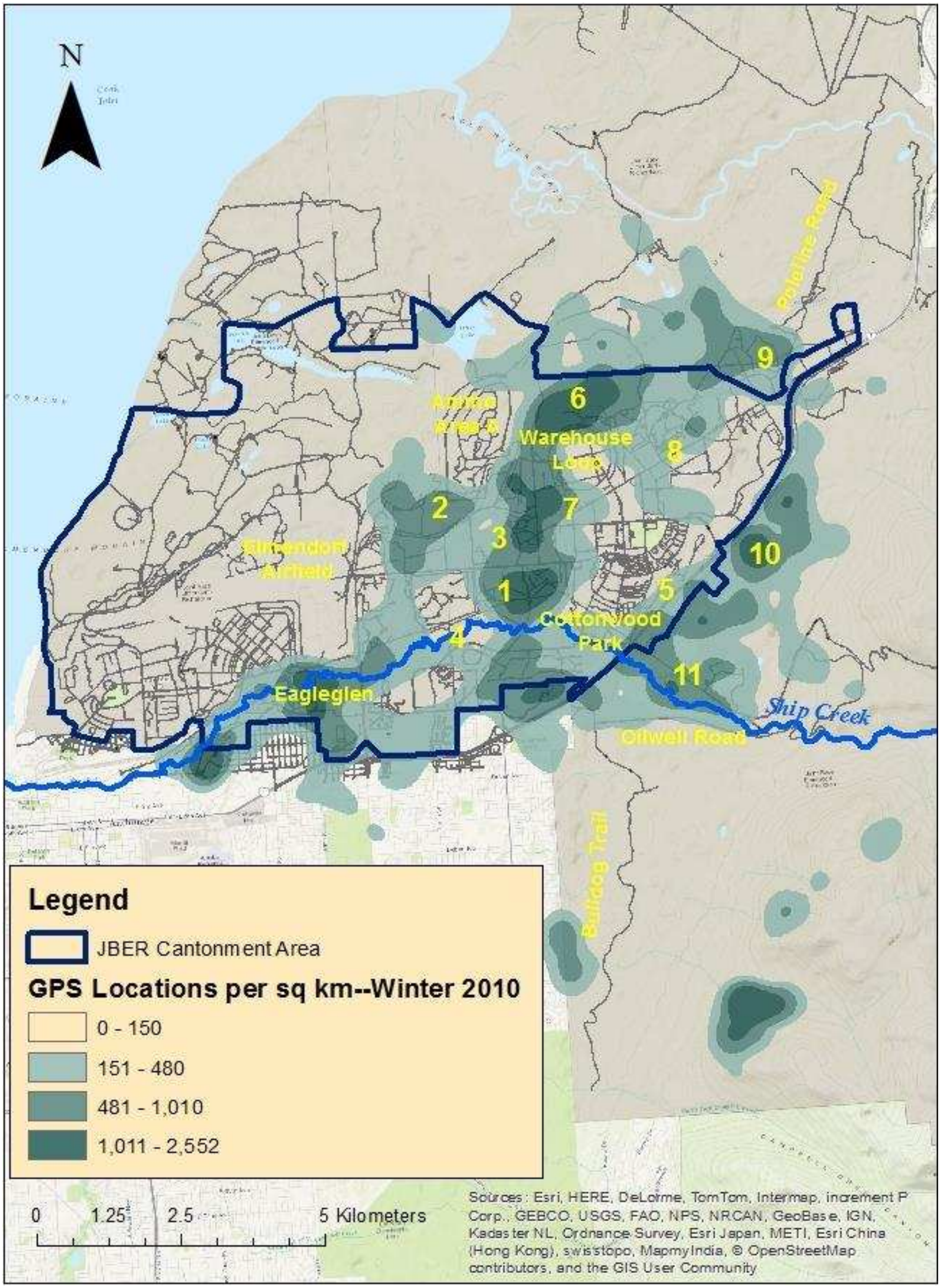
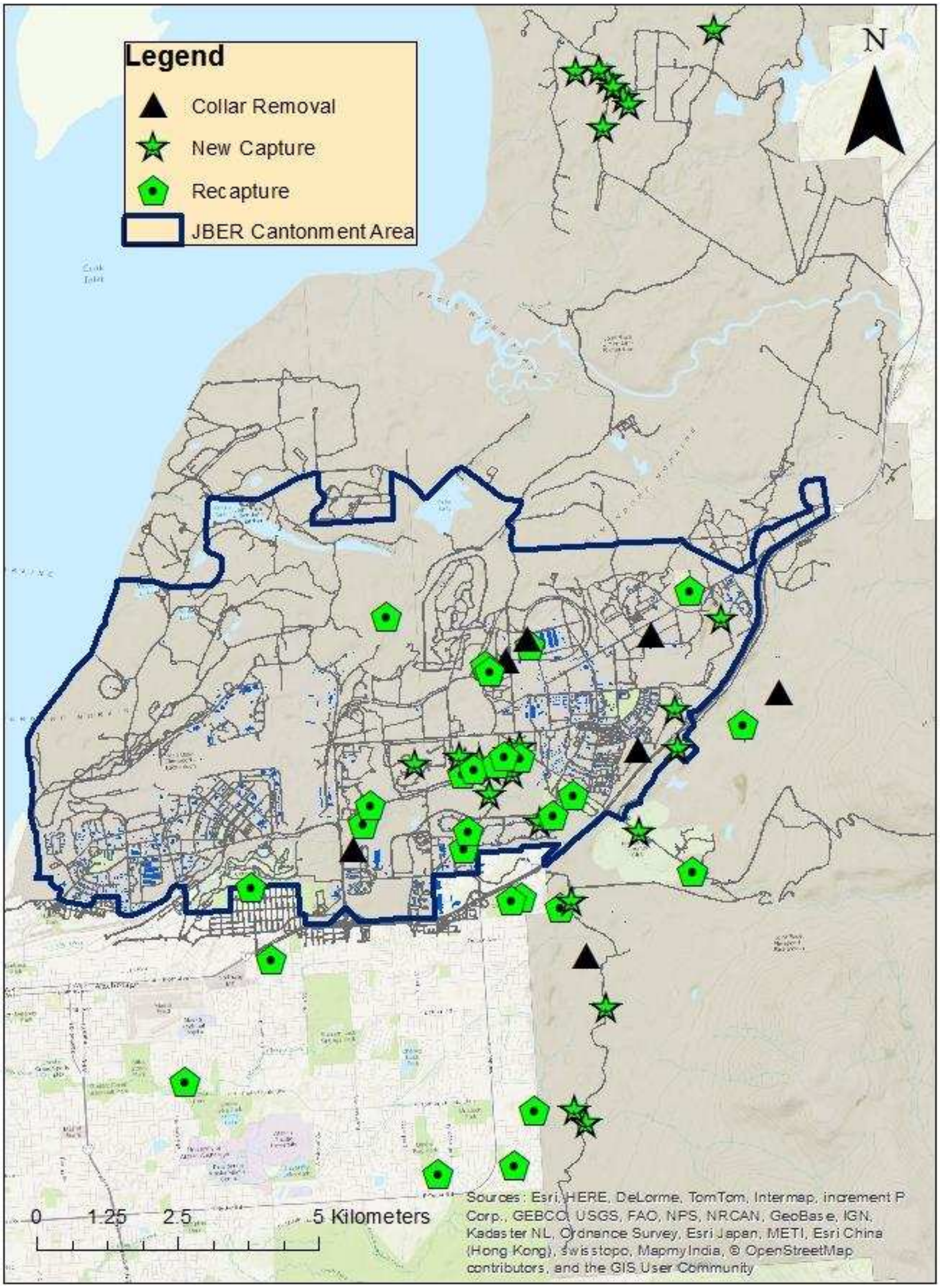


Figure 3.5. Kernel density map for 10 female moose (Alces alces) for the period 8 November 2010 – 14 March 2011 within the Cantonment Area on Joint Base Elmendorf-Richardson, Alaska (all moose locations pooled). Numbers on map correspond to habitat patches described in Appendix B.



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3.6. Geographical location of captures of 24 female moose tracked March 2009 – October 2012 on Joint Base Elmendorf-Richardson, Alaska. Data were retrieved for 18 of these moose.

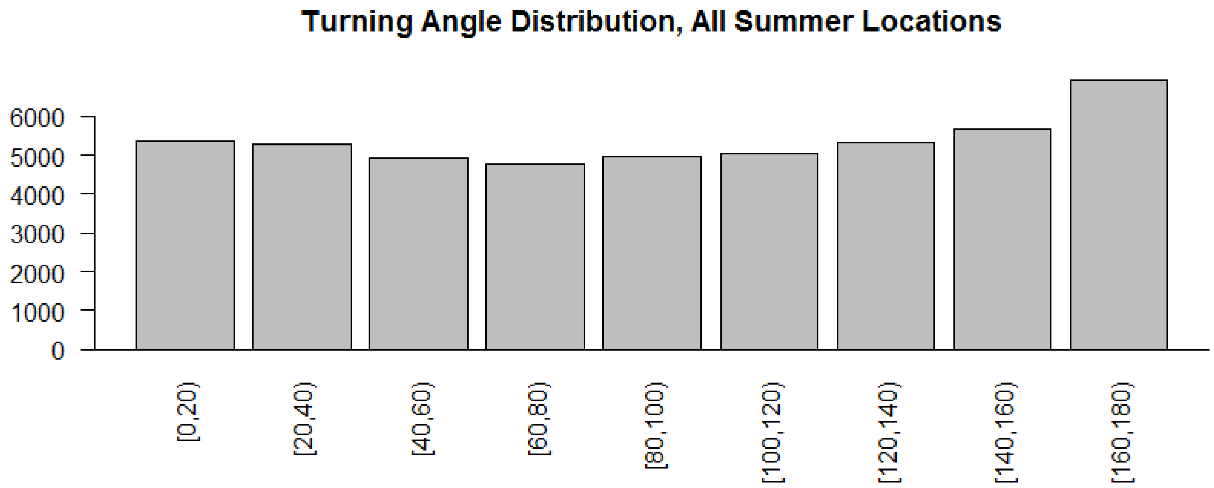


Figure 3.7. Turning angle distribution during summer for 18 female moose (Alces alces) tracked March 2009 – October 2012 on Joint Base Elmendorf-Richardson, Alaska (all moose pooled).

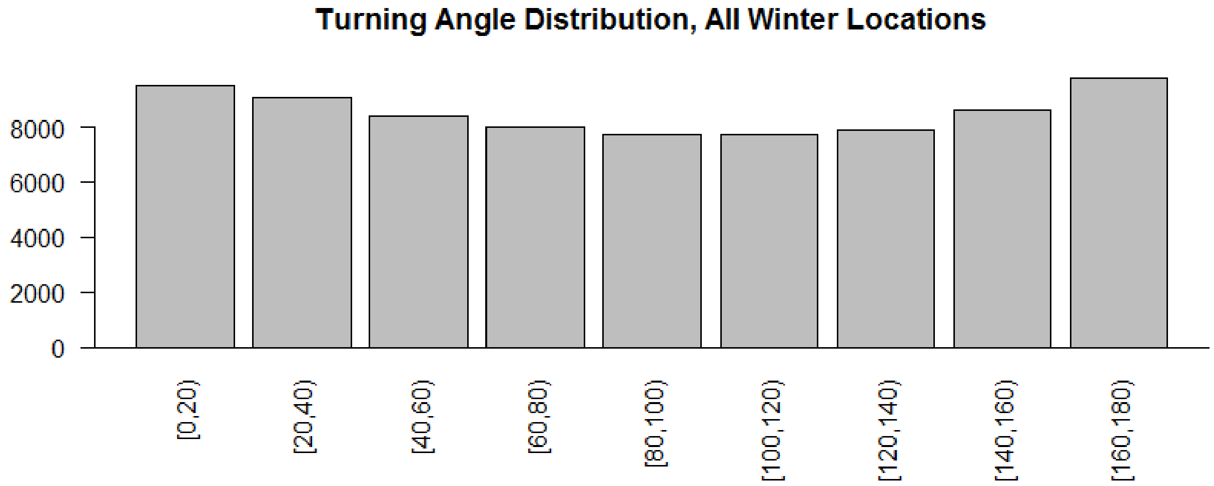


Figure 3.8. Turning angle distribution during winter for 18 female moose (Alces alces) tracked March 2009 – October 2012 on Joint Base Elmendorf-Richardson, Alaska (all moose pooled).

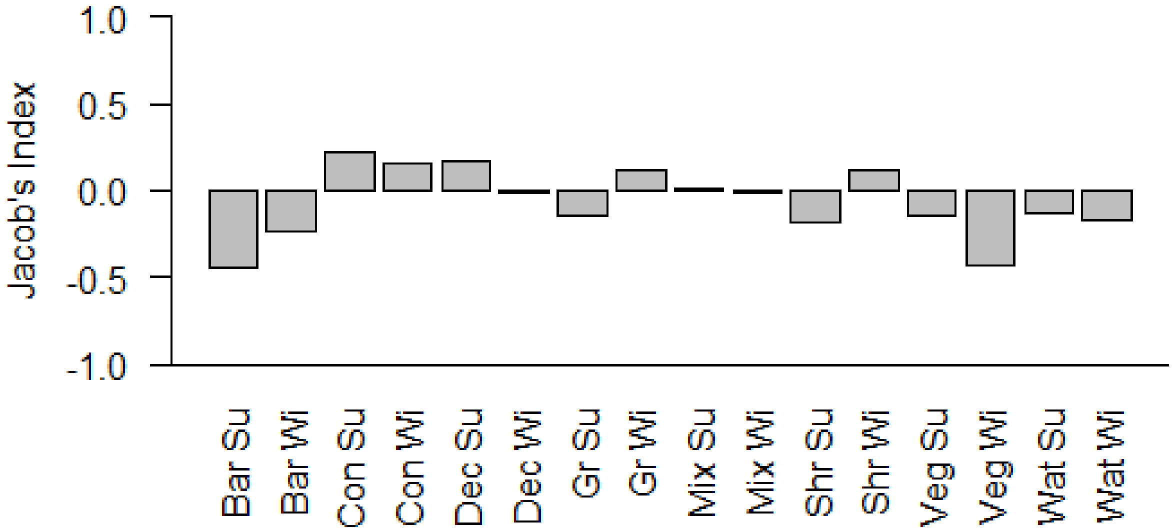


Figure 3.9. Jacobs Index for second order selection for each habitat by season for 18 female moose (Alces alces) tracked March 2009 – October 2012 on Joint Base Elmendorf-Richardson, Alaska (all moose pooled).

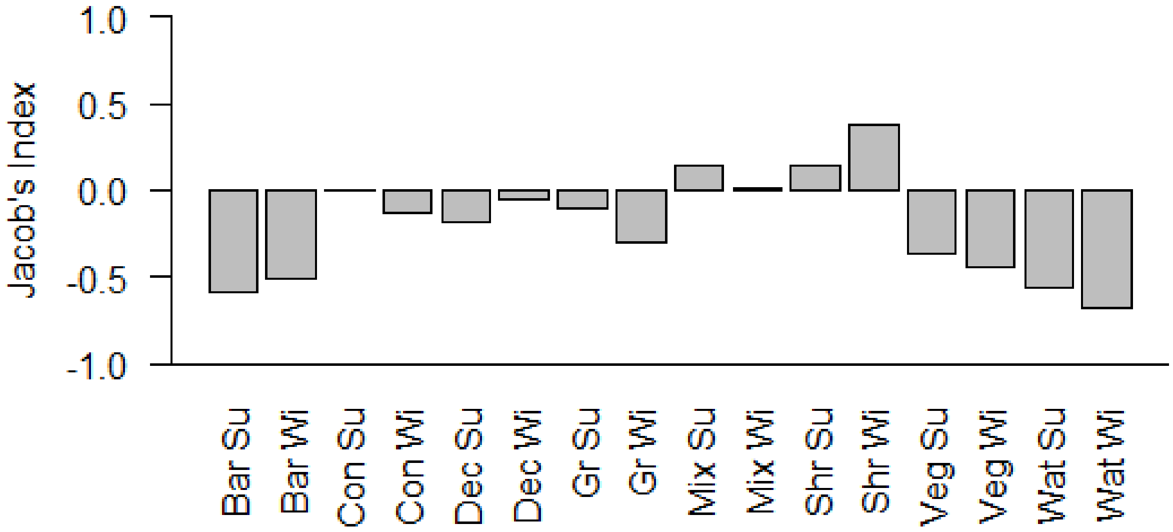


Figure 3.10. Jacobs Index for third order selection for each habitat by season for 18 female moose (Alces alces) tracked March 2009 – October 2012 on Joint Base Elmendorf-Richardson, Alaska (all moose pooled).

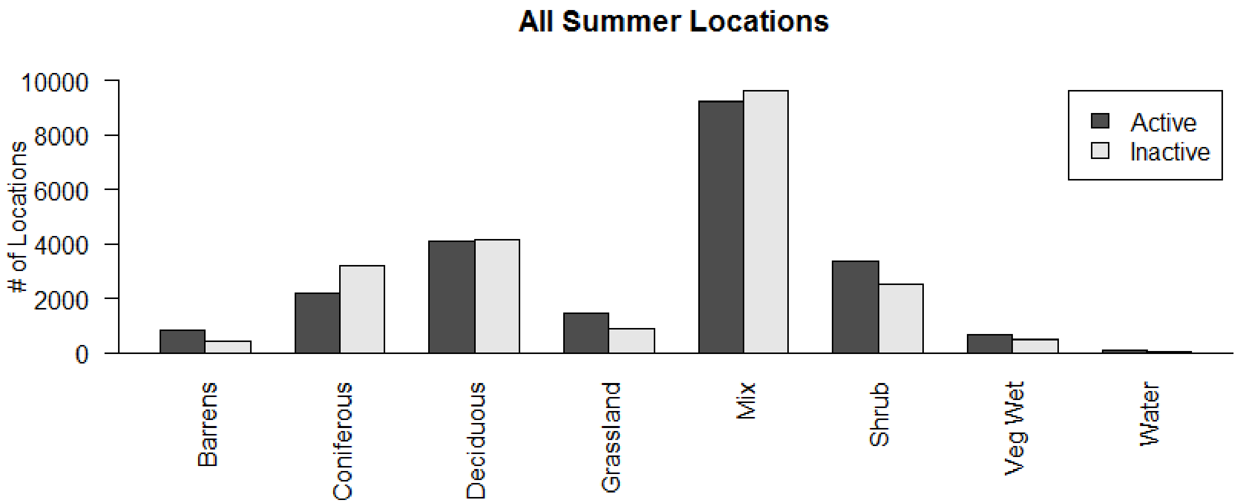


Figure 3.11. Number of active and inactive locations during summer in each habitat for 18 female moose (Alces alces) tracked March 2009 – October 2012 on Joint Base Elmendorf-Richardson, Alaska (all moose pooled).

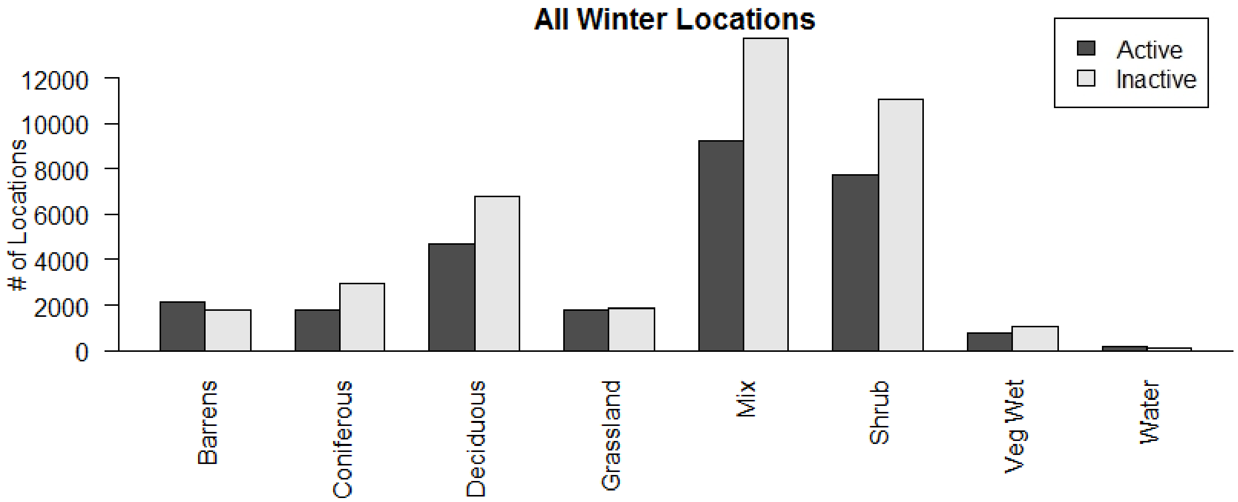
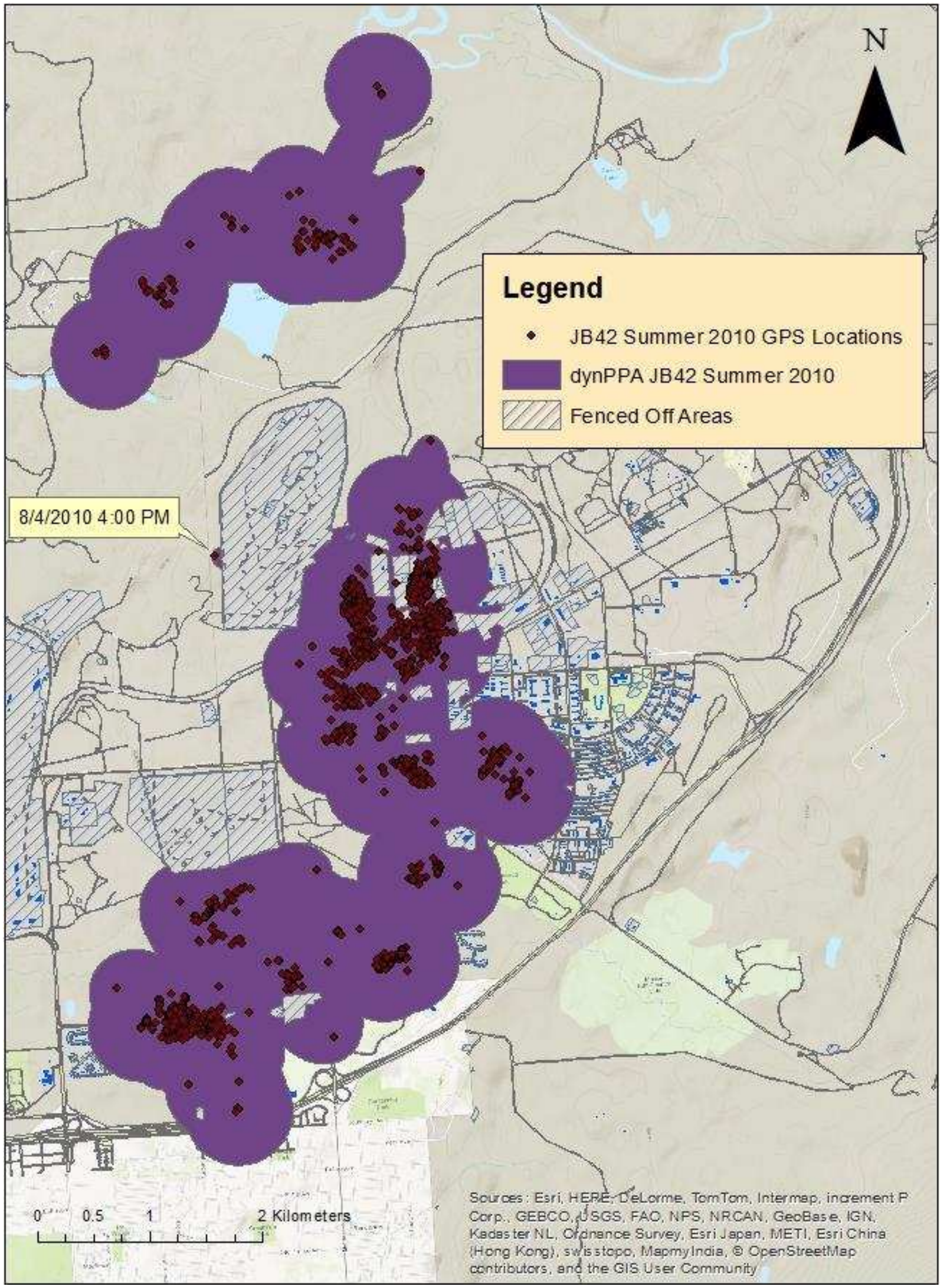
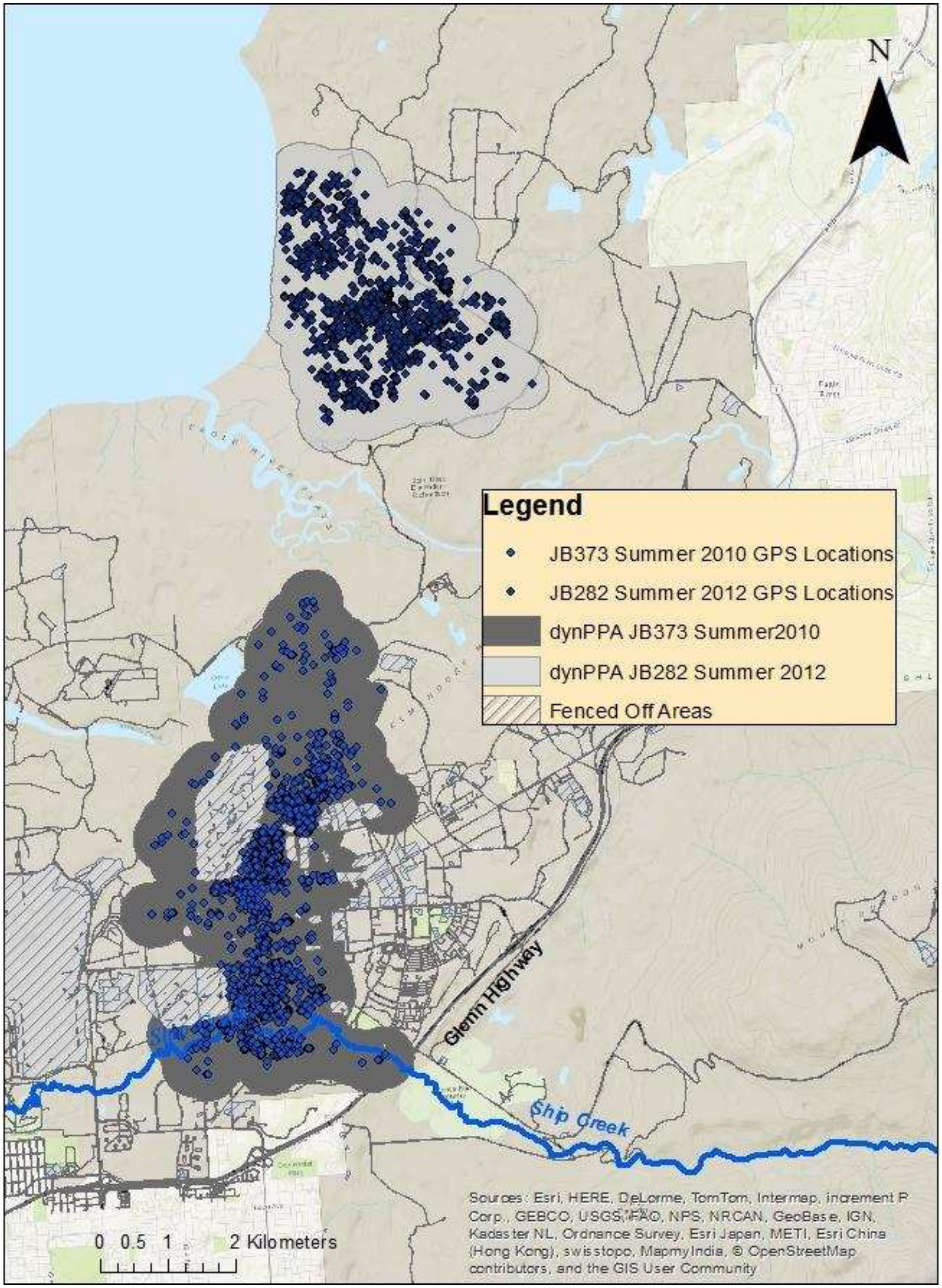


Figure 3.12. Number of active and inactive locations during winter in each habitat for 18 female moose (Alces alces) tracked March 2009 – October 2012 on Joint Base Elmendorf-Richardson, Alaska (all moose pooled).



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3.13. Dynamic Potential Path Area home range for moose JB42 during the summer of 2010 on Joint Base Elmendorf-Richardson, Alaska.



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3.14. Dynamic Potential Path Area home ranges for moose JB373 during the summer of 2010 and moose JB282 during the summer of 2012 on Joint Base Elmendorf-Richardson, Alaska.

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Appendix A

The below list includes all moose behaviors and behavior categories used during data collection. It also includes some behaviors that were included in the data collection program, but which were not actually seen during the data collection period.

Feeding Behaviors: Stepping and moving during feeding bouts is still counted as feeding.

- Browsing: Biting off and ingesting pieces of woody plants, including twigs and leaves.
- Grazing: Biting off and ingesting grasses and forbs close to the ground, or eating leaves off the forest floor. During the data collection period, the majority of feeding behavior consisted of "grazing" leaves off the forest floor. There are no sudden, abrupt movements associated with this behavior, which may have contributed to lower activity counts than browsing.
- Feeding - Other: This classification was intended for use to note drinking, feeding on aquatic vegetation, feeding from a trough, or any unanticipated behavior deemed to fit into the feeding category. During the data collection period, this classification was used when subject animals were feeding from the trough or drinking. As feeding from a trough is not a behavior exhibited by wild moose, this classification was excluded from analysis.

Traveling Behaviors: Traveling behaviors are used for recognizable long distance traveling. Stepping and moving during feeding bouts is still counted as feeding.

- Walking: A mode of travel wherein at least two feet are in contact with the ground at all times.
- Running: A mode of travel wherein less than two feet are in contact with the ground at some times. This category includes trotting, galloping, etc. Very little running behavior was observed during the data collection period, and the few times it was noted it only lasted for a few seconds. These observations were only included in the "Active/Inactive" dataset (as an active behavior).
- Travel Other: Any unanticipated behavior deemed to fit into the traveling category. During the data collection period, this classification was only used for instances of minor negative interactions between moose in the captive pen, and these observations were only included in the "Active/Inactive" dataset (as an active behavior).

Resting Behaviors

- Lying: Bedded, typically head up.
- Standing: Standing, little or no movement.
- Resting Other: Any unanticipated behavior deemed to fit into the resting category. This classification was not used during the data collection period.

Active vs. Inactive Behaviors

- Active: All traveling and feeding behaviors are considered “active”.
- Inactive: All resting behaviors are considered “inactive”.

Break: The “Break” button in the data collection program was used when there is a brief interruption in data collection (e.g., the observer lost sight of the focal animal momentarily). This is not reflected in the datasets and is only mentioned as part of the methodology of data collection.

Appendix B

Important patches of habitat for moose (based on kernel density maps, habitat maps, GPS locations, and observations during field work) which contribute to the high use areas and corridors within and in close proximity to the Cantonment Area include (Figures 3.3-3.5):

1. Richardson Antenna Fields: The Richardson Antenna Fields contain a high amount of available forage year round, and are near a dense stand of conifers to the north that provide cover. The close proximity to development may yield a slight reduction in the probability of predator encounter when compared to the northern forests, although Ship Creek is a known corridor for bears. This area is one of the most important pieces of habitat in the Cantonment Area.

2. Shrub Clearcut South of Ammo Area A: This is a young growth forest block heavily utilized by moose year round. It has close proximity to cover forests and is on the edge of the Cantonment Area.

3. Conifer forest directly north of the Antenna Fields: While there is little available nutrition, this area seems to be a very important cover area for moose in the Cantonment Area and is also a link between the two shrub areas noted above. It is likely an important component of the corridor between the Cantonment Area and the extensive forests of North Post.

4. Ship Creek/Grady Highway: This area, from Cottonwood Park on JBER-Richardson to the Eagleglen Golf Course on JBER-Elmendorf, received consistent use from multiple study moose year round. It contains thick cover and is in close proximity to foraging areas. It also appears to be an important area for calving.

5. The greenbelt between the east side of Richardson housing and the Glenn Highway fence: This thin strip of forest connects the Ship Creek greenbelt to the block of woods north of the Richardson main gate. This may be more of a “pure” travel corridor, as some moose simply pass through quickly without spending large amounts of time in the area.

6. Northern Perimeter of the Warehouse Loop fenced area: Some moose will travel east and west across the Richardson side of the Cantonment Area by roughly following the Davis Highway. However, it seems to be more common that moose will circumvent the Cantonment Area by moving through the woods north of Warehouse Loop and south of the Cantonment Area fence.

7. Davis Highway south of Warehouse Loop: While this region appears to be less utilized than the northern perimeter of Warehouse Loop, some moose will pass through the area, utilizing some of the small woodlots in the vicinity.

8. Camp Carroll/Air National Guard: This mosaic of disturbed and undisturbed habitat sees relatively heavy use.

9. Young growth forest near the corner of Davis Highway and Poleline Rd: This is an extensive cut area with high forage availability between the widespread forests of North Post and the Cantonment Area. This area is used more during the summer than during the winter, as can be seen by comparing Figures 3.4 and 3.5.

10. Small Arms Complex/McVeigh Marsh: There was a high degree of fidelity of certain collared moose to this complex mosaic of open ranges, roadside shrubs, cut areas, wetland shrubs, and mixed deciduous/conifer forest. In addition, other than during training exercises there is a very low amount of human disturbance, as the Small Arms Complex is a restricted area.

11. Moose Run Golf Course/Corner of Oilwell Rd and Bulldog Trail: This is another area consisting of a mosaic of habitats that is heavily utilized by many moose. The shrub clearcuts at the junction of the two roads is an important foraging site for moose on the south side of the Glenn Highway.