HABITAT COMPOSITION AND SPATIAL RESPONSE OF WHITE-TAILED DEER TO FORESTRY TREATMENTS IN MOOSE RANGE, GRAND PORTAGE INDIAN RESERVATION, MINNESOTA

by

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ABSTRACT

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Key Words: brainworm (*Parelaphostrongylus tenuis* D.), forest and wildlife management, habitat composition, home range, kernel density estimation, moose (*Alces alces* L.), northeastern Minnesota, northwestern Ontario, spatial overlap, white-tailed deer (*Odocoileus virginianus* Z.)

Moose (*Alces alces* L.) have long been an important subsistence species are of great cultural value to the Ojibwe peoples. White-tailed deer (*Odocoileus virginianus* Z.) have been implicated in negatively impacting ecosystems as distribution shifts northward with changes in climate and land cover. In response, moose populations have shown declines due to transmission of brainworm (*Parelaphostrongylus tenuis* D.) where ranges overlap spatially with deer. Brainworm was identified as a primary factor in moose mortalities in the Grand Portage Indian Reservation of northeastern Minnesota. Spatial data was collected over a nine-year period from GPS collared moose and deer captured within the reservation. Home and seasonal ranges were delineated from GPS locations using kernel density estimation (KDE). Outputs were evaluated in ArcMap to determine spatial and temporal overlap, habitat composition of moose relative to deer, and responses to forest harvest and silvicultural treatments. Hypotheses tested include 1) white-tailed deer habitats are different from those of moose, 2) deer range overlaps significantly with moose range during the summer months, 3) forest management treatments aimed at benefitting moose, do not encourage deer use, while 4) forest management treatments made in deer range are utilized by deer. Results for deer show larger ranges and seasonal movements, unlike moose. Deer habitat use differs from that of moose with the exception of cover types that are limiting or support browse communities that are used similarly by both species. Both moose and deer utilize all forestry treatments showing the same order of intensity in use, with the exception of Prescribed Fire treatments that are concentrated in core deer range and rarely visited by moose because they are not in moose range.

CONTENTS

TABLES

FIGURES

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I would like to acknowledge that all data used in this study was gathered from the Grand Portage Indian Reservation within the 1854 Ceded Territory and the traditional territory of the Chippewa.

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INTRODUCTION

Climate change is significantly altering the distribution of many wildlife species in North America. Moose (*Alces alces* L.*)* is a vital subsistence species and is of significant cultural importance to Anishinabek First Nations throughout Ontario and northern states surrounding Lake Superior, including Minnesota, Michigan, Wisconsin, and North Dakota. However, declining moose densities have significantly affected the ability of Indigenous communities to meet their needs from subsistence hunting in recent years. For example, annual moose harvest on Grand Portage Indian Reservation lands has declined approximately 50% since 1990 (GPTL 2014). This decline in moose abundance is thought to be due to climate change and its effects on habitat conditions and interspecies relationships.

The Grand Portage Indian Reservation (Treaty 1854) is located in Cook County and the Arrowhead Region of northeastern Minnesota and is home to The Grand Portage Band of Lake Superior Chippewa. Fifty years of data from the National Oceanic and Atmospheric Administration (NOAA) weather station in Grand Portage show a 2°C rise in summer air temperatures and almost 3°C increase in winter since 1950, resulting in a decline in average snow depth. The effect of warming temperatures on terrestrial biota has been most prominent in resident populations of moose, due to heat stress and increased parasite transmission from deer.

In response to changes in temperature, habitat, and land use, distributional shifts have been documented and further projected in white-tailed deer (*Odocoileus* *virginianus* Z.*)*, trending northwards towards the Boreal Forest ecoregion (Thompson et al. 1998; Pickles *et al.* 2013). White-tailed deer are the natural host of brainworm (*Parelaphostrongylus tenuis* D.*)* inside which the protostrongylid nematode must complete its life cycle (Lankester 2001). While this parasite has little effect in white-tailed deer, several other ungulates of ecological, economic, social and/or cultural importance can serve as alternate hosts and often suffer severe neurological dysfunction due to the pathogenicity of the parasite (Lankester 2001; Pickles *et al.* 2013). Of particular concern to wildlife conservation and management in upper North America are those alternate host species most closely related to white-tailed deer, such as moose, caribou, and elk.

As the primary host of *P. tenuis*, increased densities of white-tailed deer are thought to be a significant factor in moose population declines (Ranta and Lankester 2017). Biologists with the Grand Portage Band of Chippewa conducted necropsies from 2010-2018 and found *P. tenuis* as the cause of death in 33% of collared adult moose mortalities (Grand Portage Trust Lands 2018). In western Minnesota, a second parasite transmitted by white-tailed deer, liver fluke (*Fascioloides magna* B.), was also found to be a significant source of moose mortality, though not of comparable concern (Murray *et al.* 2006). These findings coincided with a local decline in moose population and increase in deer population with range expansion northward over the last decade (Grand Portage Trust Lands 2018). Deer in the midwestern United States were reported to have 80% prevalence rates for brainworm in 2006 and have been identified as the driver of transmission to moose (Murray *et al.* 2006).

In addition to parasite transmission, the increased abundance of white-tailed deer appears to be associated with an increase in the Grand Portage wolf population, promoting apparent competition. Rising wolf densities were found to coincide with higher predation rates of moose calves resulting in as low as 20% survivorship and significantly impacting annual recruitment. In 2013 for example, 41 collared calves revealed a mortality rate of 71% in their first year, with 86% of those mortalities due to wolf or bear predation (Grand Portage Trust Lands 2015). However, factors such as brainworm, winter ticks, and other health issues that contribute to poor body condition were collectively found to be the greatest cause of adult moose mortality on the reservation from 2010-2014 (Grand Portage Trust Lands 2015). During this time period, 60% of moose necropsies tested positive for sarcocystosis, cysticercus, hydatid cysts, neuroendocrine inflammation, anemia and winter ticks, liver flukes and/or rumen flukes, though brainworm was found to be the leading health-related cause of mortality (Grand Portage Trust Lands 2015).

The increase and expansion of deer populations driven by climate change has been facilitated by changes in land use and harvest practices that have created more suitable habitat (Thompson et al. 1998). Since 2006, deer populations have been increasing in Grand Portage despite cold winters, with the doe to buck ratio nearly doubling from 1.76 in 2009 to 3.00 in 2014 (Grand Portage Trust Lands 2015). As local deer populations rise and invade moose range, the risk of brainworm transmission is projected to increase (Pickles *et al.* 2013). Understanding the extent to which deer use habitat in moose range and how deer respond to forest harvest and silvicultural treatments relative to moose will inform best management practices for forestry, moose and deer.

Studies of how forest and habitat management practices influence deer movement and habitat use are required to inform strategies aimed at limiting spatial overlap of deer and moose. The objective of this thesis is to evaluate moose and deer home range, habitat use, and response to timber management and silvicultural practices, and identify primary areas of spatial overlap on the Grand Portage Indian Reservation to inform best management practices for moose habitat creation. Here, four hypotheses are tested using GPS locations collected from moose and deer collar data on the Grand Portage Indian Reservation. These include: 1) white-tailed deer habitats are different from those of moose, 2) deer range overlaps significantly with moose range during the summer months, 3) forest management treatments aimed at benefitting moose, do not encourage deer use, while 4) forest management treatments made in deer range are utilized by deer.

Our findings could provide metrics necessary to determine how different management actions will potentially affect moose and facilitate better decision-making. Furthermore, the results of this study could provide insight for the development of best management practices for moose habitat creation that limits the spatial overlap with white-tailed deer and minimizes the risk of *P. tenuis* transmission. Reducing *P. tenuis* transmissons should have a positive impact on moose health and reduce mortality rates.

LITERATURE REVIEW

TRANSMISSION OF *PARELAPHOSTRONYLUS TENUIS*

Anderson (1964) was the first to link the neurological disease known as "moose sickness" to the parasitic nematode *P. tenuis*. Although non-pathogenic in its only natural host the white-tailed deer, brainworm causes severe neurological dysfunction in all other North American members of the family Cervidae (moose, elk, caribou, mule deer), as well as several ungulates, such as domestic sheep, goats, and alpaca (Pickles *et* *al.* 2013). *P. tenuis* is only able to complete its life cycle in its definitive host; any host other than a white-tailed deer will end the parasitic cycle of transmission. From between the meninges and the cranial venous blood vessels at the surface of the host's brain, adult worms pass eggs that hatch larvae as they travel through the body and are shed in feces. Terrestrial gastropods on the forest floor feed on fecal matter and become a secondary host inside which larvae develop into the infective life-stage. Host gastropods make their way up woody plants and are inadvertently consumed by foraging cervids. The ingested larvae mature within the cranium of the new host, thus restarting the cycle in deer or leading to neurological impairment in other ungulates and death in severe cases (Anderson 1964). More than 20 species of slugs and snails are known to facilitate transmission (e.g. the meadow slug, *Droceras laeve* M.) (Lankester 2001).

DYNAMICS OF CLIMATE CHANGE, RANGE OVERLAP, AND PARASITE TRANSMISSION

As patterns in plant communities respond to changing climate conditions across the landscape, patterns in animal distribution adapt accordingly (Thompson *et al.* 1998). Until about 200 years ago, occurrences of white-tailed deer in the boreal and mixed-forest ecotones were constrained by several factors (Voigt *et al.* 2000). The southern extent of moose and caribou range was mostly mature forest, characterized by cold winters with considerable snow depth (Ranta and Lankester 2017). Large mammal species including lynx (*Lynx canadensis* K.), bobcat (*Lynx rufus* S.), fisher (*Martes pennant* E.), gray fox (*Urocyon cinereoargenteus* S.), porcupine (*Erethizon dorsatum* L.), caribou (*Rangifer tarandus* L.) and white-tailed deer, showed altered distributions during a warming trend from 1900-1940 and a subsequent cooling trend from 1940-1970

(Peterson 1957; Outram 1967; Thompson *et al.* 1998). The expansion of deer northwards was greatly facilitated by warmer winters, land development (e.g. clearing, logging, agriculture) and greater incidence of forest fires (McShea *et al*. 1997), as well as the eradication of gray wolves (*Canis lupis* L.) by the 1950's (Mech *et al*. 1971). Both moose and deer require early successional mixed forest for food and older mixed or conifer forest for shelter from snow and harsh conditions, as well as summer heat in the case of moose. Thus, changes in landscape patterns, forest patch diversity, browse species richness and distribution likely impact both moose and deer and promote overlap in their distribution (Thompson *et al.* 1998).

Since deer began their expansion north into moose range, several researchers have found deer population growth to be concurrent with moose population decline where their distributions overlap in northwestern Ontario, Nova Scotia, Minnesota, and North Dakota (Whitlaw and Lankester 1994; Parker 2003; Beazley *et al.* 2006; Murray *et al.* 2006; Maskey 2008; Lankester 2010; Lenarz *et al.* 2010). Shorter, mild winters and/or longer, wetter growing seasons, associated with 15-20 year declines in moose, were found to improve conditions for deer, increase survival of fawns, and also increase *P. tenuis* transfer which was suspected as the principal cause of the declines (Maskey 2008; Lankester 2010; Maskey *et al.* 2015; Lankester 2018). Fawn survival and abundance is an important factor in transmission, as they are better producers of *P. tenuis* larvae than adult deer, and prevalence of the parasite within the fawn cohort is a good indicator of transmissibility to new hosts. (Peterson and Lankester 1991). However, there are other known cases where reservoir populations of deer occur in moose range with little impact (Lankester 2010; Pickles *et al.* 2013). In a 10-year study across 45 management units, Whitlaw and Lankester (1994b) found moose densities were highest when co-habiting deer density was <4/km$_2$ and only posed potential risk of impacting a moose population at > 5/km$_2$. Declines in this study occurred independent of disease (Whitlaw and Lankester 1994b) and deer densities normally remained below 5/km$_2$ due to severe winters, hunting and predation. When moose declines do occur in relation to deer, they generally happen slowly over several years and within the deciduous-boreal ecotone that stretches from the Atlantic coast and around the Great Lakes Basin to the edge of the central Great Plains (Figure 1) (Lankester 2010).

Figure 1. The deciduous-boreal ecotone (Goldblum and Rigg 2010).

Climatic conditions are also an important factor in transmission rates as winter length and severity are limiting to deer abundance and summer length and amount of precipitation is limiting to abundance of terrestrial gastropods, crucial for transmission from deer to moose (Lankester 2010). Longer summers with more precipitation promote gastropod survival, abundance, and activity (Peterson and Lankester 1991; Whitlaw and Lankester 1994; Lankester 2010; Wasel *et al.* 2003), but in a dry season, desiccation reduces survival of first-stage larvae (Shostak and Samuel 1984). Larvae can tolerate lower temperatures (Shostak and Samuel 1984) and are known to survive extreme winter conditions inside aestivating gastropod hosts (Lankester and Peterson 1996), but more research is required to understand the implications of this for transmission rates. Ranta and Lankester (2017) suggest moose population declines result when the conditions of distributional overlap with infected deer, winter conditions that promote survival of fawns with population growth over several years, and environmental conditions that promote survival and activity of gastropods required for transmission occur simultaneously. The odds of transmission from deer to gastropod to moose (or other ungulates) increase with the density and degree of spatial overlap of all three hosts (Wasel *et al.* 2003). Thus, the dispersal ability of a parasite is constrained by the distribution of its host(s); host and parasite may share a similar response to changes in climate (Pickles *et al.* 2013). Pickles *et al.* (2013) predicted over time, habitat suitability for the full life cycle of *P. tenuis* (and other parasites) will increase in the Boreal Forest ecoregion, resulting in a distributional shift from the Great Plains and southeastern USA. This aligns with Thompson's (1998) projection that rising summer temperatures and loss of preferred habitat resulting from climate change will encourage the movement of deer into the lower edge of moose range, promoting factors (parasite transfer, increased wolf populations, etc.) that will drive moose northwards, although, a higher frequency of fires in the boreal impacting conifer cover could lead to lower population densities of both species.

A suggested secondary cause of moose declines is apparent competition from higher abundances of deer associated with increasing local wolf populations, thus driving up predation rates on moose calves and impacting recruitment (Ranta and Lankester 2017) Apparent competition between deer and moose has been documented in northeastern

Minnesota in recent years (Grand Portage Trust Lands 2015). Wolves will also target injured or sick moose when the intensity of infection increases the chance of predation success (Ranta and Lankester 2017). Brainworm is often difficult or impossible to detect in predated mortalities based on the degree to which the carcass has been scavenged or decomposed, thus, estimates of prevalence are likely under-represented (Carstensen *et al.*2017). Although wolves are more likely to hunt deer than moose and are not typically found responsible for extremely low levels of prey (Mech *et al.* 1971), higher than normal wolf populations (in response to increased deer abundances) have been implicated as a primary factor in declines of moose and woodland caribou in Northern Alberta and southern parts of the Northwest Territories (Latham *et al.*, 2011).

Other factors contributing to moose decline include winter ticks and their associated bacteria, liver flukes transmitted by deer, resource competition with deer, poor habitat quality and increased fragmentation, trace element deficiencies, direct and indirect effects of climate change (e.g. increased heat stress), and additional human-induced stressors (Lankester and Samuel 2007). However, both direct (diagnoses and reports) and indirect (parasite and host biology, pathogenicity, and correlations in population dynamics between moose and infected deer) evidence presents a strong case for *P. tenuis* as a primary source of stress on moose populations (Lankester 2010). Lankester (2010) provides perspective with a comparison of moose densities: typically less than 0.4 moose per km_2 were found for populations that overlapped with infected deer across mainland eastern North America (Timmermann *et al.* 2002), whereas 1-2 moose per km_2 were found on Isle Royale (Vucetich and Peterson *et al.* 2008) and 3-5 per km_2 in Newfoundland (McLaren and Mercer 2005) in the absence of deer.

STATUS OF MOOSE POPULATIONS IN MINNESOTA

Carstensen *et al.* (2018) claims moose mortality rates are higher in Minnesota than other parts of North America. Moose have almost been extirpated (from a population of 4,000 to 100) in the northwest since the 1980's, and the northeastern population has declined approximately 53% (from 8,840 to 4,000) since 2006 (DelGuidice 2019). A report from DelGuidice (2019) of the Department of Natural Resources (DNR) states this decline in the northeast shows a significant linear trend with some apparent stabilization over the past 7 years (Figure 2). Calves represented 13% of the estimated 4,180 individuals in the 2019 population and survival was expected to remain low through the winter (DelGuidice 2019), primarily due to wolf predation as past survival rate estimates of 29-40% would indicate (Severud 2017). While annual calf recruitment (survival to 1 year old) can influence population dynamics, annual survival of adult moose is the greatest contributing factor to long-term population performance and has fluctuated between 80-90% in Minnesota since 2002 (Lenarz *et al*. 2010). DelGuidice (2019) also notes bull:cow ratios have fluctuated around 1:1 since 2005 with no apparent trend.

The Minnesota Department of Natural Resources (DNR) conducts annual aerial surveys to acquire population estimates and collects data from GPS collared moose, as well as anecdotal reports of the sick or deceased across the state. From 2013 to 2018, necropsies where performed on 60 collared individuals from the northeast and 91 anecdotal moose from across the state. Of the collared moose, parasites were implicated in 30% of deaths, 35% were due to other health-related causes, 30% were wolf-related, and 5% were legally harvested. Brainworm accounted for 44% of parasite-related deaths and had infected 22% of those predated on by wolves (Figure 3). In addition, 42% of the anecdotal mortalities tested positive for brainworm. While most moose in the study tested positive for liver flukes (*F. magna* B.), severe infections were implicated in only three mortalities and were not deemed a significant cause of death (Carstensen *et al.* 2018). Due to biases in detection of *P. tenuis* (based on the physical state of carcasses), sightability of sick moose, and reporting rates from outside sources, Carstensen (2018) concludes the true prevalence of brainworm is likely higher than evident and a key factor in population decline.

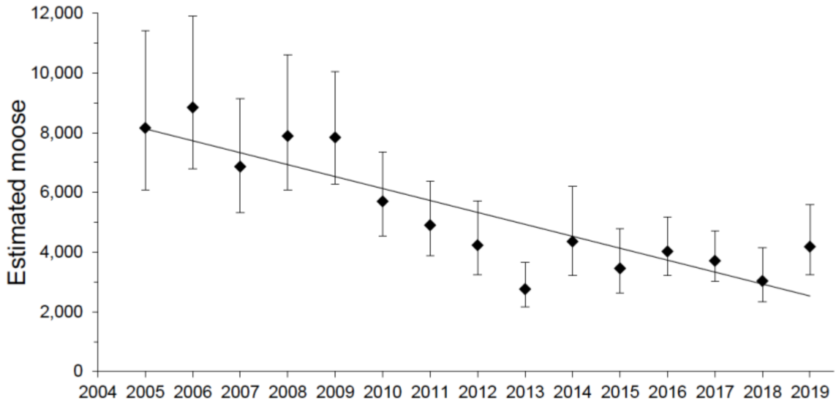


Figure 2. Moose abundance in northeastern Minnesota from DNR aerial surveys, 2015-2019 ($r_2 = 0.76$, $P<0.001$) (DelGuidice 2019).

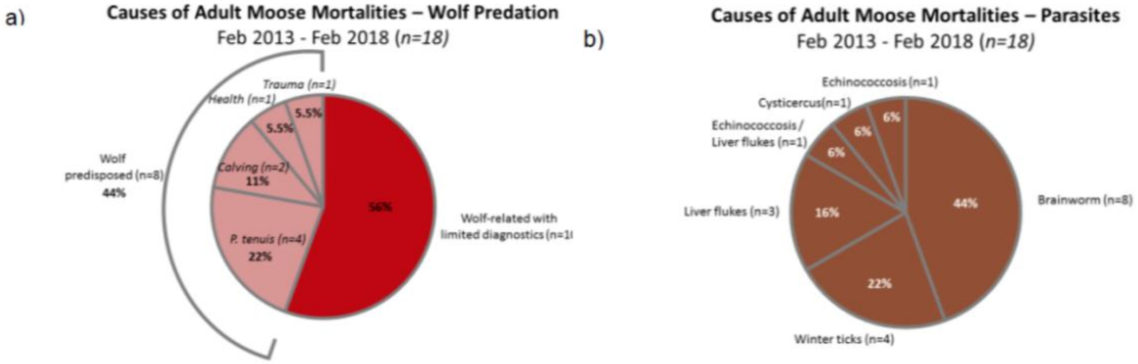


Figure 3. Causes of adult moose mortalities related to wolf predation (a) and parasites (b), in northeast Minnesota, 2013-2017 (modified from Carstensen *et al. 2018)*.

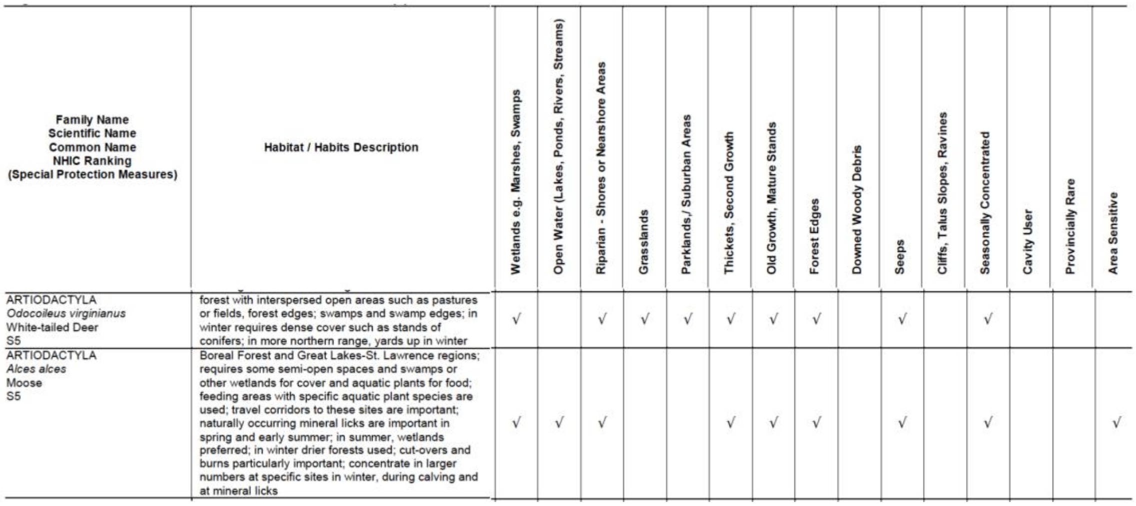
FOREST MANAGEMENT FOR THE PROVISION OF CERVID HABITAT

In Ontario, cervid habitat management on Crown land is addressed through forest management planning at the stand scale for support of cervid density and at the site scale for enhancement of habitat suitability. In Northern Ontario Crown lands, First Nation community-based land use planning determines how habitat areas should be allocated for protection or economic development (OMNR 2009). Private and municipal lands are managed internally but are advised to remain consistent with the Ontario Ministry of Natural Resources management guidelines, including the *Cervid Ecological Framework* (2009), *The Natural Heritage Reference Manual* (1999) and the *Significant Wildlife Habitat Technical Guide* (2000). These guidelines are more focused on identification of areas to protect, rather than effective methods or prescriptions for harvest and silvicultural practices to benefit moose and deer while meeting socio-economic objectives. The publications *Timber Management Guidelines For the Provision Of Moose Habitat* (1988) and *Forest Management Guidelines for the Provision of White-tailed Deer Habitat* (1997) are much more specific from a management perspective, but were published over 30 and 20 years ago respectively; both have since been identified as a "former guide" by independent review and archived. The *Forest Management Guidelines for Conserving Biodiversity at the Stand and Site Scales* (2010) is therefore the most current OMNR publication Ontario foresters may reference for details specific to moose and deer habitat management, addressing broad population-based considerations down to areas of concern (AOCs) such as those for calving and aquatic feeding.

While such guidelines provide a comparison of moose and deer habitat suitability and beneficial management practices, there are no recommendations for limiting habitat sharing where suitability aligns. However, in 2014, the OMNR developed *Ontario's Landscape Tool* (OLT), an analysis application which can be used to assess and forecast landscape-scale change. The OLT showed promise as an important aid for wildlife management and forestry, and in 2019, Elkie *et al.* released a package with simulation results for moose density and carrying capacity based on bioclimatic and habitat suitability factors for several forest and wildlife management units in Ontario Boreal and Great Lakes-St. Lawrence forest. A similar package has been released for Caribou, but not yet for the white-tailed deer; if produced, this could provide a valuable comparison of how deer use the landscape relative to moose.

A comparison of general habitat requirements for moose and deer as defined by the OMNR (2000) is summarized in Figure 4. Moose dependence on early successional plant communities highlights the importance of tree harvest and prescriptive burns for the provision of browse, especially in the absence of major natural disturbances such as forest fire and insect damage (Rempel *et al.* 1997; Thompson and Stewart 1998). However, deer also thrive in early successional mixed forest and greatly benefit from these same natural disturbances that promote browse replenishment and range expansion. For example, Figure 5 illustrates how peaks in deer abundance have been correlated with spruce budworm infestations and blowdowns associated with increased mortality of balsam fir, promoting an abundance of lichens (*Usnea spp.)* on which deer browse in winter (Ranta and Lankester 2017).

From summer to winter, both moose and deer feed on a wide variety of early successional herbaceous forbs and woody plant species, refining their diet to budding twigs (such as birch, *Betula spp.*, cherry, *Prunus spp.*, aspen, *Populus spp.*, maples, *Acer spp*., beaked hazel, *Corylus cornuta*, dogwood, *Cornus spp.,* willow, *Salix spp.*, service berry, *Almenchier spp.*, and mountain ash, *Sorbus spp.*) and conifer leaves (such as balsam fir, *Abies balsamea*, eastern white cedar, *Thuja occidentalis*, and eastern



Family Name Scientific Name Common Name NHIC Ranking (Special Protection Measures)	Habitat / Habits Description	Wetlands e.g. Marshes, Swamps	Open Water (Lakes, Ponds, Rivers, Streams)	Riparian - Shores or Nearshore Areas	Grasslands	Parklands / Suburban Areas	Thickets, Second Growth	Old Growth, Mature Stands	Forest Edges	Downed Woody Debris	Seeps	Cliffs, Talus Slopes, Ravines	Seasonally Concentrated	Cavity User	Provincially Rare	Area Sensitive
ARTIODACTYLA *Odocoileus virginianus* White-tailed Deer S5	forest with interspersed open areas such as pastures or fields, forest edges; swamps and swamp edges; in winter requires dense cover such as stands of conifers; in more northern range, yards up in winter	√		√	√	√	√	√	√		√		√			
ARTIODACTYLA *Alces alces* Moose S5	Boreal Forest and Great Lakes-St. Lawrence regions; requires some semi-open spaces and swamps or other wetlands for cover and aquatic plants for food; feeding areas with specific aquatic plant species are used; travel corridors to these sites are important; naturally occurring mineral licks are important in spring and early summer; in summer, wetlands preferred; in winter drier forests used; cut-overs and burns particularly important; concentrate in larger numbers at specific sites in winter, during calving and at mineral licks	√	√	√			√	√	√		√		√			√

Figure 4. Comparison of habitat requirements for White-tailed deer and Moose (Modified from OMNR 2000).

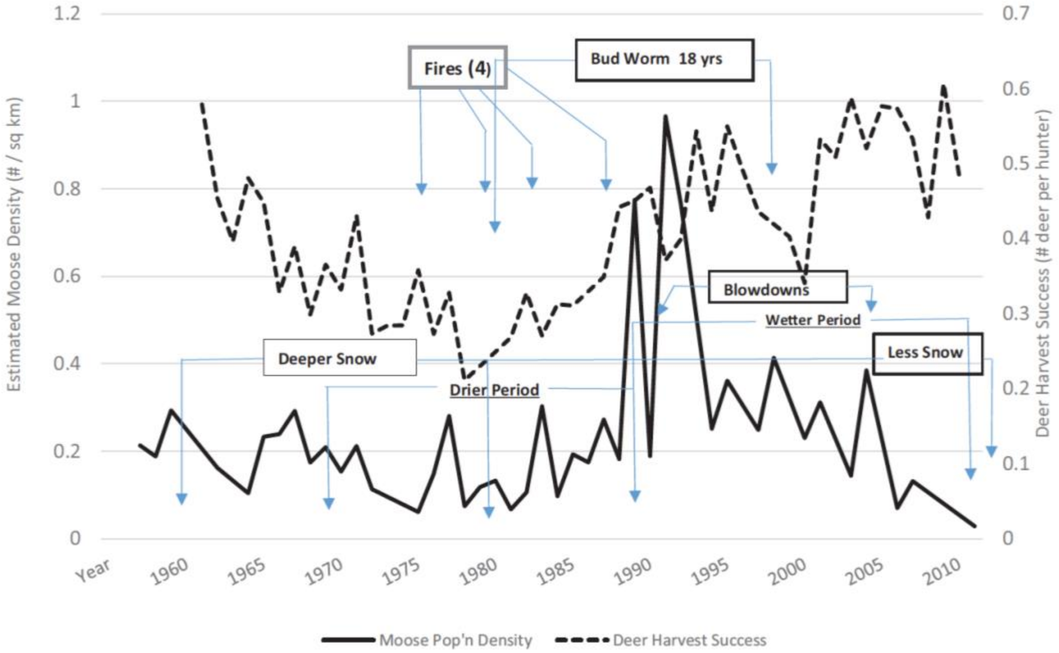


Figure 5. Changes in moose and deer density and harvest in response to natural disturbances and climatic factors from 1995 to 2014, Kenora District, Ontario, Canada (Ranta and Lankester 2017).

hemlock, *Tsuga canadensis*) through winter (Voigt *et al.* 1997; OMNR 2000). Deer are known to seek out foraging areas with abundant mast (e.g. beech nuts and acorns) to build up fat reserves approaching winter (Voigt *et al.* 1997). For summer habitat, the OMNR (2000) recommends a minimum of 40% regenerating or secondary growth stands within reach of conifer shelter and edge habitat for deer, and large areas of conifer cover patches amongst hardwood forest with minimal fragmentation for moose.

The OMNR (1988) identifies sites that provide the season-specific habitat needs of wildlife as Areas of Concern. In late winter, both moose and deer require dense conifer stands to provide cover for predator evasion and protection from the elements, and show preference for eastern hemlock, *Tsuga canadensis*, balsam fir, *Abies balsamea*, white spruce, *Picea glauca*, and eastern white cedar, *Thuja occidentalis* (OMNR 2000). Snow depth is much more limiting to deer and they generally migrate to traditional yarding areas with a thick canopy of conifers once snow builds up 20-50 cm (Voight *et al.* 1997). However, a series of mild winters would allow deer to establish new yarding areas in moose winter range (Broadfoot and Voigt 1996). For winter habitat, the OMNR (2000) recommends a minimum of 60% canopy closure for moose and 80% for deer, with trees exceeding a minimum height of 6 m. For moose, dependency on conifer dominant habitat decreases with latitude (higher temperatures and shallower snow depths), while deer yard up in higher latitudes but are more mobile in lower latitudes and also utilize mixed or deciduous forest and agricultural fields. In spring and early summer, moose require wetlands or streams that provide aquatic macrophytes (e.g. pondweeds, milfoils, and water lilies) and/or areas with groundwater upwellings that provide mineral licks as a source for sodium replenishment. Cow moose seek out isolated areas that provide cover and predator escape pathways for calving purposes, often in more elevated areas and close to or surrounded by open water (OMNR 2000). The OMNR (1988) recommends establishing such areas as reserves (>120 m) with safe access to surrounding stands.

The *Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales* (2010) outlines best practices for managers of Crown forest in planning of silvicultural prescriptions that emulate natural conditions of ecosystems moose inhabit, and addresses the needs (i.e., browse availability, aquatic forage, mineral licks, summer shelter from heat and winter thermal cover) and habitat preferences of moose through the seasons. An area is a candidate for moose habitat management if outcomes will not compromise the designated strategic landscape pattern (i.e. mature or old forest) and landscape class composition (i.e. tree species) targets; a suitable managed landscape consists of 5-30% young browse-producing patches of 10 to 500 ha in amongst 15-35% mature conifer and 20-55% hardwood forest habitat, managed for mixed-wood regeneration, and with wetlands left undisturbed across 5-10% of the land base (OMNR 2010).

A current example of Crown forest management with respect to moose habitat can be found in the *Pic Forest Management Plan* for 2019-2029, produced by the Nawiinginokiima Forest Management Corporation (NFMC). The NFMC (2018), referenced the *Cervid Ecological Framework* (OMNR 2009) to determine appropriate objectives for moose population and habitat density based on the *Cervid Ecological Zone* (CEZ) B in which Pic Forest is situated. Moose population objectives were designed in the interest of both ecological sustainability and socio-economic benefits. However, in contrast to recommendations from the OMNR, the NFMC (2018) selected areas for moose habitat management using a coarse filter (landscape) approach with a broad range of indicators (i.e., structure, composition and patterns of young, mature, and old forest). Variability in resource abundance across the landscape was assessed using habitat modelling to identify sites with a lower moose carrying capacity. Areas with a landscape pattern target for young forest are managed to provide moose forage, while areas with a mature conifer pattern target are managed for winter cover (NFMC 2018).

Some basic guidelines for timber harvest (with respect to moose habitat) were provided by the OMNR in 1988 and are still referenced in management today. These are specific to forest region as follows: In the Boreal Forest Region shelterwood or clear cuts are restricted to 80-130 ha and cut in irregular shapes while providing access to shelter spaced 200 m (or scattered patches of shelter within, spaced 400 m apart), and have buffer zones between cuts. Recommended shelter patch sizes are 3-5 ha (larger to provide protection from predators) of conifer or mixed wood trees ≥6 m tall with a basal area of ≥11 m$_2$/ha, stocking of 70% immature, 40% mature trees and 70% conifers if the objective is to provide winter cover. In the Great Lakes – St. Lawrence Forest Region, selection and shelterwood cuts should be sized to promote regeneration of early successional species and some conifers, with 3-5 ha patches of mature conifer cover retained in 15% of the total area. Payne *et al.* (1988) suggests several patterns for cuts that will provide edge habitat and improve regeneration; these are group seed tree areas, alternate block cuts, alternate strip cuts, and linear (waterway) reserves. Prescribed burning is preferred (when care is taken to maintain the nutritional integrity of soil and protect shelter patches) over mechanical site preparation, although mechanical methods may encourage coppicing or root sucking, increasing browse. Chemical site preparation is not recommended as herbicides such as glyphosate may inhibit regeneration of browse species over an extended period of time. The purpose of regeneration is to maximize growth of commercial species and minimize growth of competing species, often those that are preferred by browsers. Thus, natural regeneration is desired over artificial regeneration unless conifer cover for winter shelter is desired (OMNR 1988).

The goal of restricting cut size to <130 ha was to improve browse availability and provide foraging opportunities close to protective cover, thus mitigating the negative effects of conventional clearcutting (OMNR 1988;). Voigt *et al.* (1997) suggests this method of clearcut modification would further suit deer in terms of increasing edge habitat and habitat diversity. Payne *et al.* (1988) assessed the effectiveness of this strategy in two northern Ontario case studies. In one study, moose populations doubled in a modified cut (i.e. alternate block pattern that provided 38% more edge habitat and 65% more residual cover) versus a traditional clearcut. In the second study, moose populations tripled where cuts were made in linear reserves, leave blocks, and alternate strip patterns (Payne *et al.* 1988). However, Rempel *et al.* (1997) found higher moose densities in an unmodified, progressive clearcut with regeneration of nonuniform age classes than in a modified clearcut following the OMNR (1988) guidelines which fail to pattern landscape structure after natural broad-scale burns or fine scale gap disturbance.

DEFINING HOME AND SEASONAL RANGES

Home range is defined as the entire area that is inhabited by an individual or group of animals while engaging in daily activities (Burt 1943) and can be refined by quantifying the probability of an animal using different locations to determine their relative importance (Powel 2000). Various methods for defining home range have the potential to influence results differently. Method(s) should be carefully chosen based on the context in question and relevant variables (feeding ecology, body size, population size, and habitat quality and type distribution, etc.) (Borger *et al.* 2007: Gregory 2017). As habitat use may shift with the seasons, the data analyzed should encompass a full year cycle (Gregory 2017). Two methods for home range estimation commonly used by wildlife biologists are minimum convex polygons (MCP; Mohr 1947) and the kernel density estimation (KDE; Worton 1989).

A convex polygon is one with no internal angles less than 180 degrees and should encompass all location points for the group or a subset (%) from high-use areas. The MCP method of home range estimation is generally more practical than the KDE method when the sample size is low relative to the population (Boyle *et al*. 2009). However, this method assumes equal use across the polygon, often resulting in an overestimation of home range size (Gregory 2017). If this method is employed, differentiation in intensity of use among habitat types or spatiotemporal scales (e.g. summer versus winter ranges) may be more apparent by combining several categorized MCPs as subsets of the total home range and by excluding points in areas that are very rarely used. For example, Lesage *et al.* (2000) used multiple MCPs to estimate annual summer and winter home ranges of individual adult and immature deer across 4 years and quantified philopatry as percent overlap of seasonal ranges over consecutive years.

Kernel density estimation is a tool used to delineate areas where and to what extent an animal or population under study spends time. In KDE methodology, a utilization distribution (UD) is created to describe probabilities of animals spending time in given locations (based on location point densities) and is free from the parametric assumptions that cause bias (e.g. grid size and placement) in other methodologies (Worton 1989).

Bandwidths (smoothing parameters, SP) are set to increase the efficiency of the locational data used. Complex KDE methods, such as adaptive kernel (AK) and fixed kernel (FK), are more commonly used because they can be applied to both univariate and multivariate probability density estimations (Powell 2000). AK uses variable bandwidths depending on location point density, while FK uses one bandwidth that is fixed across all points (Worton 1989). As with the MCP method, overestimation of home range size is a common problem in KDE analyses due to inappropriate smoothing parameter (bandwidth) selection (Gregory 2017) and could also be addressed by subsampling. However, Walter *et al.* (2011) advises against subsampling for KDE when using autocorrelated data because important movement parameters or habitats (e.g. corridors) could be missed, resulting in a different home range size from that of a complete dataset. Low Convex Hull (LoCoH) is a KDE method that employs MCP methodology and accounts for areas without location points within the home range. This method is more appropriate for large datasets and may underestimate home range size (Gregory 2017).

Walter *et al.* (2011) investigated challenges in determining home range and spatial movements (i.e. migration) from autocorrelated GPS collar and transmitter data using KDE methodology, and made recommendations for best results using estimators that are freely available. In their study, Walter *et al.* (2011) found the reference bandwidth (h_{ref}) caused over-smoothing of multimodal data (produced by mobile species), and the least squares cross-validation (h_{lscv}) and bias crossed validation (h_{bcv}) struggled to identify clumped distribution of overlapping points. However, the plug-in bandwidth ($h_{plug\text{-}in}$) was found to be conservative in smoothing, and thus more appropriate for animals in fragmented landscapes, patchy environments, or small geographic areas and for resident or seasonal habitat use. Brownian bridge movement models (BBMM) were found to be most accurate for datasets 1,000-10,000 points over large geographical areas because the UD incorporates time duration between successive locations (Walter *et al.* 2011). While KDE is best used with independent location points (Worton 1989), BBMM was designed for use with data correlated in space and time (e.g. seasonal migration) as it has the ability to predict movement paths by connecting sequential points with a bridge; time travelled from one to the other is reflected with adjustment in width (i.e. width increases as the time interval between points increases) (Walter *et al.* 2011). Walter *et al.* (2011) concludes that KDE with $h_{\text{plug-in}}$ would be a better choice for defining home range based on resource selection because only areas of concentrated use are incorporated in the UD, whereas BBMM incorporates exploratory pathways unrelated to an animal's fitness.

An example of how KDE methods can be used to analyze the influence of multiple variables on home range can be found in Borger *et al.* (2006). To better understand intraspecific, interspecific, and individual variation in home range size of roe deer, (*Capreolus capreolus* L.), Borger *et al.* (2006) used a hierarchal analytical approach to analyze variation in temporal (photoperiod and climate), spatial (distribution of habitat types), and individual-level processes. Accurate estimations of home range were facilitated by the Animal Movement extension for ArcView, fixed-kernel methods, and a regression approach of linear mixed-effects modeling of time series of home range sizes using R. Borger *et al.* (2006) found that variance was primarily influenced by habitat type distribution, photoperiod (home range was smaller in summer), climate (home range decreased with increases in rainfall and mean temperature) and individual differences rather than sex or age class. Such an analysis may be too in-depth for the purposes of this undergraduate thesis. However, the study of Borger et al. (2006)

highlights the potential value of investigating the influence of natural and modified habitat distribution on home range size in white-tailed deer and moose.

METHODS AND MATERIALS

STUDY AREA

The Grand Portage Indian Reservation (Figure 6), established as part of Treaty 1854, is located in the northeastern tip of Minnesota, U.S.A. Its boundaries are delineated by the Pigeon River and the province of Ontario to the north in Canada, state and federal forests to the west, and 38 km (24 mi) of Lake Superior shoreline to the east

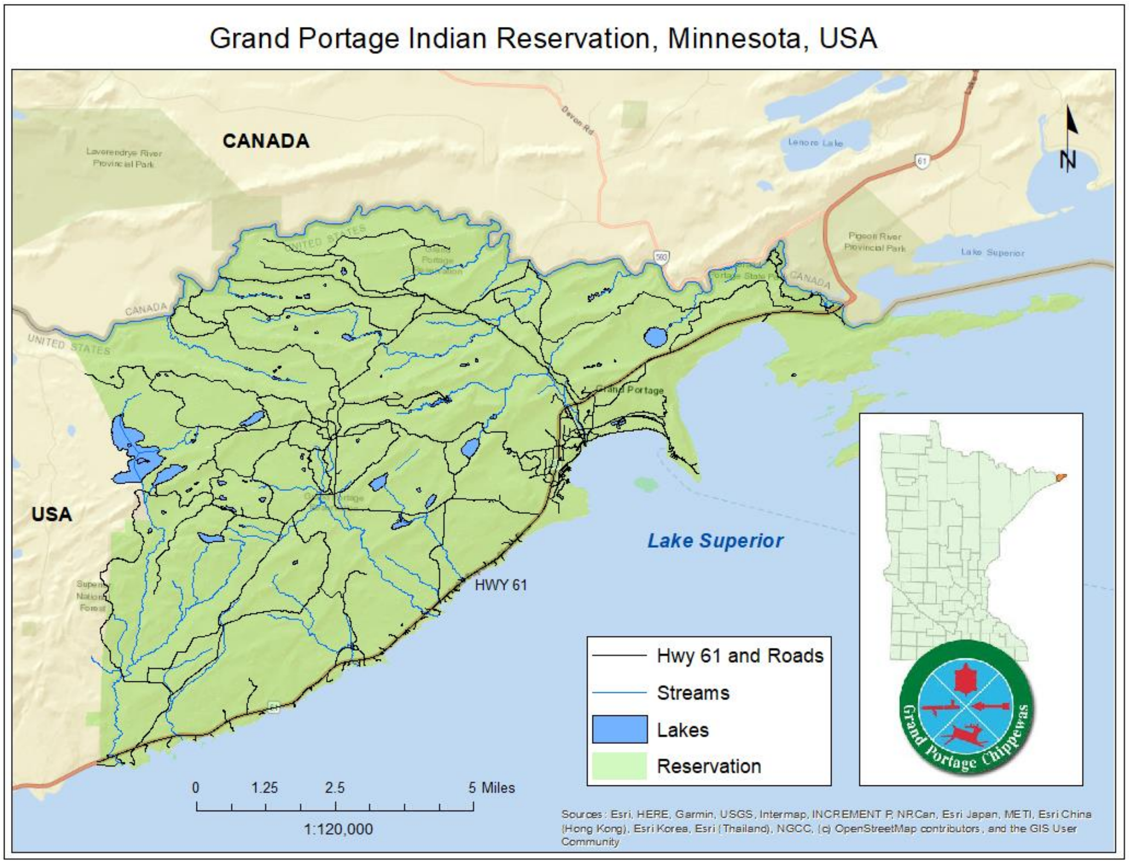


Figure 6. Map of Grand Portage Indian Reservation, Minnesota.

and south. The reservation surrounds the Grand Portage National Monument (GRPO) which protects the historic site of the North West Company fur trading post and its main portage trail, stretching 14 km (8.5 mi) from Canada to Lake Superior. Because this corridor is only 180 m (600 ft) wide, the natural resources within GRPO are co-managed by the National Park Service and the Grand Portage Band of Lake Superior Chippewa at both landscape and watershed scales through a Tribal Self-Governance Act agreement (Kraft *et al.* 2014).

The reservation encompasses approximately 22,600 ha (56,000 acres) of rugged terrain characterized by steep ridges up to 550 m (1,800 ft) ASL and low valleys down to 180 m (600 ft) ASL. The bedrock is sedimentary shale and siltstone with dikes of diabase and igneous rock carved out by glacial advance 12,000 year ago (Kraft *et al.*2014). Within the reservation boundaries, 17 inland lakes and several wetlands cover a total area of about 32 ha (8,000 acres) and are connected by almost 160 km (100 mi) of seasonal and perennial streams that flow into Lake superior, making up part of the northwestern Lake Superior watershed (GPTL 2014).

Northeastern Minnesota is within the Deciduous-Boreal Ecotone or the Northern Lakes and Forest Ecoregion as defined by the United States Environmental Protection Act (USEPA). Forest structure and condition was historically dependent on a fire disturbance regime and is further influenced by wind, insect and disease outbreaks, and changes in climate (GPTL 2014; Kraft *et al.* 2014). Several forest types sprawl across 88% (approximately 40,000 acres or 16,200 ha) of the reservation land base (GPTL 2014). These are classified by the *Grand Portage Reservation Forest Inventory Analysis* (2001) as summarized in Table 1. Aspen/Birch Forest represents 58% of forest cover on the Reservation. Eastern white pine and tamarack are not as prevalent as they were before the 19th century and are not likely to recover (Kraft *et al.* 2014). Forest harvest and silvicultural treatments across the Grand Portage Indian Reservation are numerous and detailed according to forest structure and harvest objectives.

The hot summer and cold winter temperatures of inland Grand Portage are moderated in close proximity to Lake Superior, producing increased precipitation along the shore and drier interior conditions (Kraft *et al.* 2014). Winter and summer temperatures are projected to increase 3-8°C and 4-9°C respectively, by 2099 (Kling *et al.* 2003).

Table 1. Forest types of the Grand Portage Reservation Forest Inventory (GPTL 2001).

Forest Type	**Dominant Tree Species**
Aspen/Birch Forest	Trembling Aspen (*Populus tremuloides)* White Birch (*Betula papyrifera)* some Eastern White Pine (*Pinus strobus)*
Upland Spruce/Fir Forest	White Spruce (*Picea glauca)* Balsam Fir (*Abies balsamea)*
Pine (low diversity plantations)	Red Pine (*Pinus resinosa)* Eastern (White Pine, *Pinus strobus)*
Lowland Brush/Swamp Hardwood	Alder (*Alnus spp.)* Balsam Poplar (*Populus balsamifera)* Black Ash (*Fraxinus nigra)*
Swamp Conifer	Black Spruce (*Picea mariana)* Tamarack (*Larix laricina)*
Northern White Cedar	Northern White Cedar *(Thuja occidentalis)*
Northern Hardwoods	Sugar Maple (*Acer saccharum)* some Red Maple (*Acer rubrum)*

DATA ACQUISITION

Spatial data was acquired from GPS collared moose (*Alces alces* L.) and white-tailed deer (*Odocoileus virginianus* Z.) inhabiting Grand Portage Indian Reservation lands. Each year, Grand Portage biologists capture and collar a representative sample of deer and moose with Vectronic Aerospace GPS collars, which are monitored daily using Vectronics GPS PlusX and Google Earth software. Moose and deer populations are estimated annually within the reservation perimeter during aerial surveys by helicopter using methods in DelGuidice (2019). Moose are selected for collaring during population and/or calf survivorship survey flights in winter, then located again during capture flights from mid-January to mid-March and darted with tranquilizer for collaring. Deer are captured from mid-February to mid-April, using collapsible clover traps, set and baited with corn at 10 unique locations across the Reserve.

Additional data collected at the time of a capture includes sex and approximate age, a blood sample, sign of pregnancy or presence of a fawn/calf, and general health condition (coat condition, fat reserves, sign of injury, disease, or parasites). During the capture and collaring process, every care is taken to ensure the animal's safety is prioritized by monitoring for stress levels indicated by heart rates (BPM) and respiratory rates. For deer which are not anesthetized (to reduce risk of mortality), a time limit of 10 minutes is imposed for handling, after which the animal must be released regardless of blood sampling success. For moose under anesthesia, the collaring and examination process is limited to 25 minutes after which the animal is monitored from distance to confirm full recovery.

Deer are outfitted with collars that employ one-way Globalstar communication, which are pre-programmed to send 6 location signals per day. Moose are outfitted with collars that employ two-way Iridium communication, which are manually programmed to send coordinates once every 1.5 hours normally or every 30 minutes during calving season. As of the spring in 2019, Grand Portage biologists have collared 74 deer including 19 bucks, 44 does, and 11 fawns, and 101 moose including 75 cows and 26 bulls (Isaac pers. comm., Feb. 21, 2020). Our sample population sizes (*n*) for this study include 65 deer (64 collars) from the years 2016 to 2019 and 53 moose (57 collars) from 2010 to 2019 which have provided year-round data for a comparative analysis between seasons.

For our purposes, natural cover types are defined by the Land Cover Classification system used in Grand Portage and forest treatments types are generalized into categories. A geodatabase with land cover (Figure 7) and forestry treatment (Figure 8) shapefiles and accompanying data was provided by the Grand Portage Band of Chippewa forest management unit for analysis in ArcGIS.

DATA ANALYSIS

The following methods were chosen to investigate habitat selection by white-tailed deer and moose at spatial and temporal scales by quantifying home and seasonal ranges, extent of spatial overlap, composition and preferential selection of habitat (land cover classes), and relative response to forest (harvest and silvicultural) treatments across the Grand Portage Indian Reservation land base.

To estimate range sizes and distribution, R was used along with packages *rgdal* and *adehabitatHR* (Calenge 2005) to facilitate kernel density estimation (KDE; Worton 1989), generating 95% utilization distributions (UD) for home, summer, and winter

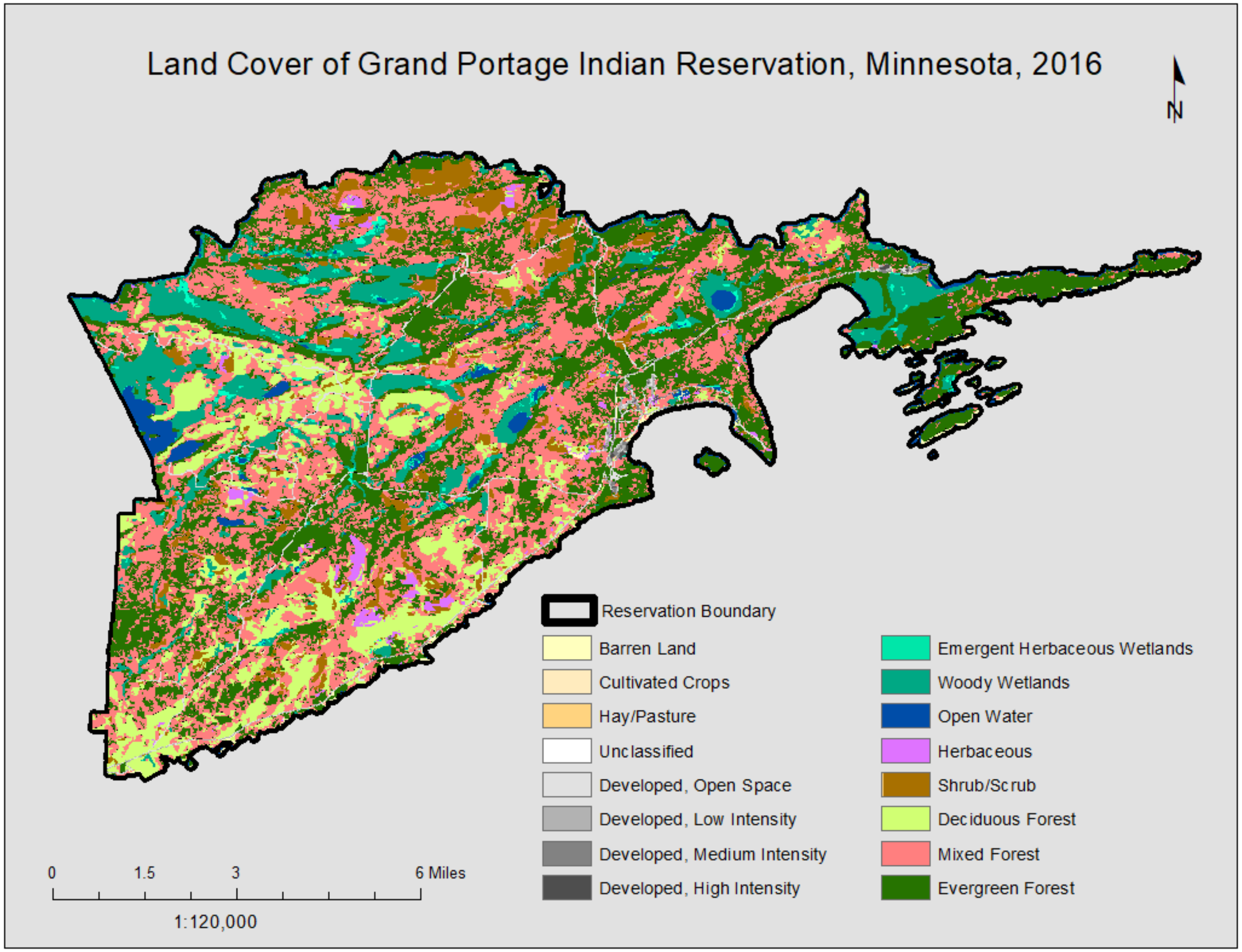


Figure 7. Land Cover Classes of Grand Portage Indian Reservation, Minnesota, 2016.

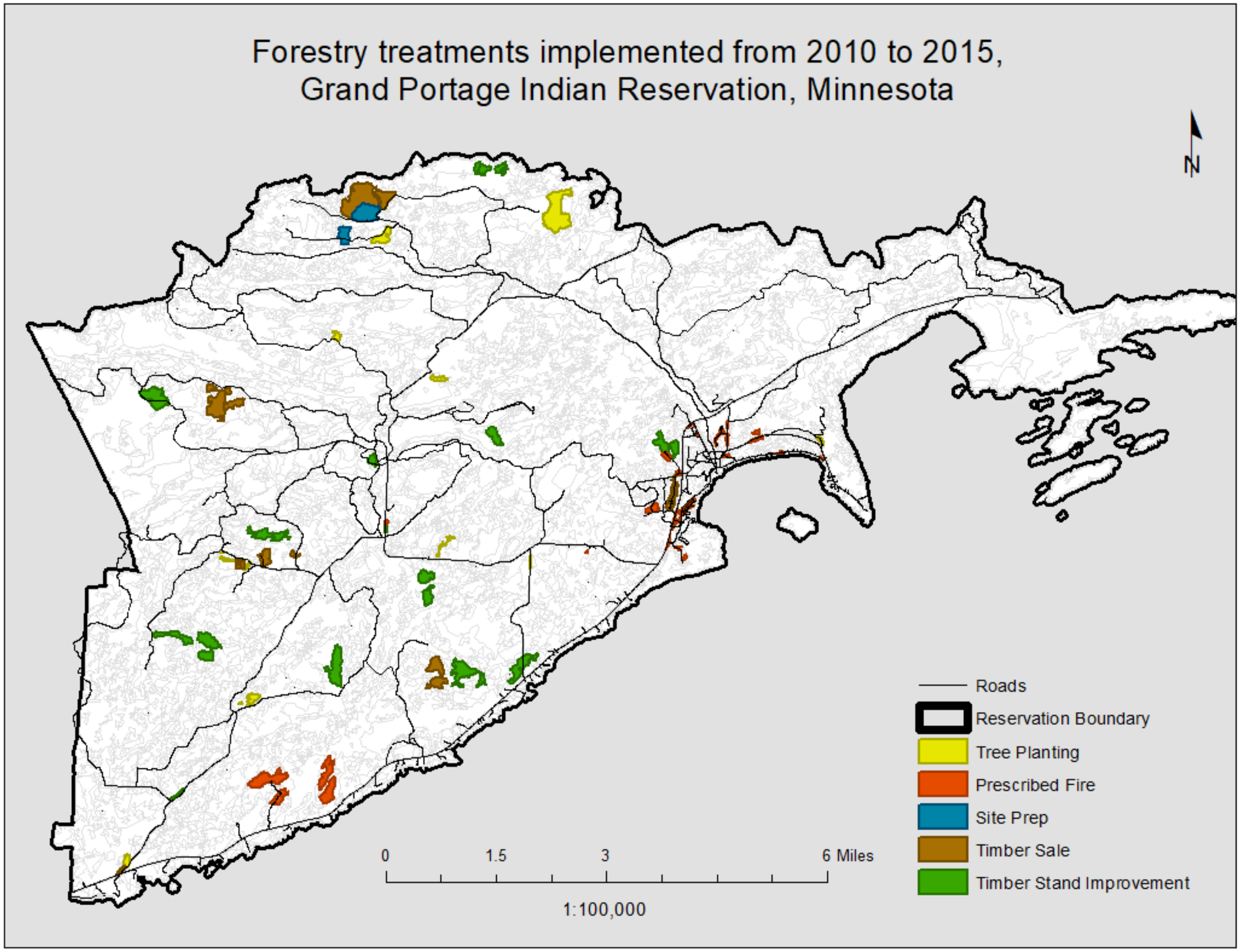


Figure 8. Forest harvest and silvicultural treatments implemented from 2010 to 2015 on the Grand Portage Indian Reservation, MN.

ranges for each species. The R script for deer home range is presented in APPENDIX I KERNEL DENSITY ESTIMATION R SCRIPT. The reference bandwidth (h_{ref}) was chosen to calculate a spatial probability density function for each individual animal, producing separate outputs per range type based on GPS point cluster densities and distributions. UD outputs for home ranges were produced from 97,280 GPS locations from 64 white-tailed deer collars and 1,048,573 GPS locations from 57 moose collars. To delineate seasonal ranges, these locations were subdivided to produce winter range UDs (November 1st to April 30th) with 172,294 points for 57 moose collars and 353,096 points for 64 deer collars, and summer range UDs (May 1st to October 31st) with 107,123 points for 51 moose collars and 67,603 points for 47 deer collars.

The resulting utilization distributions (UD) were analyzed in ArcMap to calculate areas (km^2) of total home ranges and seasonal ranges by species and for each individual animal. Mean area (km^2), standard deviation, and standard error (for total, summer, and winter ranges) were calculated across individuals of each species.

To estimate the spatial overlap of white-tailed deer in moose range, the ArcMap tool *Intersect* was used to create new polygons where UDs for total deer home and seasonal ranges co-occur with those of moose. Spatial overlap was quantified as the total (km^2) of overlap in moose and deer ranges and as a percentage (%) of moose range that deer utilize.

For analysis of inter- and intra-specific seasonal differences in habitat use, the ArcMap tool *Union* was used to join UDs for individual home and seasonal ranges to the Land Cover Class shapefile and calculate the areas (m^2) of each cover class used by individual moose and deer. Outputs were further analyzed to determine the composition of natural habitats used on an individual basis as a percentage of the estimated total area (m$_2$) used by the individual across all classes. The following seven classes used for analysis of habitat composition (%) include deciduous forest, mixed forest, evergreen forest, shrub/scrub, woody wetlands, emergent herbaceous wetlands, and herbaceous. range areas outside reservation boundaries or within anthropogenic or open water land cover classes were excluded from these calculations. All GPS location data collected from 2010 to 2019 and occurring within these habitat types were included in this analysis with the exception of individuals with less than 100 GPS location points, considered non-representative of habitat use within the Reservation. Three such animals were removed from the datasets for each season-species pairing. The reduced samples consisted of 286,919 GPS location points from 61 deer collars and 141,448 points of 54 moose collars in winter, and 55,855 points from 44 deer collars and 92,365 points from 48 moose collars in summer.

One-way (Single Factor) ANOVAs were used to determine intraspecific variance in means of habitat composition (%) between summer and winter, and interspecific variance in means for each season.

For the purpose of analyzing interspecific differences in utilization of forestry treatments, the ArcMap tool *Union* was used to join UD individual home ranges to a shapefile of treatments implemented between 2010 and 2015. All forest treatments investigated were categorized into five broad classes as follows: Prescribed Fire, Site Prep, Timber Sale, Timber Stand Improvement, and Tree Planting. In managed forest blocks, only those location points acquired post-treatment were analyzed to better understand how each species responds to each treatment. Since deer collaring in Grand Portage only began in 2016, treatments included in this analysis were restricted to those implemented from 2010 to 2015 to allow for succession to occur and forage to establish before a response by browsers was measured. The moose dataset was reduced accordingly to include only 2016-2019 GPS locations by excluding those received from 2010 to 2015 before or during treatment implementation. The extent of forestry treatment utilization was estimated from sample populations of 8,446 GPS location points from 54 deer collars and 294 points from 15 moose collars from the years 2016 to 2019.

The *Union* output provided estimates of areas (m$_2$) used of each treatment type for individual moose and deer. The output was further analyzed to determine the relative utilization of forestry treatment types by each individual as a percentage (%) of the total area (m$_2$) used by the individual across all treatments. One-way (Single Factor) ANOVAs were used to determine interspecific variance in means for each treatment category. In addition, heat maps were created using the ArcMap tool *Kernel Density (Spatial Analysis)* to identify and visually illustrate core areas of habitat and forestry treatment utilization based on GPS Location point densities.

RESULTS

HOME AND SEASONAL RANGES OF MOOSE AND DEER

Table *2* shows the results for total home and seasonal ranges of each sample population (*n*) by species, and the mean ranges and standard deviations across all individuals by species. Range sizes (m$_2$) and UD outputs for all individuals are presented in APPENDIX III UTILIZATION DISTRIBUTION (UD) ESTIMATED RANGE AREAS (M$_2$) FOR MOOSE AND DEER.

Table 2. Total home and seasonal ranges of moose and white-tailed deer populations (n) by species, mean ranges and standard deviations across all individuals.

Area (km$_2$)	Moose				White-tailed Deer			
	n	Total	Mean	St. Dev	*n*	Total	Mean	St. Dev
Home Range	57	767.0	49.7	57.23	64	3769.4	152.1	385.2
Winter Range	57	786.0	47.6	60.8	64	2737.6	117.9	286.7
Summer Range	51	646.9	37.0	47.5	47	3453.5	108.9	356.8

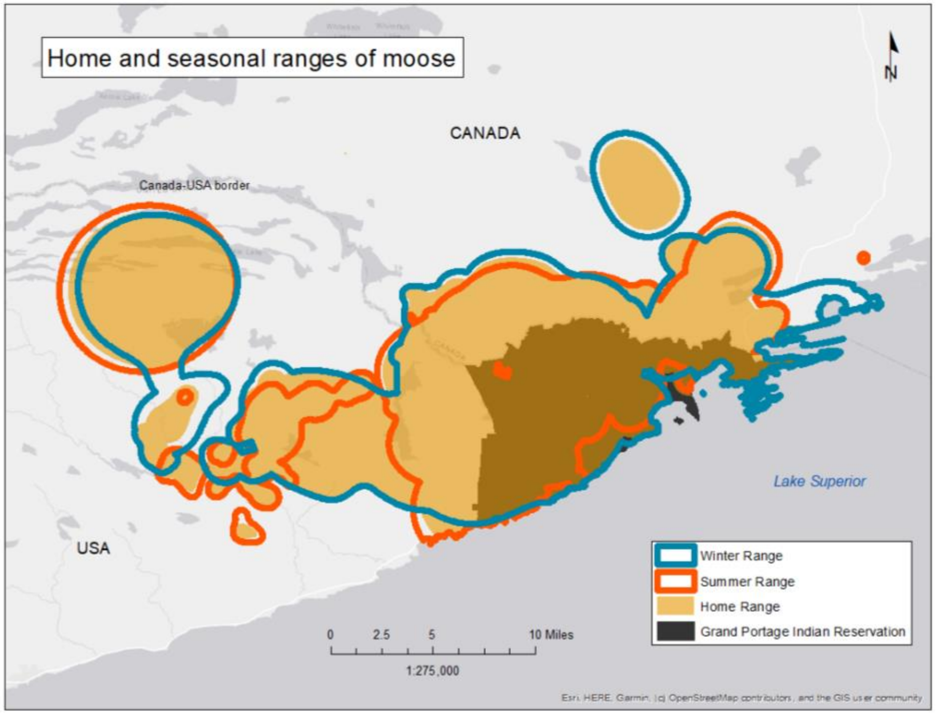
In moose, the UD for winter estimated a larger range than for the home range, but mean home range is greater than mean winter range. For both moose and deer, mean winter range is greater than mean summer range, but total winter range is less than total summer range for deer. White-tailed deer total and mean ranges are consistently greater in area than moose ranges and are more variable across individuals, regardless of differences in sample size (*n*). Figure 9 illustrates the spatial extent of moose and deer home and seasonal ranges as determined by the KDEs.

SPATIAL OVERLAP OF DEER IN MOOSE RANGE

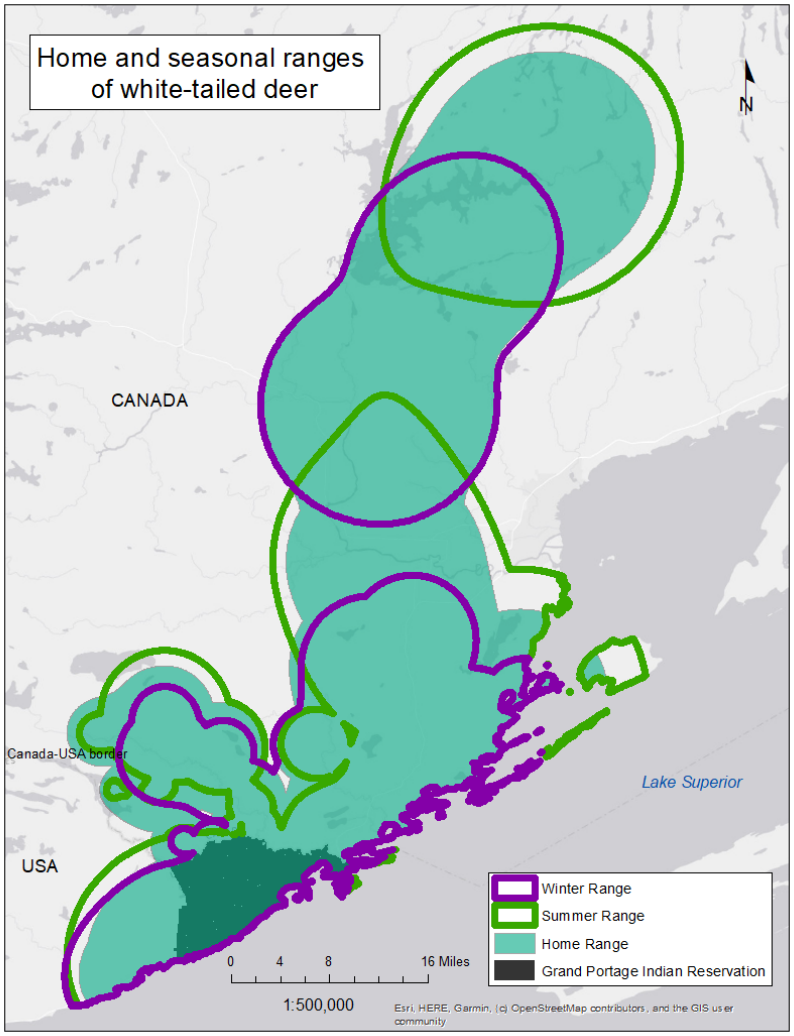
Table 3 shows the results for spatial overlap of deer by area (km$_2$) and as a percentage (%) of the total moose range. For seasonal ranges, area of overlap is highest in winter, but as a percentage of total range, overlap is comparatively greater in summer. Figure 10 illustrates the extent of spatial overlap by moose and deer, home and seasonal ranges.

Table 3. Total spatial overlap of deer by area (km$_2$) and as a percentage (%) of the total moose range.

Spatial Overlap by White-tailed Deer	Moose Range		
	Home	Winter	Summer
Area (km$_2$)	494.7	479.5	407.7
% of total range	64.5	61.0	63.0



(a)



(b)

Figure 9. Map of home and seasonal ranges of (a) moose (*Alces alces* L.) and (b) white-tailed deer (*Odocoileus virginianus* Z.) collared in the Grand Portage Indian Reservation, MN.

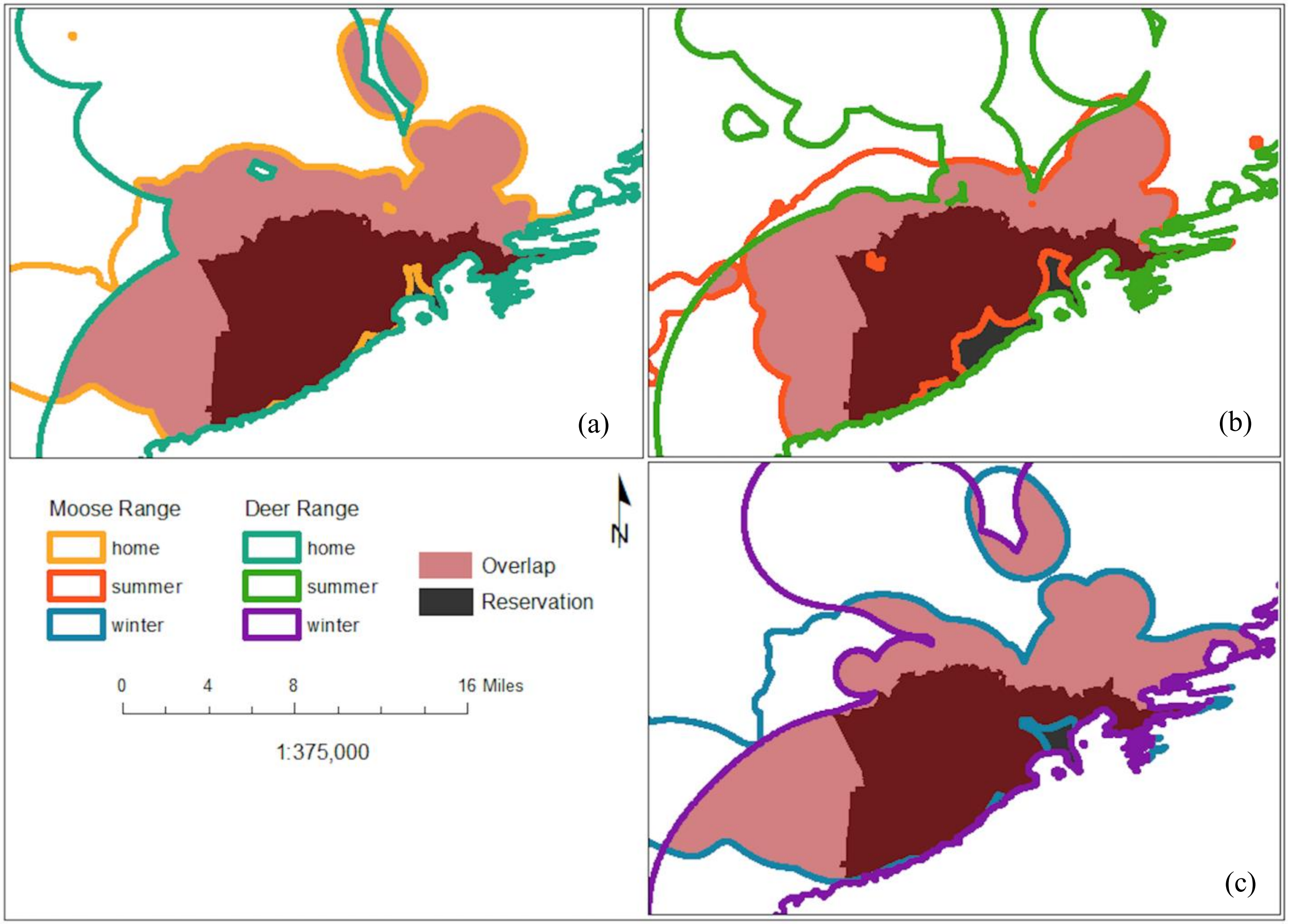


Figure 10. Map of spatial overlap in the total (a) home, (b) summer, and (c) winter ranges of white-tailed deer (*Odocoileus virginianus* Z.) and moose (*Alces alces* L.) collared in the Grand Portage Indian Reservation, MN.

HABITAT COMPOSITION OF MOOSE AND DEER RANGES

Figure 11 compares mean habitat composition (%) by cover class for moose and deer.

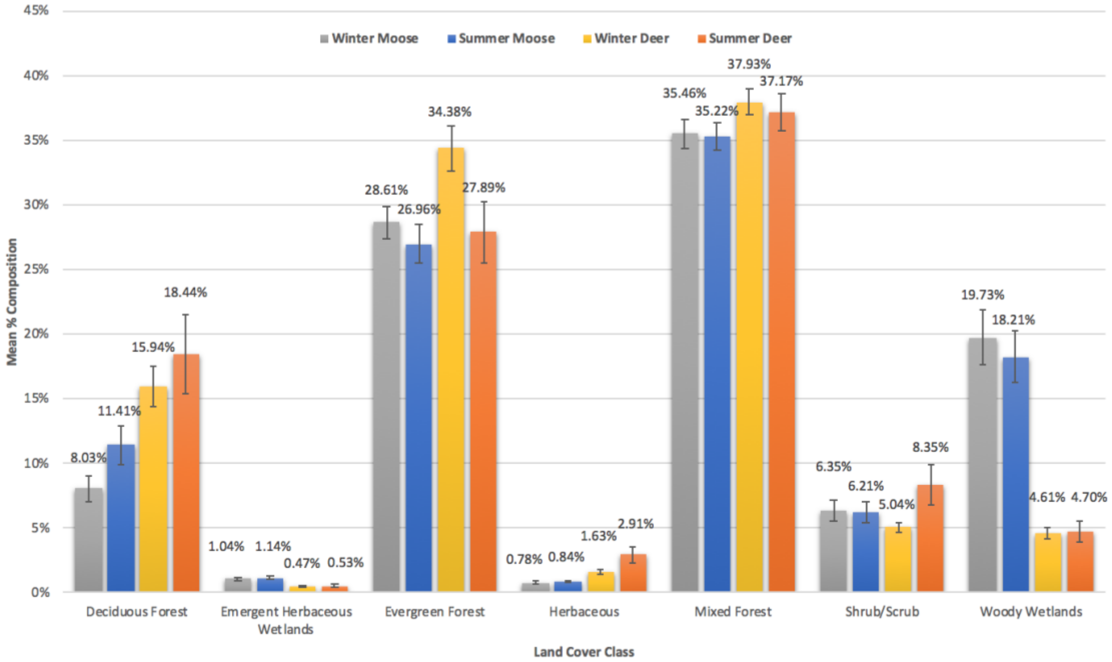


Figure 11. Cover class utilization as mean percent composition by moose and deer in winter and summer with confidence intervals.

During summer, moose utilized mixed forest most heavily (35%), followed by evergreen forest (27%), woody wetlands (18%), deciduous forest (11%), and shrub/scrub (6%). In winter, moose show the same order of cover class preference, but use evergreen forest (29%) and woody wetlands (20%) with more intensity, while deciduous forest (8%) were used to a greater extent in summer. Emergent herbaceous wetlands and herbaceous habitats were used by moose minimally across seasons (≤ 1.14%). In comparison, deer summer habitat was composed mostly of mixed forest (37%) and evergreen forest (28%); stronger preference is shown for deciduous forest (18%) and shrub/scrub (8%) than woody wetlands (5%). Deer used mixed forest (38%)

and evergreen forest (34%) more heavily in winter while deciduous forest (16%), shrub/scrub (5%), and woody wetlands (5%) were used less than in summer. Herbaceous habitat (<3%) was used more than emergent herbaceous wetlands (≤0.53%) in both seasons and to the same extent across seasons. Mean areas (m_2) utilized for all land cover classes by species and season are presented and compared graphically as percentages in APPENDIX IV UTILIZATION DISTRIBUTION (UD) MEAN AREA (M_2) AND COMPOSITION (%) BY LAND COVER CLASS FOR MOOSE AND DEER SEASONAL RANGES.

Table 4, Table 5, Table 6, and Table *7* present the results of one-way ANOVAs for inter- and intra-specific variances in habitat composition by season. No significant difference in utilization of the various land cover classes was observed between moose winter and summer ranges. Deer used evergreen forest significantly more in winter, and herbaceous and shrub/scrub habitats were used significantly more in summer. woody wetlands and emergent herbaceous wetlands accounted for a significantly higher percentage of habitat composition than for deer in both summer and winter; while deer show significantly stronger utilization of herbaceous habitat. Deer browse in deciduous forest significantly more than moose, while both species browse in mixed forest to a similar extent. Deer utilize evergreen forest significantly more than moose in winter.

Figure 12 illustrates the intensity of land cover class utilization by deer and moose based on relative densities of GPS location signals. The northwestern portion of the Grand Portage Indian Reservation, dominated by Woody Wetlands, Emergent Herbaceous Wetlands, Mixed Forest and Deciduous Forest, is core range for moose. Wetlands are represented to a lesser extent in core deer range which is more fragmented by development with smaller forest patches.

Table 4. ANOVA results for winter and summer habitat composition (%) of moose ranges.

	ANOVA					
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Deciduous Forest	Between Groups	0.027	1	0.027	3.901	0.051
	Within Groups	0.628	92	0.007		
	Total	0.654	93			
Emergent Herbaceous Wetlands	Between Groups	2.41E-05	1	2.41E-05	0.330	0.567
	Within Groups	0.007	92	7.29E-05		
	Total	0.007	93			
Evergreen Forest	Between Groups	0.006	1	0.006	0.734	0.394
	Within Groups	0.794	92	0.009		
	Total	0.800	93			
Herbaceous	Between Groups	1.1E-05	1	1.1E-05	0.213	0.645
	Within Groups	0.005	92	5.15E-05		
	Total	0.005	93			
Mixed Forest	Between Groups	0.000	1	0.000	0.025	0.874
	Within Groups	0.502	92	0.005		
	Total	0.502	93			
Shrub/Scrub	Between Groups	4.63E-05	1	4.63E-05	0.016	0.899
	Within Groups	0.264	92	0.003		
	Total	0.264	93			
Woody Wetlands	Between Groups	0.005	1	0.005	0.269	0.605
	Within Groups	1.832	92	0.020		
	Total	1.838	93			

* Significant at the 0.05 level

Table 5. ANOVA results for winter and summer habitat composition (%) for white-tailed deer; there are no significant differences.

	ANOVA					
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Deciduous Forest	Between Groups	0.012	1	0.012	0.634	0.428
	Within Groups	1.699	88	0.019		
	Total	1.711	89			
Emergent Herbaceous Wetlands	Between Groups	6.84E-06	1	6.84E-06	0.240	0.626
	Within Groups	0.003	88	2.85E-05		
	Total	0.003	89			
Evergreen Forest	Between Groups	0.083	1	0.083	4.575	0.035*
	Within Groups	1.589	88	0.018		
	Total	1.672	89			
Herbaceous	Between Groups	0.003	1	0.003	7.227	0.009*
	Within Groups	0.039	88	0.000		
	Total	0.042	89			
Mixed Forest	Between Groups	0.001	1	0.001	0.185	0.668
	Within Groups	0.530	88	0.006		
	Total	0.531	89			
Shrub/Scrub	Between Groups	0.022	1	0.022	8.133	0.005*
	Within Groups	0.233	88	0.003		
	Total	0.254	89			
Woody Wetlands	Between Groups	1.81E-05	1	1.81E-05	0.012	0.911
	Within Groups	0.128	88	0.001		
	Total	0.128	89			

* Significant at the 0.05 level

Table 6. ANOVA results for moose and white-tailed deer habitat composition (%) in winter.

ANOVA

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Deciduous Forest	Between Groups	0.172	1	0.172	15.930	0.001*
	Within Groups	1.175	109	0.011		
	Total	1.347	110			
Emergent Herbaceous Wetlands	Between Groups	0.001	1	0.001	25.469	<0.001*
	Within Groups	0.004	109	3.46E-05		
	Total	0.005	110			
Evergreen Forest	Between Groups	0.092	1	0.092	6.533	0.012
	Within Groups	1.527	109	0.014		
	Total	1.619	110			
Herbaceous	Between Groups	0.002	1	0.002	14.937	<0.001*
	Within Groups	0.016	105	0.000		
	Total	0.018	106			
Mixed Forest	Between Groups	0.017	1	0.017	2.824	0.096
	Within Groups	0.643	109	0.006		
	Total	0.660	110			
Shrub/Scrub	Between Groups	0.005	1	0.005	2.752	0.100
	Within Groups	0.187	109	0.002		
	Total	0.191	110			
Woody Wetlands	Between Groups	0.628	1	0.628	59.438	<0.001*
	Within Groups	1.152	109	0.011		
	Total	1.780	110			

* Significant at the 0.05 level

Table 7. ANOVA results for moose and white-tailed deer habitat composition (%) in summer.

ANOVA

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Deciduous Forest	Between Groups	0.086	1	0.086	5.326	0.024*
	Within Groups	1.151	71	0.016		
	Total	1.238	72			
Emergent Herbaceous Wetlands	Between Groups	0.001	1	0.001	8.439	0.005*
	Within Groups	0.005	71	7.68E-05		
	Total	0.006	72			
Evergreen Forest	Between Groups	0.002	1	0.002	0.127	0.723
	Within Groups	0.856	71	0.012		
	Total	0.857	72			
Herbaceous	Between Groups	0.007	1	0.007	19.081	<0.001*
	Within Groups	0.028	71	0.000		
	Total	0.035	72			
Mixed Forest	Between Groups	0.007	1	0.007	1.218	0.273
	Within Groups	0.388	71	0.005		
	Total	0.395	72			
Shrub/Scrub	Between Groups	0.008	1	0.008	1.829	0.181
	Within Groups	0.310	71	0.004		
	Total	0.318	72			
Woody Wetlands	Between Groups	0.319	1	0.319	28.039	<0.001
	Within Groups	0.808	71	0.011		
	Total	1.127	72			

* Significant at the 0.05 level

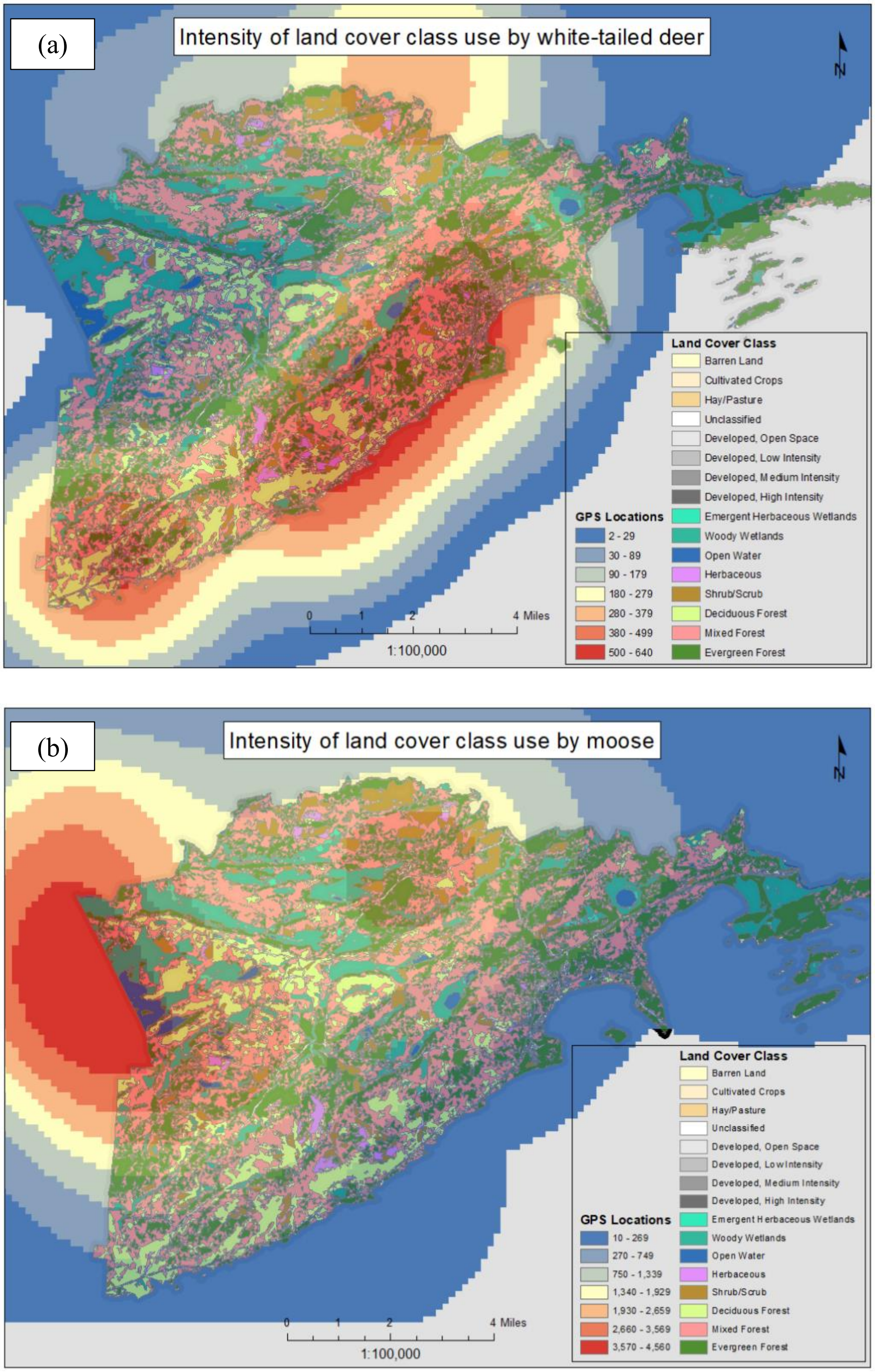


Figure 12. Map of land cover with (a) white-tailed deer and (b) moose GPS point densities.

UTILIZATION OF HARVESTED AND SILVICULRTURAL TREATMENTS

Figure 13 compares mean percent of total treatment utilization by treatment type for moose and deer, as calculated from mean areas (m2) presented in APPENDIX V UTILIZATION DISTRIBUTION (UD) MEAN AREA (M2) BY FORESTRY TREATMENT TYPE FOR MOOSE AND DEER. Deer utilized all forest treatments to some extent, showing the highest utilization in Prescribed Fire treatments. Deer showed a preference in the same order as moose for all other treatment types, but consistently utilized these treatments to a lesser extent than moose. Moose showed an overall preference for Timber Stand Improvement, as did deer with the exception of Prescribed Fire. Site Prep treatments were used infrequently by both species and Tree Planting was used minimally. Deer exhibited significantly stronger utilization of Prescribed Fire treatments than moose, which rarely used this treatment type (Table 8). Moose show significantly higher utilization of Timber Sale treatments.

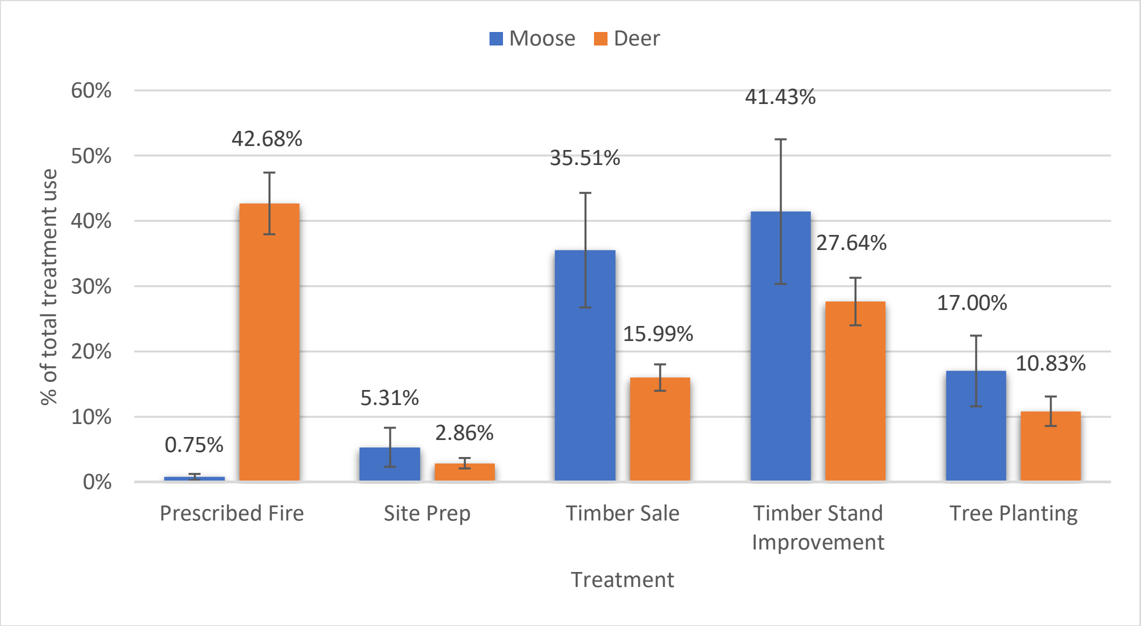


Figure 13. Forestry treatment utilization as mean percent of total treatment use by moose and deer with confidence intervals.

Table 8. Results of ANOVA for moose and white-tailed deer forestry treatment use (%).

	ANOVA					
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Prescribed Fire	Between Groups	2.064	1	2.064	21.616	<0.001*
	Within Groups	6.398	67	0.095		
	Total	8.462	68			
Site Prep	Between Groups	0.007	1	0.007	1.268	0.264
	Within Groups	0.371	67	0.006		
	Total	0.378	68			
Timber Sale	Between Groups	0.448	1	0.448	10.748	0.002*
	Within Groups	2.790	67	0.042		
	Total	3.237	68			
Timber Stand Improvement	Between Groups	0.223	1	0.223	2.347	0.130
	Within Groups	6.372	67	0.095		
	Total	6.595	68			
Tree Planting	Between Groups	0.045	1	0.045	1.446	0.233
	Within Groups	2.073	67	0.031		
	Total	2.118	68			

* Significant at the 0.05 level

Timber Stand Improvement was the only treatment type that was somewhat evenly distributed across moose and deer core areas (Figure 14). Timber Sale, Site Prep and Tree Planting treatments are better represented in areas with higher GPS location frequencies from moose, but deer also make good use this area. Prescribed Fire treatments are located in the southern portion of the Reservation where deer densities are highest and moose rarely travel.

When habitat analyses were rerun with prescribed fire removed (due to its potential to introduce bias), deer showed a higher preference for Timber Stand Improvement than moose (Figure 15). A second ANOVA showed that Timber Sale was no longer preferred significantly more by moose (Table *9*).

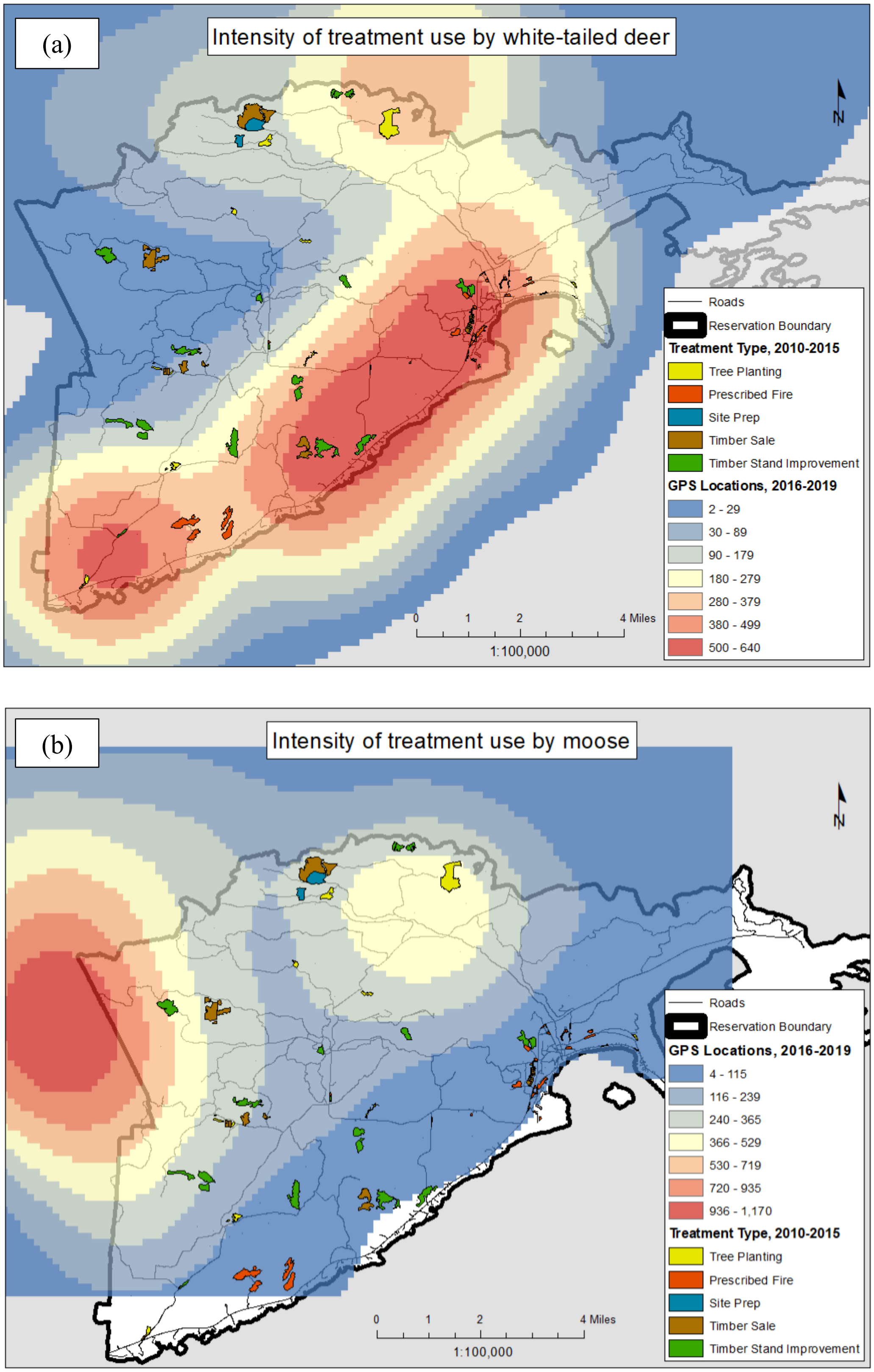


Figure 14. Map of forestry treatments with (a) white-tailed deer and (b) GPS point densities.

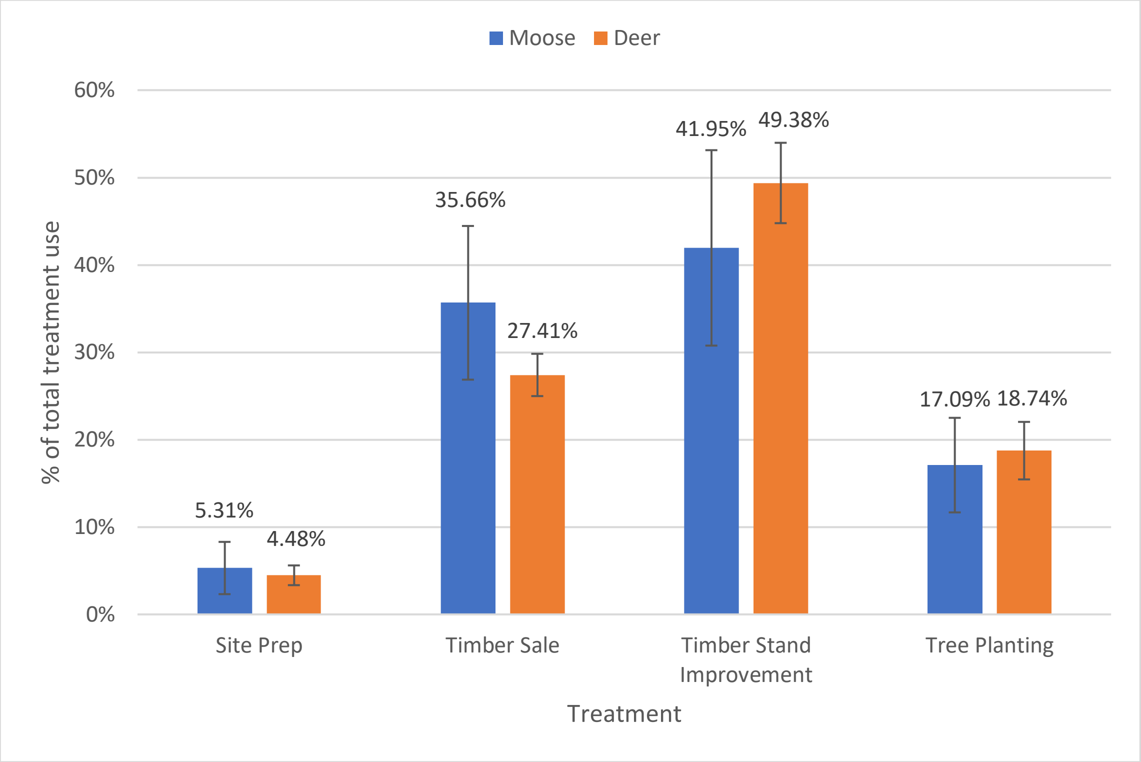


Figure 15. Forestry treatment utilization with Prescribed Fire removed as mean percent of total treatment use by moose and deer with confidence intervals.

Table 9. Revised ANOVA results for moose and white-tailed deer forestry treatment utilization after Prescribed Fire is removed; there is no significant difference between species.

ANOVA

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Timber Stand Improvement	Between Groups	0.062	1	0.062	0.531	0.469
	Within Groups	6.630	57	0.116		
	Total	6.691	58			
Timber Sale	Between Groups	0.076	1	0.076	1.590	0.213
	Within Groups	2.733	57	0.048		
	Total	2.809	58			

* Significant at the 0.05 level

DISCUSSION

DEER HOME AND SEASONAL RANGES ARE LARGER THAN THOSE OF MOOSE

The utilization distribution (UD) for moose estimated a larger total winter range than total home range, but across individuals, the mean home range was greater than the mean winter range. This could be because utilization intensity increases in habitats that provide quality browse during the winter, thus inflating UD calculations for total winter range based on higher location point densities from one or many moose using specific areas. Mean winter range across individuals is likely smaller than mean home range because moose stay close to thick evergreen and mixedwood forests for thermal cover and camouflage from predators (OMNR 2000).

For both moose and deer, mean winter range was greater than mean summer range. This may be explained by the fact that food resources are more abundant in summer (reducing the need to travel for forage) and mothers reduce their movement to avoid predation on fawns and calves (OMNR 2000). For deer however, total winter range is less than total summer range for deer as they are more limited in deep snow and share habitat requirements with moose in winter (Voight *et al.*1997).

The results of this study suggest white-tailed deer home and seasonal ranges are considerably greater in area than moose ranges and more variable across individuals. For example, deer mean winter range (117.9 km$_2$) is 2.48x larger than moose mean winter range (47.6 km$_2$); given that deer have more limited mobility in deep snow, this may be the result of milder winters in recent years (Broadfoot and Voigt 1996; Maskey 2008; Lankester 2010; Maskey *et al.* 2015; Lankester 2018). Deer are also better adapted to landscapes fragmented by anthropogenic disturbance which facilitate dispersal and range expansion (McShea *et al*. 1997).

DEER RANGE OVERLAPS SIGNIFICANTLY WITH MOOSE RANGE

Our second hypothesis predicted that deer range overlaps significantly with moose range during the summer months. Our findings suggest the spatial overlap of deer and moose in the Grand Portage Indian Reservation is significant year-round, and contrary to our prediction, covers a greater area in the winter months ($479.5 > 407.7$ km$_2$ in summer). However, the spatial overlap of deer encompasses a greater percentage of moose summer range ($63.0 > 61.0$ % of winter range). Based on these results, we conclude the distributional overlap of deer in moose range is significant, suggesting high potential for transmission of brainworm to moose, and the extent of overlap is similar throughout the year. However, more refined location point density-specific results may be achieved using a different method of kernel density estimation, such as adaptive kernel (AK) as suggested by Powell (2000), or an alternative bandwidth such as $h_{plug-in}$, recommended as the best option for resource selection studies by Walter *et al.* (2011). Therefore, it likely results would differ using alternative methodology.

COMPARISON OF DEER AND MOOSE HABITAT COMPOSITION

Our findings in the Grand Portage Indian Reservation suggest moose and deer utilize the same habitat types, but with some significant differences in preference or intensity of use. These results are in many ways consistent with known moose and deer habitat preferences as described by OMNR guidelines (2000).

Deer in Grand Portage utilize deciduous forest significantly more than moose (*p*=0.001 in winter; *p*=0.024 in summer) while both species browse in mixed forest to a similar extent. This finding is indicative of a preference for deciduous forest types that are characteristic of the natural range of deer within the Great Lakes-St. Lawrence forest region. Deer are also particular to areas with abundant mast approaching winter (Voigt *et al.* 1997).

In winter, deer were found to spend significantly more time in evergreen forest (*p*=0.012) than moose and a near equal amount of time as moose in summer. Both moose and deer are dependent on thick conifer cover for thermal cover, shelter from the elements, and predator avoidance in winter (OMNR 2000). Regardless, this finding is expected as deer yard up under dense conifers when snow depths reach 20-50 cm or greater as movement becomes difficult (Voight *et al.*1997). Conversely, moose are more mobile in snow and less dependent on conifer cover in lower latitudes (OMNR 2000).

Deer show a stronger preference for herbaceous habitat (*p*=0.005), but visited woody wetlands infrequently, while moose spent significantly more time in this cover type (*p*=0.001) which makes up 18.21% of moose summer habitat composition. These findings are expected, as deer are known to graze on grasses and forbs, while only moose require wetland habitat in spring and summer for aquatic vegetation and tend to seek out isolated and sheltered areas near open water when calving (OMNR 2000).

Our findings indicate there is no significant difference in the percentage of cover composition for any class between summer and winter moose habitat, including woody wetlands and emergent herbaceous wetlands. This would indicate moose are remaining in the same areas consistently throughout the year, although an alternative kernel density estimation bandwidth less prone to over-smoothing may produce different results as indicated by the *Kernel Density (Spatial Analyst)* rasters produced in ArcMap (Figure 12). In comparison, deer used evergreen forest significantly more in winter than in summer, and herbaceous and shrub/scrub habitats were used significantly more in summer as expected due to browse availability.

Overall, these findings support our first hypothesis that preferred white-tailed deer habitats are different from those of moose, but with the exception of those cover types that are limiting (e.g. evergreen forest) or that support browse communities preferred by both species (e.g. mixed forest and shrub/scrub).

FORESTRY TREATMENTS UTILIZATION

Our results indicate deer utilize all forest treatments to some extent, showing the highest utilization in Prescribed Fire treatments (42.68% of total treatment use by deer), with significantly stronger preference (p=0.001) than exhibited by moose which rarely use this treatment type. This finding is unexpected considering moose rely on natural disturbance for the provision of early successional browse (Rempel *et al.* 1997; Thompson and Stewart 1998) and prescribed burns are the recommended method of site prep for the provision of moose habitat (OMNR 1988). The result was likely influenced by Prescribed Fire treatment locations; all are close to the southeastern boundary of the Reservation where moose are less common and deer densities are highest, made evident by the kernel densities produced in ArcMap using the *Kernel Density (Spatial Analyst)* tool (Figure 14).

For all other treatment types, deer show preference in the same order as moose (i.e. Timber Stand Improvement > Timber Sale > Tree Planting > Site Prep) but consistently utilize these treatments to a lesser extent (Figure 13). Moose show significantly higher utilization of Timber Sale treatments (*p*=0.002) than deer; Timber Sale treatments with the greatest area (km$_2$) are located in moose range. Moose show an overall preference for Timber Stand Improvement (41.43%), as do deer (27.64%) with the exception of Prescribed Fire; this is the only treatment type that is somewhat evenly distributed across moose and deer core ranges. Site Prep treatments are used infrequently by both species and Tree Planting is used minimally; both treatment types are better represented in areas with higher GPS location frequencies from moose. Only mechanical methods of site preparation were used; chemical applications such as glyphosate were not represented in the 2010-2015 treatment dataset. Mechanical site preparation can promote browse from coppicing or root sucking but are not as effective are prescribed fire (OMNR 1988). Tree Planting treatments were established to maximize the growth of commercial species rather than those preferred by deer and moose. All plantations consisted of white spruce, white pine, and red pine, with the exception of one jack pine plantation; these tree species provide thermal cover, but browse is limited to infiltrating trembling aspens and white spruce where availability of preferred browse is low.

Based on these results, we can conclude that deer make use of Timber Stand Improvement, Timber Sale, Tree Planting, and Site Prep treatment types showing the same pattern of preference as moose. Although deer show a high preference for Prescribed Fire relative to moose, we suspect this is because these treatments are concentrated along the southeastern boundary of the Grand Portage Indian Reservation where moose densities are low and deer densities are high, causing bias in the data. If Prescribe Fire treatments are removed as a source of bias, analysis shows a higher preference for Timber Stand Improvement by deer and there is no longer a significant difference in preference for Timber Sale between moose and deer (Figure 15).

Our third hypothesis predicted forest management treatments aimed at benefitting moose, do not encourage deer use. Our results do not support this prediction, but the intensity of treatment use by deer decreases with increased distance from core deer areas. Our fourth hypothesis predicted that these same treatments made in deer range are utilized by deer and our results support this hypothesis for all treatment types.

Because our current deer dataset is limited to 3 years (2016-2019), we were not able to assess harvest and silviculture treatment use by deer in detail, nor compare post-treatment response to use in the pre-treatment state. Future studies on the Reservation may revisit this question once data has been collected from deer for several more years. The treatments were broadly categorized for our purposes, but it should be noted that each individual treatment area was specific in its application (e.g. size and location of treatment block, block management history, methods of implementation, cover before and after, tree species present or planted, etc.), an important consideration for further analyses. Furthermore, moose browse and successional vegetation data was collected from transects in many of these treatments in 2019. This data can be incorporated into future analyses to enhance our understanding of which browse species are naturally produced by succession in different treatments and how this influences preferential use by moose and deer.

POTENTIAL SOURCES OF ERROR

Differences in number of location signals received per day from moose relative to deer may have introduced bias during any of our analyses, as home and seasonal ranges were estimated by referencing point densities and then used for interspecific comparison of habitat composition and treatment use. Our moose dataset represents 9 years of GPS location signals received 16 to 48 times per day from 57 collars, while our dataset for deer was much smaller with only 3 years represented and 6 GPS signals received per day from 64 collars.

Differences in sample size are another potential source of error, especially for the determination of home and seasonal ranges of moose over 9 years relative to deer over 3 years. A solution for this would be to delineate annual ranges for each year of data and determine means, or alternatively to remove pre-2016 moose data so that both data sets match on a temporal scale as was done only for treatment use analyses in this study. It is also important to note that our analyses may have benefitted by reducing our datasets to a scale more appropriate in the context of site-specific habitat management. For example, an animal that spends the majority of its time outside reservation boundaries may not be representative of habitat use on the study site. Although animals with less than 100 location points were removed from seasonal datasets, more in-depth scrutinization of each animal’s ability to represent habitat and treatment use within the reserve may have improved our analyses of variance. There is also the potential for bias as a result of several aspects in the sampling procedure. For example, bias may have been introduced as a result of animal capture and collaring location distribution based on the relative ease of accessibility to backcountry capture sites.

In this study, KDE (Worton 1989) methodology was chosen over the MCP (Mohr 1947) method in an effort to refine ranges based on relative point densities. MCP delineates a range by connecting the outermost location points, assuming equal use across the polygon regardless of point density (Gregory 2017) rendering it inappropriate for analyses of habitat composition. Home and seasonal ranges of moose and deer were delineated in R from location point densities using the KDE package *adehabitatHR* along with the common smoothing parameter (SP) known as the reference bandwidth (h_{ref}). Our results suggest that both home and seasonal ranges of moose and deer cover areas much larger than, and almost encompassing the entirety of the Grand Portage Indian Reservation. These kernel density estimated ranges differ considerably from known core seasonal ranges within Grand Portage; they are grossly overestimated, highlighting a need for refinement in our selected methodology.

It is likely our results would have been different using an alternative SP or methodology better suited for the questions raised in this study. Borger *et al.* (2007) and Gregory (2017) both warned that overestimation of range size can occur in KDE analyses when the chosen bandwidth is inappropriate for the context and/or variables of the study. Furthermore, when comparing SP alternatives, Walter *et al.* (2011) found the bandwidth h_{ref} has a tendency to cause over-smoothing when applied to data acquired from mobile species (Walter *et al.* 2011). For this reason, it is possible our utilization distribution (UD) outputs overestimated home and seasonal ranges, causing a lack of precision and/or inaccuracies in our analyses of overlap and the relative importance of habitat types or treatment types.

Delineation of home and seasonal ranges may have been refined by using the plug-in bandwidth ($h_{plug\text{-}in}$) which references only areas of concentrated location points to produce a UD. Walter *et al.* (2011) recommended $h_{plug\text{-}in}$ specifically for defining resident or seasonal ranges based on habitat and resource selection in fragmented areas, patchy environments, or small geographic areas; our study site matches these criteria.

Alternatively, higher accuracy in analyses for differentiation in intensity of habitat and forestry treatment use may have been achieved by delineating additional site-specific ranges from subsamples of all points located within reservation boundaries.

Walter *et al.* (2011) warned against the subsampling approach for KDE when working with autocorrelated data, as important habitats or movement pathways can easily be overlooked. However, using multiple categorized MCPs that exclude outliers may have been an appropriate option for this study; Lesage *et al.* (2000) subsampled from deer location data to create convex polygons for annual and seasonal ranges of adult and juveniles and to analyze philopatry of individual ranges over 4 years. Furthermore, Boyle *et al.* (2009) recommended MCP methodology over KDE for a conservative sample size meant to represent a much larger population.

A compromise between KDE and MCP methodologies is suggested by Gregory (2017): Low Convex Hull (LoCoH) is a KDE method that uses MCP methodology to account for areas within a range that are void of location data. This approach would facilitate a more accurate determination of habitat composition within the reservation but is said to be most appropriate for large datasets (Gregory 2017). As our moose dataset represents many more years and a higher frequency of location signals than our deer dataset, LoCoH may be more appropriate in the future when a larger dataset for deer is available.

Finally, the kernel densities produced in ArcMap using the *Kernel Density (Spatial Analyst)* tool provided a clear, visual understanding of how deer and moose densities vary in distribution across the Reservation land base (Figures 12 and 14). By converting these raster outputs into vectorized polygons, it would be possible to analyze habitat composition and relative use of forestry treatments based on different levels of location point density defined by standard deviation, equal intervals, or natural breaks in the point frequencies between clusters. Furthermore, these vector polygons could be used to redefine moose and deer core ranges and identify areas of species overlap that are minor to severe in intensity. This approach is suggested for future analysis of moose and deer resource-based interactions on the Grand Portage Indian Reservation.

CONCLUSION

In this study, we addressed the impacts of spatial overlap of white-tailed deer in moose range and associated implications for wildlife and forest management in the Grand Portage Indian Reservation, a community where moose are highly prized as a subsistence species. The increase and expansion of deer populations taking place across North America is driven by climate change and facilitated by changes in land use and harvest practices (Thompson et al. 1998). As deer populations rise and invade moose range in and around the reservation, the risk of brainworm transmission is likely to increase (Pickles *et al.* 2013). Our objective was to evaluate home range and utilization of habitat and harvest/silvicultural treatments by deer relative to moose across the Grand Portage Indian Reservation land base, and identify primary areas implicated by distributional overlap to inform a strategic direction for future management.

The results of our analyses support the following hypotheses: 1) white-tailed deer habitats are different from those of moose, but with the exception of those cover types that are limiting (e.g. evergreen forest) or that support browse communities preferred by both cervid species (e.g. mixed forest and shrub/scrub); 2) deer range overlaps significantly with moose range during the summer months, but also in the winter months; and 4) forest management treatments made in deer range are utilized by deer. Our 3rd hypothesis is not supported by the results of this study; we found that forest management treatments aimed at benefitting moose are also used by deer. However, these findings were likely inaccurate due to overestimations of home and seasonal ranges caused by the smoothing parameter (h_{ref}) and therefore, did not provide the spatial resolution needed for accurate analyses.

Our findings are not presently sufficient to provide the insight necessary to determine how different prescriptive forest and habitat management actions can be utilized to limit overlap in habitat use of white-tailed deer and moose. Understanding the extent to which deer use habitat in moose range and how deer respond to timber harvest and silvicultural treatments relative to moose on the reservation will require further analyses with refinement in methodology. Future studies of moose and deer resource-based interactions on the Grand Portage Indian Reservation are vital for the development of best management practices for the creation of moose habitat. If occurrence of *P. tenuis* in moose can be reduced in the Grand Portage Indian Reservation and surrounding areas, increases in survival rates and populations are likely to follow.

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APPENDICES

APPENDIX I KERNEL DENSITY ESTIMATION R SCRIPT

```
library(adehabitatHR)
library(rgdal)
deer <- read.csv('deer.csv', sep=",", head=TRUE)
head(deer)
coordinates(deer) <- c("X", "Y")
class(deer)
plot(deer, col=deer$CollarID)
proj4string(deer) <- CRS("+init=epsg:4269")
summary(deer)
deerproj <- deer <- spTransform(deer, CRS("+init=epsg:26916"))
summary(deerproj)
kud <- kernelUD(deerproj[,1],h="href",grid=1000)
homerange <-getverticeshr(kud)
plot(homerange)
vud <- getvolumeUD(kud)
plot(vud)
homerange=getverticeshr(kud,95)
class(homerange)
plot(homerange)
writeOGR(homerange, layer='kud_95_deer', '.', driver="ESRI Shapefile")
```

APPENDIX II FORESTRY TREATMENT AND SILVICULTURE TYPE DEFINITIONS

Treatment Type	Basic Definition
Tree Planting	Hand planting of seedings
Timber Sale	Timber sold for revenue. Includes permits
Site Prep	Mechanized preparation of soil surface for planting
Timber Stand Improvement	Range of treatments used to improve growth, vigor, or quality of trees or habitat
Prescribed fire	Prescribed burning: broadcast and piles

Silviculture	Basic Definition
Clearcut	Removal of all trees of merchantable size (> 5")
Clearcut with Reserves	Occasional mature trees retained in clearcut
Clearcut by species	Clearcut of only selected species. Applies to wood permits with "invisible" species not included in permit
Seed Tree	Timber harvest leaving light cover of trees as seed source
Commercial Thinning	Partial tree removal which leaves many remaining trees free to grow. Often completed in planted areas
Shelterwood	Timber harvest leaving light to moderate (~10%) tree cover as seed source and shade for developing seedings.
Selection harvest	Thinning method that harvests based on tree specifications. Generally leaves well distributed overstory trees
Strip Shelterwood	Cutting in lanes, leaving undistured areas between lanes for seed source
Precommercial Thinning	Density reduction in young stands. Done by hand
Planting	Planting in open area
Underplant	Planting under established overstory

Silviculture	**Basic Definition**
Spot Planting	Could also be called fill planting. Used to fill small gaps in tree stocking
Residual felling	Hand felling of poor quality trees left after timber operations
Understory weeding	Removal of select species
Cleaning	Removal of select species which are overtopping desired stock
Crop tree pruning	Pruning branches of trees to improve quality of stemwood
Blister rust pruning	Pruning to correct for damage to leader in young trees and reduce low branches that could support blister rust
Pile burn	Ignition of hand or machine piles
Broadcast burn	Ignition of broad area
Crop tree release	Clear around desirable tree species in sapling or larger size
Seedling release	Clear around young desirable tree species. Generally done in fixed radius
Group Selection	Removal and/or retention of groups of trees
Single Tree Selection	Removal of individual trees based on specific qualities
Winter shear	Clearing of undesirable trees and vegetation with heavy equipment, generally bulldozer. Done in winter to minimize soil impact and improve efficiency
Weeding	Cutting no later than sapling stage: Removing undesirable species regardless of competitive position
Herbicide	Spraying of herbicide to reduce deciduous vegetation. Not used recently

APPENDIX III UTILIZATION DISTRIBUTION (UD) ESTIMATED RANGE AREAS (M$_2$) FOR MOOSE AND DEER

Moose Range Area (m^2) Utilization Distribution (UD) Estimates

Collar ID	Home Range (*n*=57)	Summer Range (*n*=51)	Winter Range (*n*=57)
101126	18281215.73	16067695.35	11537494.40
101210	61628903.36	55316287.93	39459175.71
101211	32008224.56	20833381.56	36992931.56
101212	19397963.89	20205744.93	8825522.67
12557	257725517.27		257725517.27
12617	60598902.71	5173898.65	61115600.47
12618	42685300.93	13449848.14	140891314.48
12619	27601488.85	24379599.74	27844931.93
12634	20499064.94	24118584.16	4593301.57
12661	58121727.73	39941136.88	58568787.88
12670	44781603.71	22129062.18	46991363.83
12673	19606107.37	12005796.94	20032640.36
12674	68337293.92	56331054.73	42890269.38
12675	64403208.84	34050633.94	74867707.65
12676	69463784.90	67803170.48	21414004.96
12678	46066821.64	35387003.09	45127852.16
12679	156795696.10	139422672.99	151791447.66
12680	31381414.46	22039595.50	29870232.23
12681	28069152.76	28373906.69	11190232.99
12682	36560100.40	26641265.66	26488737.60
12683	46217256.37	26986243.50	39546294.46
12684	22016891.16	16883181.12	25949132.09
12685	33063755.77	17795827.82	47364859.49
12690	19027022.98	16268769.13	5054099.20
12691	96323160.39	42764007.79	130791698.48
12692	32123943.05	22140252.47	34290588.73
14619	21184413.27	18097904.22	21569941.72
14620	4328.40		4328.40
14621	44118550.50	37739710.39	38414906.58
14623	15053319.23	13395153.75	16734168.52
14624	55176018.42	33817907.26	39451956.05
14625	32446916.94	29617851.21	25523846.92
14626	31912755.50	21386935.09	42342517.29
16734	30941116.81	18185180.88	42942347.35

16735	11792690.54	11099758.38	10521569.47
16736	29152758.39	25414954.36	26613545.30
16737	28951024.51	23123182.70	23774839.63
16738	32600457.43	28433266.05	25164167.84
16739	155530839.14	137729455.60	159276068.95
16740	57793978.94	31768106.45	67295443.97
20965	35207672.89	32310571.96	21401053.54
23187	30082753.28	31767533.20	19308664.46
29899	2230804.45		2230804.45
29901	48769556.89	31034751.38	21330216.55
29902	81273788.03	80950335.78	14695214.41
29906	22992580.96	13552609.20	27221537.18
36569	3023854.53		3023854.53
36571	4012583.59		4012583.59
47693	45062056.77	23017377.14	57662272.86
47694	342097354.44	315206269.51	343509055.97
47695	19886537.12	7885761.14	16789637.52
47704	20015995.27		20015995.27
47733	18382460.76	21572302.26	7355087.44
47766	50839464.99	33396527.85	35286322.75
47770	69132950.97	22503172.60	87071417.04
47771	54193406.70	12701616.91	71345614.72
99212	25499299.06	26322890.33	19638100.75

Deer Range Area (m^2) Utilization Distribution (UD) Estimates

Collar ID	Home Range (*n*=64)	Summer Range (*n*=47)	Winter Range (*n*=64)
20747	1129360.16	1093036.46	1144143.98
20748	3289751.69	3317611.12	1501221.62
20749	1055121.84	755645.53	1212853.64
20960	8997156.89	1141658.24	20435926.16
20961	221015406.55	32008266.05	288096679.92
20962	23542418.35	2439836.07	35692406.73
21088	19506675.88	4637408.41	67241655.53
21089	1210011.63	933217.78	1444686.27
21090	75460097.56	39879067.45	44980835.51
21091	12043391.54	2351578.70	21202102.28
21092	36075516.33	5152342.39	32590104.08
21093	53630108.98	6835414.91	50630309.12
21094	2170429.11	2174715.16	1971040.58
21095	9413472.20	1036646.17	176731467.50
21096	737774183.79	5211452.40	845174734.03
21097	26096788.20	3567121.84	67379492.71
21098	2694443774.48	2218985030.81	1929338738.90
21099	1214274791.96	69019930.76	783453630.31
21100	14758755.57	10929229.37	16240070.36
21101	2689467.83	2875225.60	2147735.33
24792	483563.38		483547.62
24793	157357220.27	136026861.95	140452558.10
24794	267293503.26	4316549.36	225213109.14
24795	45225319.17	42853213.74	1394728.68
24796	167901471.95	91211156.87	166750109.77
24797	177107672.82	161014485.48	76816071.16
24798	703906169.63	980233346.07	335904241.43
24799	289716694.87	429609911.62	22826140.73
24800	531900822.82	517939765.43	642611552.66
24801	174253735.15	6520000.92	180373225.04
24802	200185443.63	7591226.10	196879827.74
24803	370942030.69	91310614.18	246909967.19
24804	35026775.20	9927407.76	39057427.72
24805	139261353.84	12054547.31	70303253.27
24806	77907023.01	34473003.48	102364075.27
29105	1219403.84	818792.57	1220166.21
29106	47783317.97	4419771.45	12636855.26
29107	46741329.81	30150282.22	12970737.69
29108	11461116.70		11461116.33
29110	4293892.98	4453103.09	2281087.76

29111	94203651.68	23801508.91	34524124.77
29112	242207768.42	18165591.13	24430115.44
29113	118366437.02	24886160.98	65458825.27
29114	237601980.38	8312616.04	275518830.12
29115	14560448.20	35357196.68	3400029.66
29116	1345023.07	892742.80	1498669.86
29117	662999.23	643482.71	608836.68
29118	284908629.91	20680338.78	93474177.96
29119	89260343.06	4004932.53	129571628.08
35931	1419085.47		1419100.01
35932	630159.72		630150.52
35934	1066524.51		1066511.63
35948	2709734.78		2709733.40
35949	1656236.66		1656227.10
35950	4289903.28		4289914.96
35951	1586359.64		1586358.48
35952	5414099.02		5414151.49
35953	470487.91		470495.99
35954	549039.89		549052.40
35955	2274796.78		2274764.11
35956	2085447.39		2085426.28
35957	2542015.93		2542011.21
35958	14682140.12		14682125.31
35960	901831.73		901817.42

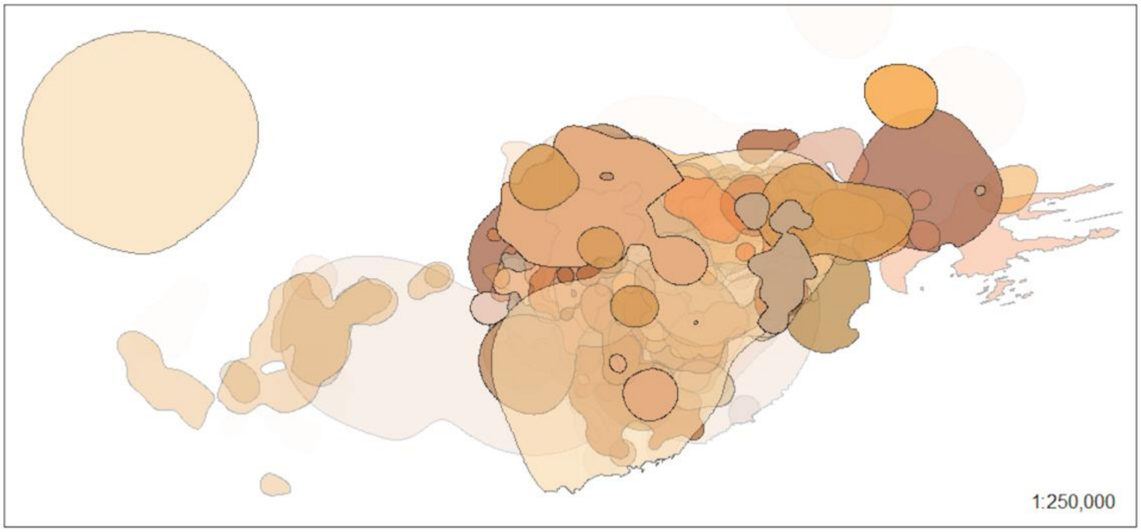


Figure 16. Kernel density estimation utilization distribution outputs for individual moose.

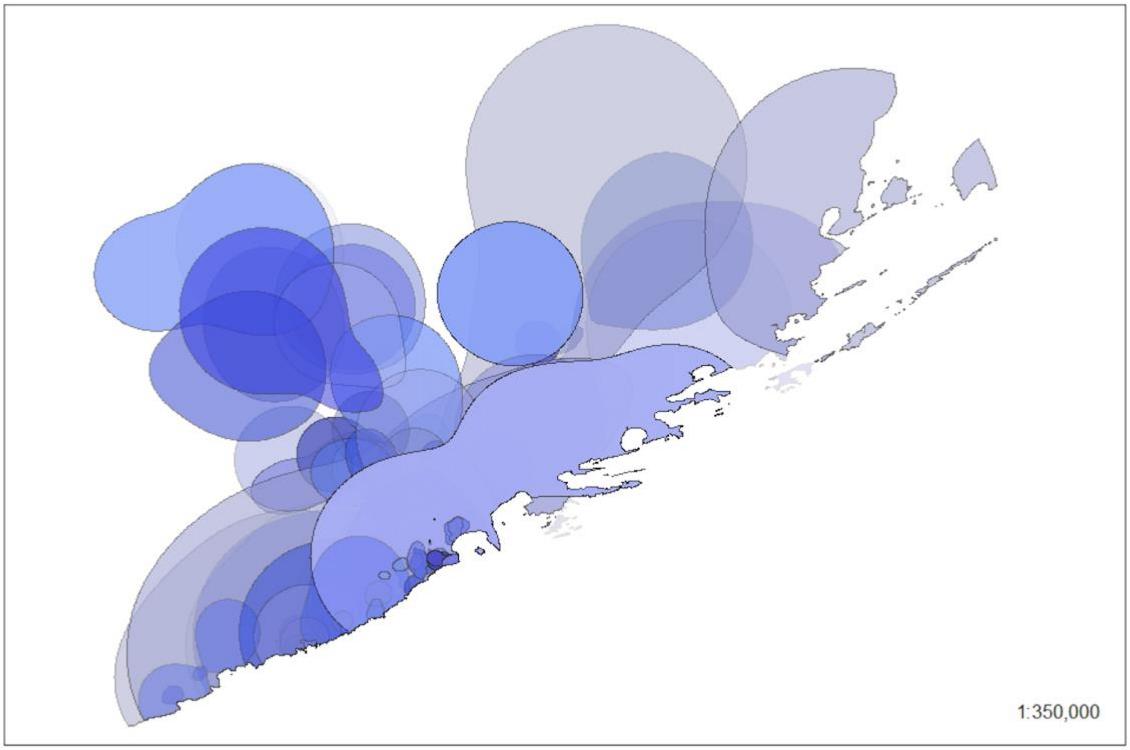


Figure 17. Kernel density estimation utilization distribution outputs for individual deer.

APPENDIX IV UTILIZATION DISTRIBUTION (UD) MEAN AREA (M$_2$) AND COMPOSITION (%) BY LAND COVER CLASS FOR MOOSE AND DEER SEASONAL RANGES

	Mean Area (m²) used seasonally			
	Moose		**White-tailed Deer**	
Land Cover Class	**Summer**	**Winter**	**Summer**	**Winter**
Barren Land	31728.01	45250.16	92574.44	145419.68
Cultivated Crops	900.14	900.14	900.14	900.14
Deciduous Forest	2111417.44	2422765.99	2982573.16	4489098.11
Developed, High Intensity	5949.03	4855.27	24500.94	45053.57
Developed, Low Intensity	42262.74	42737.84	145788.27	275154.73
Developed, Medium Intensity	15168.19	18872.39	54163.24	112655.20
Developed, Open Space	281764.61	321699.11	416728.87	739359.42
Emergent Herbaceous Wetlands	195107.26	238511.84	245486.63	400073.24
Evergreen Forest	4641141.96	5612713.81	6087846.01	11459083.99
Hay/Pasture	2832.37	2574.35	3255.89	4705.21
Herbaceous	186339.08	239083.77	349192.01	548130.41
Mixed Forest	6455011.80	7631981.37	8023008.51	13988598.62
Open Water	432333.81	523786.92	421787.61	621211.35
Shrub/Scrub	1337145.24	1817273.57	1268856.76	2155026.15
Unclassified	7647.59	6811.38	6291.03	9838.01
Woody Wetlands	2289430.73	2968180.86	1996119.86	3097814.52
Outside Reserve	24205737.78	33672459.48	132409664.76	124580888.56

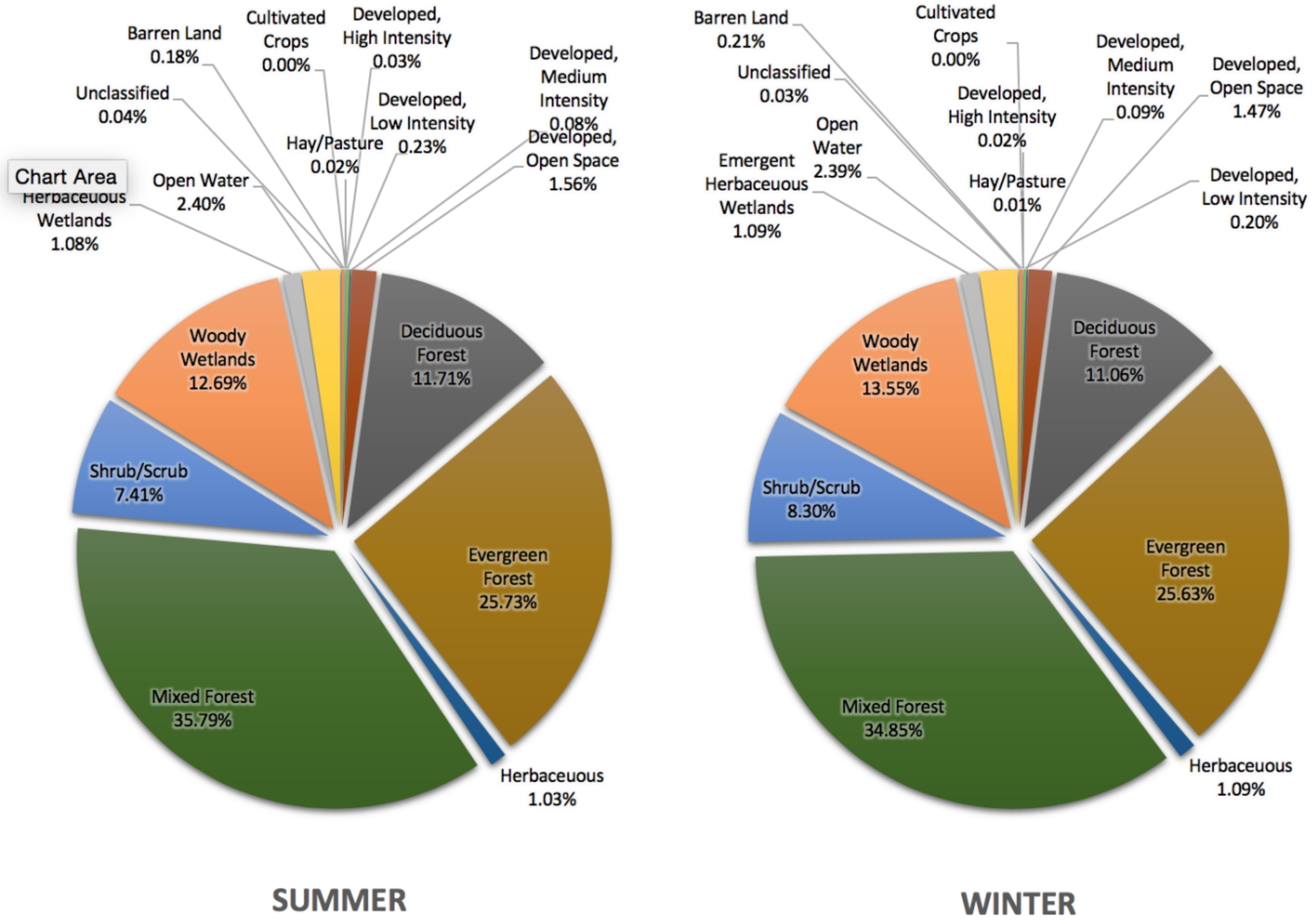
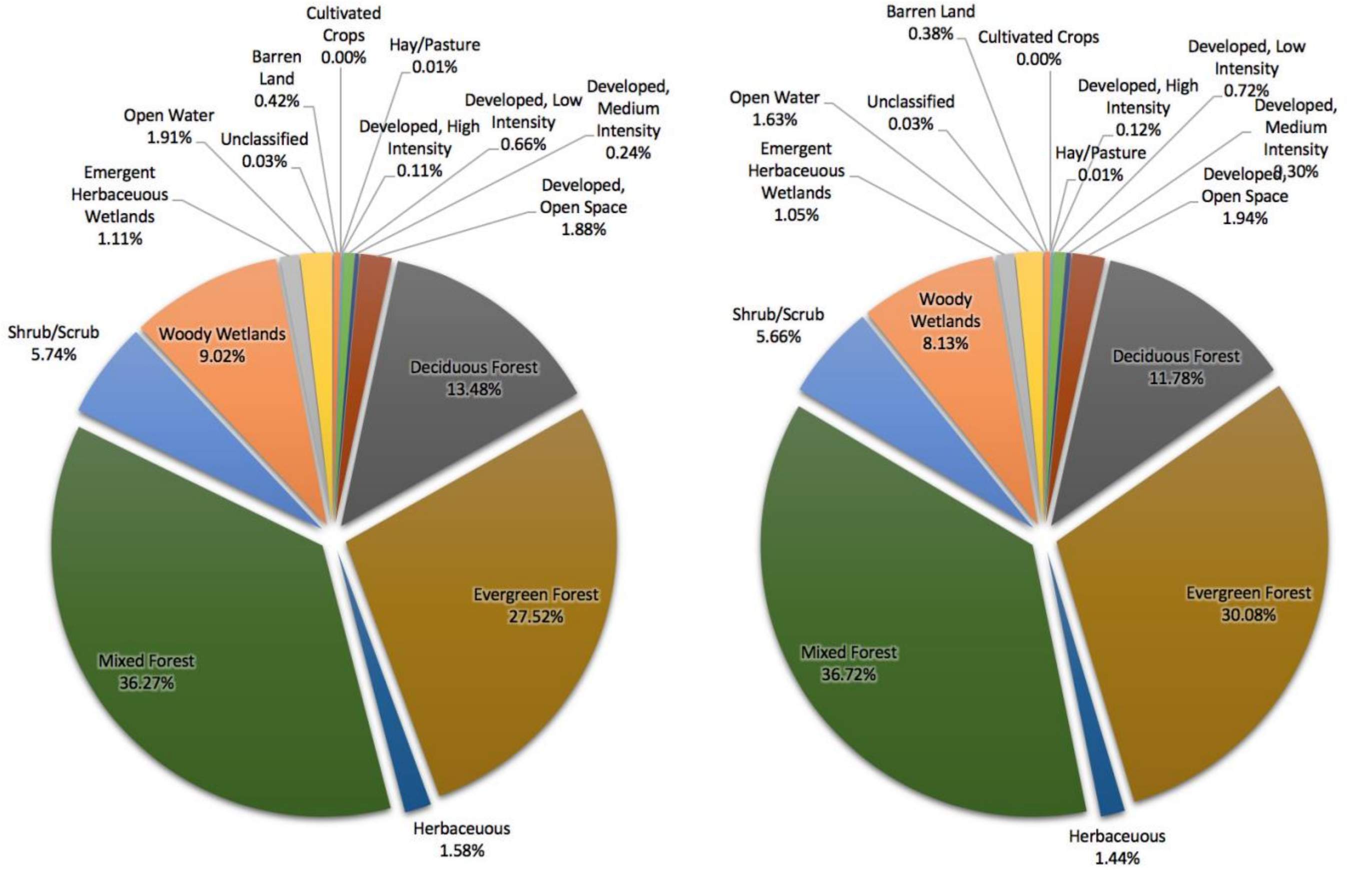


Figure 18. Comparison of land cover class composition (%) in moose seasonal ranges.



SUMMER **WINTER**

Figure 19. Comparison of land cover class composition (%) in deer seasonal ranges.

APPENDIX V UTILIZATION DISTRIBUTION (UD) MEAN AREA (M_2) BY FORESTRY TREATMENT TYPE FOR MOOSE AND DEER

	Mean Area (m^2) Used	
Treatment Type	Moose	Deer
Prescribed Fire	15865.76	459156.58
Site Prep	119283.33	145727.63
Timber Sale	268832.43	438558.95
Timber Stand Improvement	192277.66	591798.97
Tree Planting	162801.02	222578.33