HABITAT SELECTION BY SYMPATRIC UNGULATES IN AN AGRICULTURAL LANDSCAPE: IMPLICATIONS FOR DISEASE TRANSMISSION AND HUMAN-WILDLIFE CONFLICT

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ABSTRACT

As areas of agricultural production expand worldwide, complex zones of wildlife-agriculture interface present numerous benefits and challenges to farmers and wildlife managers. In western Canada, free-ranging elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*) make frequent use of cereal, oilseed, and pulse crops. However, cervid use of annual crops presents substantial socio-economic concerns for producers. Additionally, use of crops may facilitate cervids co-mingling and increase the risk of intra- and inter-specific transmission of chronic wasting disease (CWD).

The purpose of my thesis research was to determine the key environmental factors influencing the selection of agricultural crops by elk, white-tailed deer, and mule deer, analyze overlap in species' selection, and develop predictive models to identify the spatial distribution of crop damage risk. In this study, I analyzed 19,069 damage claims paid by Saskatchewan Crop Insurance Corporation to Saskatchewan farmers for confirmed losses to annual crops (cereals, oilseeds, pulses) from 2000-2012 by elk, mule deer, and white-tailed deer. These data were used to conduct species-specific ecological niche factor analyses (ENFAs), which relate habitat variables within damaged sites to that of the surrounding landscape. The key habitat variables influencing selection of annual crops were then incorporated into resource selection probability function (RSPF) models. These models characterize and predict the probability of crop damage by elk, mule deer, and white-tailed deer, and each possible dual species combination. By integrating damage probability values and historical monetary values of regional crop production, I evaluated the risk of annual crop damage by each of the three species, and dual species combinations, across all sections of agricultural land in Saskatchewan.

The ENFAs revealed that elk and white-tailed deer selected for areas where a high proportion of farmland is seeded to oats, barley, canola, and alfalfa, while avoiding areas farther from protected areas, with a high density of paved or unpaved roads and a high proportion of open grassland. Alternately, mule deer favoured open grasslands, shrublands, and areas with a greater density of streams or water bodies, while avoiding areas where a high proportion of farmland is seeded to oats, canola, flaxseed, wheat, and barley. Areas at highest risk for annual crop damage by elk bordered the northern edge of the study area; mule deer damage risk was highest in south-western and central Saskatchewan; while white-tailed deer damage risk was highest in north-eastern and north-central areas of the province.

Identifying these specific associations between landscape variables, rates of crop damage, and associated species overlap may provide an important opportunity for agencies to develop cooperative management strategies to efficiently allocate mitigation resources. Efforts to prevent the selection of cereal, oilseed, and pulse crops by free ranging elk, mule deer, and white-tailed deer in Saskatchewan could prove to be a valuable step in not only minimizing crop damage and maintaining wildlife tolerance in rural communities, but also in managing the spread of chronic wasting disease throughout western Canada.

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Dedication

This thesis is lovingly dedicated to my parents
Torben and Diane Sorensen
For teaching me the value of determination, hard work, and kindness.

It's nice to be important, but more important to be nice.

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ABBREVIATIONS

AIC	Akaike’s Information Criterion
AUC	Area under the curve
CWD	Chronic wasting disease
EGV	Eco-geographical variable
ENFA	Ecological niche factor analysis
PCA	Principle component analysis
ROC	Receiver operator characteristic
RSPF	Resource selection probability function
SCIC	Saskatchewan Crop Insurance Corporation
TSE	Transmissible spongiform encephalopathies
UTM	Universal transverse mercator
WAC	Wildlife acceptance capacity

CHAPTER 1: GENERAL INTRODUCTION

1.1 Thesis Structure

This document was prepared in the format of a manuscript-style thesis. The first chapter presents a general introduction to the theme of my research and the second chapter provides a review of the relevant literature. The two data chapters (Chapters 3 and 4) are developed as independent scholarly manuscripts written in preparation for publication in a peer-reviewed journal. My final chapter (5) summarizes and integrates the key results of my research and provides recommendations for applying these findings to disease management and damage control strategies.

1.2 Background

Worldwide, croplands and pastures in combination have become one of the largest terrestrial biomes, occupying 40% of the planet's land surface (Ramankutty and Foley 1999, Asner et al. 2004). In response to unprecedented human population growth, approximately 12 million km^2 of the earth's forests and woodlands have been cleared, native grasslands have diminished by an estimated 5.6 million km^2, and crop land areas have increased by 12 million km^2 over the last three centuries (Richards 1990). Within the past forty years alone, areas of crop production have increased by 12% (Matson et al. 1997, Foley et al. 2005). As a result of these dramatic modifications in global land use, biodiversity declines have continued through the loss, modification, and fragmentation of natural habitats (Myers et al. 2000, Pimm and Raven 2000). However, many wildlife species have adapted to these drastic landscape shifts, and are able to exist in fragmented agricultural landscapes, often benefiting from altered predator distributions, fire suppression, or increased forage availability (McCabe and McCabe 1984, Wrobel and Redford 2009, Brook and McLachlan 2009). Therefore, human-wildlife conflicts have increased throughout the world as the complex zones of wildlife-agriculture interface have expanded (Thirgood et al. 2005). Management of such conflicts is crucial for conservation, ensuring sustainability of agricultural production, and facilitating the coexistence of people and wildlife (Woodroffe et al. 2005).

In North America, no large-scale permanent cultivation of cropland occurred prior to 1750 (Ramankutty and Foley 1999). Across the Great Plains, approximately 162 million ha of tall grass, mixed grass, and short grass prairie ecosystems supported a vast array of complex ecological communities (Knopf 1992, Samson and Knopf 1994). However, as the transcontinental railroad transported European settlers across western Canada in the 1880s, prairies and parklands were systematically converted to agricultural lands (Samson and Knopf 1994). As a result, by the 1990s, only 20% of Saskatchewan's native prairie remained, primarily in the southwestern portion of the province (Hammermeister et al. 2001).Though altered in distribution and density, cervid populations (species in the deer family) persisted in this modified environment, and today, elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*) rely on agricultural regions in Saskatchewan for productive functional habitat. Common crops seeded annually in Saskatchewan such as cereals, oilseed, and pulse crops provide an important source of energy and nutrients for grazing cervids (Nixon et al. 1991, Burcham et al. 1999). As such, forage resources in privately owned cropland are often consumed by free-ranging elk, mule deer, and white-tailed deer (Irby et al. 1996, Fagerstone and Clay 1997, Brook 2009).

Although agricultural crops may provide a valuable source of nutritious forage to wildlife, local producers must balance the economic decisions of production with their conservation ethic (Brook 2009). Many farmers benefit from the presence of elk and deer, through the enjoyment of observing wildlife on their land or by income gains from hunting and tourism opportunities (Conover et al. 1995, Yoder 2002). However, the costs and benefits from wildlife are rarely distributed equitably over space and time, and while many enjoy the benefits, some producers are consistently burdened by the cost of crop damage done by these ungulates (Lacey et al. 1993, Wywialowski 1994). The impacts of crop damage on producer's economic security have been shown to greatly influence their tolerance of local wildlife populations (Decker and Purdy 1988). Therefore, in western Canada, programs have been implemented in each province to compensate ranchers and farmers for damage caused by wildlife. However, reactive compensation programs, while an effective short term strategy to mitigate the economic impacts on producers, generally fail to proactively address the root of damage problems in the long term, and indeed may serve to reduce or eliminate incentives to mitigate crop damage (Nyhus et al. 2005, Bulte and Rondeau 2005).

Baiting and artificial feeding of cervids has been shown to facilitate or enhance disease outbreaks such as bovine tuberculosis (Miller et al. 2003, O'Brien et al. 2006). While the objectives of artificial feeding and baiting of wildlife often differ, the impacts of these practices on cervids are often quite similar. Artificial feeding is broadly defined as the placement of natural or non-natural feed into the environment, and is conducted for numerous different reasons within a wide range of spatial scales. These include private citizens occasionally distributing grain to deer on their property, large scale provincial or state-funded programs, such as the feeding of several thousand elk each winter in the National Elk Refuge, Wyoming, U.S.A., or the unintentional provision of forage through standing, stored or baled agricultural crops (Smith 2001). Baiting of wildlife also involves the placement of natural or artificial feed in the environment to attract and/or retain wild animals to an area; however, some important differences in the primary objectives of baiting and artificial feeding exist. Baiting is typically used for the purposes of aiding hunters and trappers in attracting, selecting, and successfully killing animals (Litvaitis and Kane 1994, Obbard et al. 2008), or capturing wildlife for research purposes (Barrett et al. 2008). Despite any differences in the underlying objectives of these practices, the presence of an additional food source has been shown to significantly alter resource selection patterns (van Beest et al. 2010), modify the spatial distribution of animals (Georgii 1980, Boutin 1990, Tarr and Pekins 2002, Sahlsten et al. 2010), and exacerbate disease transmission (Spraker et al. 1997, Schmitt et al. 1997, Cross et al. 2007).

Free-ranging elk and deer are frequently attracted to agricultural products, such as standing crops or hay bales, and these feeds can concentrate cervids at unnaturally high densities, facilitating unique behaviours not normally occurring under natural conditions, creating opportunities for potential disease transmission (Thorne and Herriges 1992, Fischer et al. 1997). As animal density increases in sites such as dense forage patches, bait sites or artificial feeding stations, intra- and inter-specific contact rates and duration among individuals increases (Baker and Thompson Hobbs 1985). Contact can be direct through physical interactions (nose-to-nose, grooming, or sneezing in close proximity), or indirect when two animals exchange saliva, mucous, blood, urine or faeces through shared feeds. If an individual is infectious, organisms or prions may be transmitted to uninfected individuals by contact among animals congregating at a food source (Miller et al. 2004).

In North America, chronic wasting disease (CWD) is an important current issue in the management of cervids, with the potential for long-term population reductions as well as significant socio-economic impacts (Bollinger et al. 2004, Williams 2005, Sigurdson 2008). Chronic wasting disease is a fatal neurodegenerative disease belonging to the group of transmissible spongiform encephalopathies (TSE; Williams 2005), and is currently known to infect free-ranging and domestic elk, mule deer, white-tailed deer, and moose (*Alces alces*). The causative agent of CWD is a prion (Browning et al. 2004), released from diseased individuals and entering the environment through the excretion of gut-associated lymphatic tissue, saliva, urinary excretions, and the decomposition of infected carcasses (Brown 1998, Seeger et al. 2005, Haley et al. 2011). Field-based monitoring has demonstrated that CWD prions may be sequestered near the soil surface, and remain infectious for upwards of two years (Miller et al. 2004), perpetuating the likelihood of inter- and intra-specific transmission, especially in certain soil types (Spraker et al. 1997, Johnson et al. 2006, Schramm et al. 2006). Within Canada, CWD has been detected in domestic mule deer, white-tailed deer, and elk farms, as well as wild mule deer and white-tailed deer in both Saskatchewan and Alberta. Since 2008, four wild elk in Saskatchewan have also tested positive for the disease (Saskatchewan Ministry of the Environment 2008), as well as a recent confirmation of CWD infection in a road-killed moose in south-western Alberta (Alberta Environment and Sustainable Resource Development 2013).

Contamination of communal feeding areas frequently used by multiple ungulate species, coupled with conditions that facilitate concentrations of animals in high densities and with increased contact rates, have been shown to increase the rate of CWD transmission (Miller et al. 2000, 2006, Sorensen et al. 2013). In the agricultural landscapes of Saskatchewan, farm crops are frequently used by mule deer, white-tailed deer and elk, facilitating species co-mingling and contacting at feed sites, potentially increasing the risk of intra- and inter-specific CWD transmission. Therefore, an in-depth examination of crop selection by these ungulates is crucial not only to quantify spatial trends in wildlife-agricultural conflict, but also to address the challenges presented in managing the spread of this emerging disease.

1.3 Thesis objectives

The purpose of my study was to determine the key environmental factors influencing the selection of agricultural crops by elk, white-tailed deer, and mule deer, analyze overlap in species' selection, and develop predictive models to identify the spatial distribution of crop damage risk. The aim of my research is to benefit producers by identifying factors contributing to regional susceptibility of annual crop damage by cervids. Additionally, given a more comprehensive understanding of interspecific cervid interactions in an agricultural landscape, conservation efforts and disease management strategies may be better directed at areas of highest overlap and crop use. As such, the objectives of my two data chapters are as follows:

Chapter 3: Selection of agricultural crops by elk, mule deer, and white-tailed deer in Saskatchewan: Implications for agricultural production and disease transmission

i. determine if and how temporal variation in crop availability in Saskatchewan influences selection of that crop type by elk, mule deer, and white-tailed deer

ii. quantify the strength of selection for specific annual crops types by cervid species

iii. identify the key habitat variables that determine selection of annual crops by each of my study species

iv. identify the habitat variables that influence overlap in species' selection of annual crops.

Chapter 4: Spatial modelling of crop damage risk by elk, mule deer, and white-tailed deer in Saskatchewan

i. predict the spatial distribution of crop damage risk by elk, mule deer, and white-tailed deer in Saskatchewan.

ii. identify areas of highest probability of cervid species spatial overlap as a function of crop damage in annual cropland

1.4 Hypothesis

Broadly, I predicted that elk, mule deer, and white-tailed deer would each show non-random selection for or against individual eco-geographical variables in the agriculture-dominated landscape of Saskatchewan, in relation to the availability of the variables in the area. My research approach is based on the concept of multiple competing hypotheses, developed by the 19th century geologist T. C. Chamberlin (1890). Founded on the principle that there exists the possibility of more than one hypothesis being simultaneously true, this approach is commonly used in disciplines such as psychology, statistics, and wildlife biology (Elliott and Brook 2007). Unlike techniques of null-hypothesis testing, this approach is well suited to ecological modelling research lacking a true control and treatment design (Johnson and Omland 2004, Dochtermann and Jenkins 2011). By allowing numerous potential explanations to be explored by simultaneously evaluating a set of competing hypotheses, this approach circumvents the natural tendency of investigator attachment to a single hypothesis, thus reducing bias (Elliott and Brook 2007).

Operating under on this principle, I developed a set of ecogeographical variables thought to influence the selection of crops by cervids based on a review of the literature. These variables were then used in ecological niche factor analyses and the subsequent development of *a priori* models to predict crop selection by elk, mule deer, and white-tailed deer.

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CHAPTER 2: LITERATURE REVIEW

2.1 Ecology of prairie ungulates: distribution and diet

Croplands and pastures, in combination, have become one of the world's largest terrestrial biomes, occupying 40% of the planet's land surface (Ramankutty and Foley 1999, Asner et al. 2004). In addition to developments in "Green Revolution" technologies such as high-yielding cultivars, chemical fertilizers and pesticides, a 12% increase in global cropland area has resulted in world grain harvests doubling in the past forty years (Matson et al. 1997, Foley et al. 2005). As a result of these dramatic modifications in global land use, biodiversity declines have continued through the loss, modification, and fragmentation of natural habitats (Myers et al. 2000, Pimm and Raven 2000). Additionally, human-wildlife conflicts have increased throughout the world as the overall size and complexity of the wildlife-agriculture interface have expanded (Thirgood et al. 2005). Management of such conflicts is crucial for conservation, minimizing socio-economic impacts of wildlife on agricultural production, and facilitating the coexistence of people and wildlife (Woodroffe et al. 2005).

In North America, prior to the agricultural settlers, approximately 162 million ha of native prairie ecosystems dominated the Great Plains, supporting a vast array of complex ecological communities (Knopf 1992, Samson and Knopf 1994). However, as the transcontinental railroad expanded across western Canada in the 1880s, prairies and parklands were systematically converted to agricultural lands by arriving settlers (Samson and Knopf 1994). As a result, by the 1990s, only 20% of Saskatchewan's native prairie remained, primarily in the southwestern portion of the province (Hammermeister et al. 2001). In areas especially well-suited for crop production, <0.1% of the original native prairie communities remain, and any remaining native landscapes are highly fragmented (Riemer et al. 1997, Laliberte and Ripple 2004).

As a result of this rapid and widespread landscape conversion, in combination with unregulated hunting pressure, the distribution of North American ungulates changed dramatically by the beginning of the 20th century (Laliberte and Ripple 2004). White-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), and elk (*Cervus canadensis*) had experienced severe population declines, and many herds were extirpated from large portions of their former range (McCabe and McCabe 1984, Gill 1988, Russell et al. 2001, Brook 2009). With the implementation of strict hunting regulations in the 1930s and 1940s, the establishment of parks and protected areas, and extensive predator control programs, many ungulate populations began to gradually recover their range (Connolly 1981, McCabe and McCabe 1984). White-tailed deer began to increase in abundance, with populations returning to their pre-exploitation era levels, and their range gradually expanded north and westward, following the opening of forested regions for cropland (Behrend et al. 1970, McCabe and McCabe 1984, Côté et al. 2004). Subpopulations of elk in Saskatchewan and Manitoba stabilised in small portions of their former range near protected areas, though in reduced abundance (Hegel et al. 2009, Brook 2010). Fire suppression and the succession of native grassland to shrublands benefited mule deer populations in the mid-1900s, but overall trends indicate mule deer populations have declined in the past decades due to native habitat loss for cropland conversion (Carpenter 1998, Kie and Czech 2000). Today, the range distributions of mule deer remains stable, elk remain substantially reduced but stable in some small areas, while white-tailed deer continue to expand (Fig. 2.1) Currently, all three species have designated annual hunting seasons Saskatchewan, indicating that based on ongoing research and population estimates, provincial wildlife managers determined the populations to be stable and suitable to support fixed levels of hunting pressures in select areas (Saskatchewan Ministry of Environment 2013).

In the long evolutionary history (25-30 million years) of the deer family, Cervidae, great differentiation has occurred in the size, behaviour, performance, and feeding behaviour of each species. While all species across the evolutionary lineages of the Cervidae are true ruminants, being anaerobic fore-stomach fermenters with a four-compartment stomach, a wide variety of specialized feeding and digestive strategies have arisen (Van Soest 1982). According to Hofmann's morphological classification of cervids by feeding type (Hofmann 1983), both mule deer and white-tailed deer can be described as concentrate selectors. These species are defined by their poor capacity to digest fibre and their high metabolic rate, which must be satisfied by a set of highly selective feeding behaviours (Hofmann 1985)

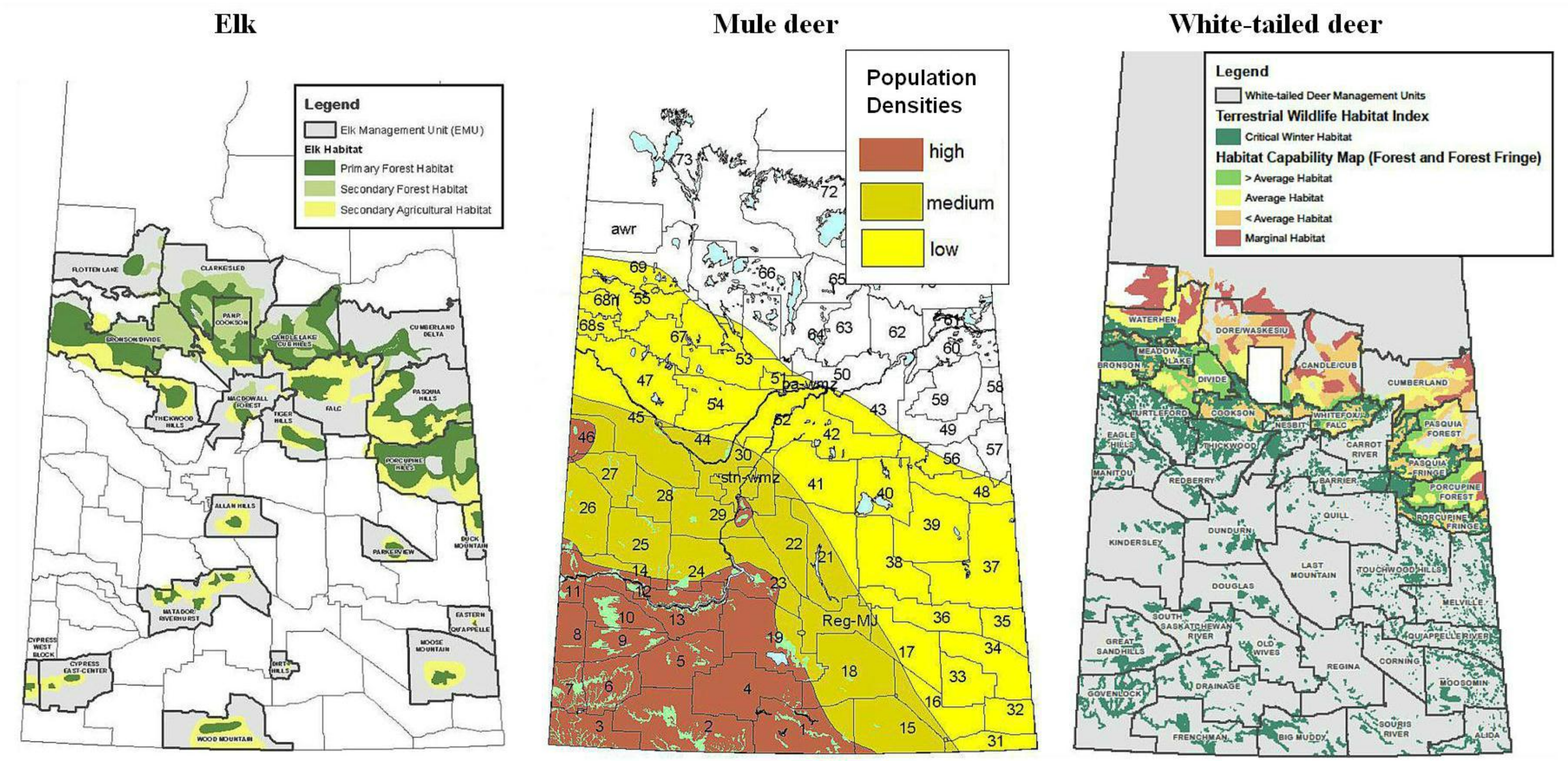

Figure 2.1. Ranges of elk, mule deer, and white-tailed deer within Saskatchewan, Canada, based on Saskatchewan Ministry of Environment’s spotlight surveys, line transect aerial surveys, hunter harvest data, and citizen-science-based Co-operative Deer Management Surveys (Arsenault 1998, 2005, 2008, 2009, and Schmidt and Arsenault 2004. Reproduced with permission from Saskatchewan Ministry of Environment).

In western Canada, *Odocoileus* species are primarily forb specialists, targeting herbaceous material rich in digestible inner cell components, with only a small portion of easily degradable cell wall portions (Murden and Risenhoover 1996, Desmarais et al. 2000). A large proportion of any fibre that is consumed is passed through undigested, thus avoiding energy-expensive digestive processes. During winter and early spring, or under drought conditions, there is a lack of easily digestible food, and required energy is derived from poorer quality forage and fat reserve mobilization (Hofmann 1985, Desmarais et al. 2000). According to Hofmann's classification (Hofmann 1983), mule deer are farther to the right of the spectrum, closer to intermediate feeders than the strictly concentrate selector white-tailed deer, with a higher tolerance for fibrous components in their diet. As intermediate feeders, elk are dietary opportunists. Their larger muzzle allows for larger bite size and greater intake rates but often at the cost of decreased selectivity (Cook 2001).The typical diet of elk shows great variability and seasonality, with preference for grasses, forbs, and shrubs in spring and early summer; forbs and shrubs in late summer/early fall; and sedges and shrubs, in the winter depending on availability and snow, with considerable variation among regions (Kufeld 1973, Toweill et al. 1982, Christianson and Creel 2007).

In Saskatchewan, elk, mule deer, and white-tailed deer also make frequent use of the rich forage resources within privately owned cropland and grazing pastures (Irby et al. 1996, Fagerstone and Clay 1997, Brook 2009). Agricultural products, such as standing or baled crops, may provide a relatively novel forage resource to co-existing cervid species. Common crops in Saskatchewan such as cereals (wheat, oats, barley), oilseeds (flax, canola), and pulse crops (peas, lentils, chickpeas) provide an important source of energy and nutrients for ungulates (Nixon et al. 1991, Burcham et al. 1999). The introduction of a novel food source may alter previously established patterns of resource partitioning, and shift niche overlap (Schoener 1974, Stewart et al. 2002) resulting in an increase in interspecific cervid interactions. This could have important implications for wildlife populations, specifically in the context of disease transmission. Additionally, the increasing reliance of cervids on agricultural land for forage presents a series of complex challenges to local agricultural producers, and these wildlife-agriculture interactions frequently result in human-wildlife conflicts.

2.2 Wildlife -agriculture interactions

Human-wildlife conflicts are a significant obstacle for regional wildlife conservation efforts within agricultural communities worldwide (Dublin and Hoare 2004, Wang et al. 2006). Wildlife populations can be considered a resource offering numerous positive societal benefits (Conover 1997). For instance, many people appreciate the aesthetic and intrinsic values of wildlife, opportunities to harvest food or other wildlife products, and income gains from hunting and tourism opportunities (Yoder 2002). However, while wildlife populations can increase the wellbeing of individuals and communities, they can also pose several challenges with negative impacts on local residents. The concept of wildlife acceptance capacity (WAC) reflects the maximum wildlife population level in an area that is tolerated by the local community (Decker and Purdy 1988). Several factors influence WAC, so this measure varies for individuals in a community and is rarely a fixed number over time due to changing patterns of benefits and impacts. These factors include the perceived role of wildlife species in disease transmission, and the intrinsic or aesthetic values humans place on a species. Factors with great influence on WAC are those concerning people's economic security, such as their tolerance thresholds for various forms of wildlife damage (Decker and Purdy 1988, Brook 2009).

Human perceptions and principles regarding wildlife vary widely across different sectors of any society. For instance, the attitudes of rural residents towards wildlife have been found to differ from urban populations, as they typically view wildlife in a utilitarian perspective and tend to be more concerned about the economic effects of wildlife (Kellert 1980). Additionally, differences in WAC have been observed amongst rural inhabitants (Messmer 2000). Agricultural producers growing high-value crops that are vulnerable to damage are less tolerant of wildlife, and thus have a lower WAC, than other farmers (Decker and Brown 1982). Conversely, many farmers not only tolerate, but benefit from the presence of wildlife, through the enjoyment of observing species on their land, consumption of harvested wildlife, or by income gains from hunting and tourism opportunities (Conover et al. 1995, Yoder 2002). Generally, the costs and benefits from wildlife are rarely distributed equitably over space and time, and some individual producers are burdened by the cost of crop damage done by wildlife while society as a whole reaps the benefits (Lacey et al. 1993, Wywialowski 1994).

In Canada, wildlife conservation efforts have largely focused on native habitats within protected areas, such as parks or privately negotiated conservation easements. The surrounding private lands are generally considered working landscapes altered into a matrix of cropland, grazing lands, and patches of native vegetation that are sometimes referred to as ‘non-habitat’ for wildlife (Herkert 1994). However, common crops in Saskatchewan such as cereals, oilseeds, and pulse crops provide an important source of energy and nutrients for ungulates (Nixon et al. 1991, Brook 2008). Additionally, the effects of fire suppression, additional water development for livestock, and greatly reduced predator distribution may in fact improve survival of some ungulate populations (Holechek et al. 1998, Kie and Czech 2000, Ballard et al. 2001). Although agricultural crops may provide a valuable source of nutritious forage to wildlife residing in an ecologically complex system further altered by agriculture, local producers must balance the economic decisions of production with their conservation ethic (Brook 2009). Therefore, in western Canada, programs have been implemented to compensate ranchers and farmers for damage caused by wildlife, based on the concept that wildlife are a public resource and thus damage by wildlife is a public responsibility.

Saskatchewan Crop Insurance Corporation (SCIC), funded through a cost-shared federal and provincial government program, operates a wildlife damage program that provides compensation payments in order to replace financial losses incurred by agricultural producers who experience damage to their agricultural crops through consumption, trampling, or excretion of faeces and urine on crops by 14 wildlife species, including white-tailed deer, elk, and mule deer (Saskatchewan Crop Insurance Corporation 2013). Over 30 crop types are eligible for compensation, with payments based on the amount of lost or spoiled production appraised within the reported damage area, multiplied by a crop price determined by annual average price surveys conducted by the provincial insurance agency. There is no maximum payment amount and no premiums or administrative fees are required of producers in order to receive coverage under the SCIC wildlife damage program. Under SCIC protocols, producers will only be compensated for losses verified by appraisers through standardized guidelines. Since the reporting and appraisal procedure is conducted at no cost to the producer, the potential for financial compensation likely encourages the majority of producers to report all potential cases of damage, however claim payments will only be made to producers if there is a minimum of $150 appraised damage. Since

2010, compensation payouts have increased from 80% of the crops' market value to its current rate of 100% of the crop value.

According to an SCIC adjustor (Dan Baber, Saskatchewan Crop Insurance Corporation, personal communication, 2013), identification of the cervid species responsible for damage is typically reported to the adjustor by the producer who incurred the loss. Previous studies have shown agricultural producers to be accurate observers and chroniclers of cervid activity on their property (Brook and McLachlan 2006, 2009, Brook 2008). Studies comparing farmer observations with empirical scientific data have shown that farmers can consistently and accurately recall relevant details over long time periods, especially when the event is of high personal importance (Brook and McLachlan 2008, 2009). Evaluating reported crop damage claims have proven to be a useful tool in identifying patterns of wildlife use of cropland and characterizing diet patterns (Naughton-Treves 1998, Sitati et al. 2005, Gooding and Brook 2011). Through the examination of thousands of damage reports, spatial and temporal commonalities can be established, and when compared to the characteristics of the available damage-free landscape, it is possible to generate estimates of the relative strength of selection of resources by wildlife. Such findings offer potential insight to producers aiming to manage their risk of crop damage, as well as providing wildlife managers with a greater understanding of species' behaviour and distribution. This information has especially important relevance for addressing complex issues related to disease transmission within cervid communities and at the cervid-livestock interface where crops can play an important role in facilitating disease risk.

2.3 Disease Ecology

Spatio-temporal patterns of diseases are strongly influenced by the hosts' life history traits, spatial distribution, and population dynamics, as well as their surrounding biotic and abiotic community (Fig. 2.2; Wobeser 2005, Whiteman et al. 2006, Sorensen et al. 2013). The field of disease ecology focuses on population interactions and looks to identify the underlying principles influencing disease emergence and transmission (Ostfeld et al. 2008).

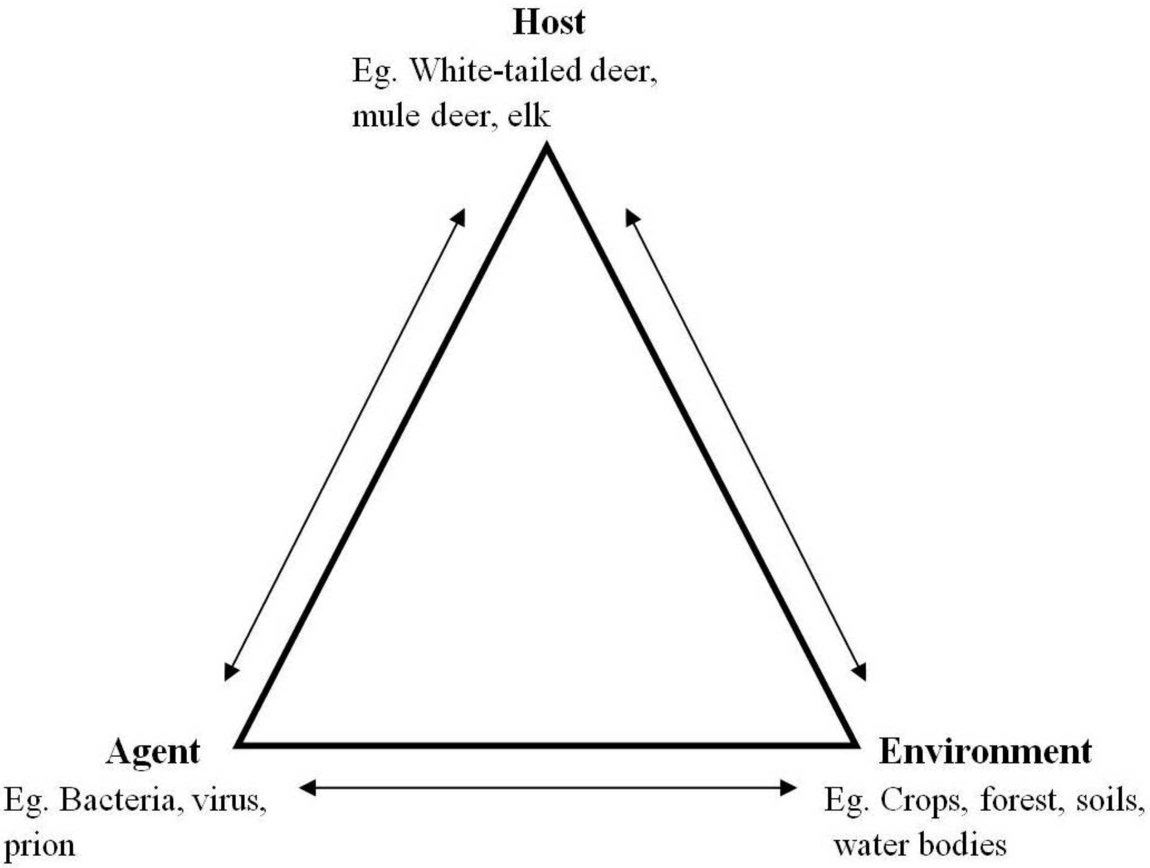

Figure 2.2. Disease ecology is represented in Wobeser's epidemiological triangle (Wobeser 2005), illustrating the relationships between disease agents, host species, and the environment they occupy.

Baiting and feeding of cervids, either for intentional hunting purposes or inadvertently through feeding at standing crops has been shown to facilitate or enhance disease outbreaks such as bovine tuberculosis (Miller et al. 2003, O'Brien et al. 2006). Artificial feeding is broadly defined as the placement of natural or non-natural feed into the environment, and is conducted to achieve different aims within different spatial scales. These include landowners providing deer on their property with additional grain or pelleted feed, the state-funded feeding of several thousand elk each winter in the National Elk Refuge, Wyoming, U.S.A. (Smith 2001), or the inadvertent provision of forage for cervids through standing, stored, or baled agricultural crops. Baiting of wildlife also involves the placement of natural or artificial food resources in the environment; however, baiting is typically used to attract and/or retain wild animals to an area for the purposes of aiding hunters in successfully harvesting animals (Litvaitis and Kane 1994, Obbard et al. 2008), or capturing wildlife for research purposes (Barrett et al. 2008). Despite any differences in the underlying objectives of these practices, the presence of an additional food source, such as standing agricultural crops, has been shown to significantly alter resource selection patterns (van Beest et al. 2010), modify the spatial distribution of animals (Georgii 1980, Boutin 1990, Tarr and Pekins 2002, Sahlsten et al. 2010), and exacerbate disease transmission (Spraker et al. 1997, Schmitt et al. 1997, Cross et al. 2007).

Free-ranging elk and deer are frequently attracted to agricultural products, such as standing crops or hay bales, in higher densities, exhibiting unique behaviours not normally occurring under natural conditions, creating opportunities for potential disease transmission (Thorne and Herriges 1992, Fischer et al. 1997). As animal density increases, in sites such as particularly rich forage patches, bait sites or artificial feeding stations, contact rate and duration among individuals increases (Baker and Thompson Hobbs 1985, Donohue et al. 2013). Contact between animals can be direct through physical interactions such as nose-to-nose touch, grooming, or sneezing in close proximity, or indirect through the exchange of saliva, mucous, blood, urine or faeces in shared feeds. If an individual is infectious, organisms or prions may be transmitted to uninfected individuals by contact among animals congregating at a food source (Hadwen 1942, Schmitt et al. 1997, Miller et al. 2004). Depending on the nature of the disease and the agricultural product, increased contact rates and animal aggregation can facilitate disease transmission within and between species (Smith 2001).

In North America, chronic wasting disease (CWD) is an important current issue in the management of cervids, with the potential for long-term population reductions as well as significant socio-economic impacts (Bollinger et al. 2004, Williams 2005, Sigurdson 2008). CWD is a fatal neurodegenerative disease belonging to the group of transmissible spongiform encephalopathies (TSE; Williams 2005), and is currently known to infect free-ranging and domestic elk, mule deer, white-tailed deer, and moose (*Alces alces*). The causative agent of CWD is a prion, denoted as PrP^{CWD}, which contains mis-folded, protease-resistant versions of normally benign cellular proteins (Browning et al. 2004). PrP^{CWD} enters the environment through the excretion of gut-associated lymphatic tissue, saliva, urinary excretions, and the decomposition of infected carcasses (Brown 1998, Seeger et al. 2005, Haley et al. 2011). Field-based monitoring has demonstrated that once released, CWD prions may be sequestered near the soil surface, and remain infectious for upwards of two years (Miller et al. 2004), perpetuating the likelihood of inter- and intra-specific transmission (Spraker et al. 1997, Johnson et al. 2006, Schramm et al. 2006).

Research from CWD epidemics in captive deer and elk demonstrate strong evidence of lateral transmission, either through direct contact between non-infected and infected individuals or contaminated environments (Miller et al. 2006, Mathiason et al. 2009). According to current evidence, the propagation of prion infection results from PrP^{CWD} imposing their abnormal conformation onto regular cellular protein molecules (Aguzzi and Calella 2009). The disease progressively affects cervids as PrP^{CWD} accumulates in the central nervous and lymphatic systems of infected individuals, resulting in spongiform lesions in the brain and microcaviation of the grey matter (Spraker et al. 1997, Edmunds 2008). The clinical signs reported in captive deer with advanced CWD include gradual weight loss despite normal or increased consumption of feed, a rough hair coat, and an atypical body posture with a drooping head and a wide leg stance (Mathiason et al. 2009). Animals may also exhibit excessive thirst, head tossing, repetitive lifting of the legs, slower reaction times, and occasionally aggressive behavior (Mathiason et al. 2009). CWD is always fatal and there is no existing cure or functional vaccine (Bollinger et al. 2004, Saunders et al. 2012).

Initially detected in Colorado and Wyoming, first in captive cervids in the 1960s and subsequently in free-ranging cervids in 1981, CWD has now been detected in wild and domestic cervids in 18 states in the USA, two Canadian provinces, and South Korea (due to elk imported from Canada; Mathiason et al. 2009, Tapscott 2011). Within Canada, CWD has been detected in wild and farm-raised mule deer and white-tailed deer in both Saskatchewan and Alberta (Mathiason et al. 2009, Tapscott 2011). Since 2008, four elk in Saskatchewan have also tested positive for the disease (Saskatchewan Ministry of the Environment 2008), as well as a recent confirmation of CWD infection in a road-killed moose in south-western Alberta (Alberta

Environment and Sustainable Resource Development 2013). Testing in other provinces found no cases of CWD.

Contamination of communal feeding areas frequently used by multiple ungulate species, coupled with conditions that facilitate concentrations of animals in high densities, have been shown to increase the rate of CWD transmission (Miller et al. 2000, 2006, Sorensen et al. 2013). In the agricultural landscapes of Saskatchewan, farm crops may be selected for by mule deer, white-tailed deer and elk, facilitating species co-mingling and contact at feed sites, potentially increasing the risk of intra- and inter-specific CWD transmission. Therefore, an in-depth examination of crop selection by these ungulates is crucial not only to quantify spatial trends in wildlife-agricultural conflict but also to address the challenges presented in managing the spread of this emerging disease. Studying the ecology and interactions of cervid species susceptible to CWD will broaden our understanding beyond conventional epidemiology and studies of prevalence, and will be a key step in developing management options. As part of this consideration, disease ecology aims to link understanding of the disease with habitat selection by potential disease hosts to understand species overlap and disease transmission risk.

2.4 Predicting cervid habitat selection and niche overlap

2.4.1 Ecological-niche factor analysis

The concept of habitat is one of the few unifying theories in contemporary ecology, with indisputable importance in wildlife conservation (Block and Brennan 1993). The term habitat describes the conditions and resources present in an area that facilitate occupancy by a given organism, including survival and reproduction (Hall et al. 1997). Therefore, this concept is specific as it relates the presence of a species, population or individual to the local environmental characteristics (Dettki et al. 2003).An important limitation in traditional studies of habitat selection is the deficiency of absence data (Hirzel et al. 2002). Ecological-niche factor analysis (ENFA) is designed to circumvent the difficulty of “false absences”. By using only confirmed presence locations as input, ENFA allows for multivariate analysis of eco-geographical variables within the species distribution in relation to that of the surrounding landscape (Austin 2007). Originally designed for the construction of habitat suitability maps, ENFA has also been used to predict the potential habitat of numerous animal taxa including insects (Gallego et al. 2004), birds (Hirzel et al. 2004, Lande et al. 2010), and mammals (Dettki et al. 2003, Zimmermann 2004, Enari and Suzuki 2010, van Toor et al. 2011).

Constructed after Hutchinson's (1957) concept of the ecological niche, ENFA is an analytical approach that identifies a subset of cells in the ecogeographical space where the focal species has a reasonable probability to occur. Species are expected to be non-randomly distributed across a landscape with regard to ecogeographical variables (EGVs). For instance, a species with an optimum temperature is expected to preferentially occupy sites occurring within its optimal temperature range (Hirzel et al. 2002). The degree of this selection can be quantified by comparing the temperature distribution in locations where the species was observed with that of the whole area available to that species.

Through ENFA, two separate measurement factors are assessed. Marginality is expressed as the difference between the "global" mean of an EGV within the scale of interest, and the "species" mean (mean EVG value within the sites used by the focal species). Therefore, higher marginality values indicate that a species' niche deviates farther from the average conditions of the available habitat(Calenge et al. 2005, Basille et al. 2008). Secondly, specialization can be evaluated by examining the ratio of the standard deviation of the global distribution to the distribution of the focal species (Hirzel et al. 2002). Hypothetically, a randomly selected set of cells is expected to have a specialization of one, and any value exceeding one would indicate some degree of specialization. Specialization values can, therefore, be interpreted as a measure of how restricted a species niche is in relation to the whole available study area (Hirzel et al. 2002, Reutter et al. 2003). Additionally, values of species' habitat tolerance are calculated as the inverse of specialization (Valle et al. 2011). Larger tolerance values indicate a greater ability for a species to adjust to fluctuations in habitat features, and thus, a wider niche (Valle et al. 2011).

ENFA can be widely defined as a descriptive analysis process which searches for directions in the ecological space so that (i) the difference between the available conditions within the study area and the conditions of the used location (i.e. marginality) is maximised, and (ii) the ratio between the variance of available conditions and the variance of used conditions (specialization) is maximised (Basille et al. 2008). In this manner, ENFA is able to address two fundamental questions in ecological research: where can a species establish, and what environmental factors is a species searching for (Basille et al. 2008). The resulting multivariate niche of the focal species can be defined on any of its axes by an index of marginality and specialization. Outputs thus have intuitive ecological meaning, and allow direct comparisons with the niche of different species within the same geographic area and temporal period.

2.4.2 Resource selection probability functions

Similar to ecological niche factor analyses, predictive geographical models are a valuable tool in understanding how environmental factors influence species' resource selection and distribution. By quantifying species- environment relationships (Guisan and Zimmermann 2000), species distribution can thus be predicted at various spatial scales (Boyce 2006). A resource selection probability function (RSPF) is a commonly used predictive model based on logistic regression that determines the probability of an individual animal selecting a resource based on comparing used and unused sample units (Boyce and McDonald 1999, Manly et al. 2002). Presumably, animals will disproportionately select resources relative to the availability of that resource based on the resource's influence on the animal's fitness (Thomas and Taylor 2006). If each resource in a finite population is characterized as x, then the RSPF is a function, $w(x)$, which weights the distribution of available resources, $fa(x)$, to the distribution of used resources, $fu(x)$ (Manly et al. 2002, Thomas and Taylor 2006). Once calculated, RSPF values can then be extrapolated across a broader study region, with output displayed visually in the form of maps depicting gradients in the probability of resource selection by a species (on a scale from zero to one).

In Saskatchewan's agricultural landscape, quantifying crop selection by elk, mule deer, and white-tailed deer, would provide valuable insight into the spatial trends in wildlife-agricultural conflict and offer predictive capabilities aimed at minimizing losses to producers. Additionally, with farm crops selected by mule deer, white-tailed deer and elk, there is potential for species overlap, potentially increasing the risk of intra- and inter-specific CWD transmission. Therefore, an in-depth examination of crop selection by these ungulates is critical in developing interdisciplinary management options

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CHAPTER 3: SELECTION OF AGRICULTURAL CROPS BY ELK, MULE DEER, AND WHITE-TAILED DEER IN SASKATCHEWAN: IMPLICATIONS FOR AGRICULUTRAL PRODUCTION AND DISEASE TRANSMISSION

3.1 Abstract

In the agriculture-dominated landscapes of western Canada, seeded farm crops offer a fundamental source of energy and nutrients for free-ranging elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*). However, cervid use of crops presents substantial socio-economic concerns, as producers face declines in crop production, harvest yields and post-harvest acceptability due to crop damage. Additionally, use of crops may facilitate cervids co-mingling and increase the risk of intra- and inter-specific transmission of chronic wasting disease (CWD). As CWD is a considerable threat to North American cervid populations, an in-depth examination of crop selection by these ungulates may help to inform efforts to mitigate the spread of this disease. In this study, I analyzed 19,069 damage claims paid by Saskatchewan Crop Insurance Corporation to Saskatchewan farmers for confirmed losses to annual crops (cereals, oilseeds, pulses) from 2000-2012 by elk, mule deer, and white-tailed deer. Using these claims, I conducted species-specific ecological-niche factor analyses (ENFAs) to relate eco-geographical variables, including crop types and habitat variables, within the species distribution to that of the surrounding landscape. K-select analysis provided further insight into variables that influence overlap in species' selection of annual crops. Using these techniques, I characterized species-specific habitat selection patterns and characterize optimal annual cropland foraging sites for each species. Elk, mule deer, and white-tailed deer all showed either significant selection for or significant avoidance of each cereal, oilseed, and pulse crop type. Elk and white-tailed deer selected for areas where a high proportion of farmland was seeded to oats, barley, canola, and alfalfa, while avoiding areas farther from protected areas, with a high density of paved or unpaved roads and a high proportion of open grassland. Alternately, mule deer favoured pea fields, open grasslands, shrublands, and areas with a greater density of streams or water bodies, while avoiding areas where a high proportion

of farmland is seeded to oats, canola, flaxseed, wheat, and barley. Identifying these specific associations between landscape variables and rates of crop damage and associated species overlap may provide an opportunity for agencies to develop cooperative management strategies to focus mitigation efforts at targeted high risk sites of wildlife damage to crops in order to minimize disease transmission.

3.2 Introduction

In North America, wildlife conservation efforts often focus on establishing and maintaining large tracts of native habitat, frequently within parks or protected areas, while the surrounding private lands are considered working landscapes altered into a matrix of cropland, grazing lands, industrial development and patches of native vegetation (Gehlbach 1975, Bender and Fahrig 2005). In many cases, these altered landscapes are even referred to as ‘non-habitat’. However, in western Canada, agricultural regions provide extensive and often highly productive functional habitat for free-ranging elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*). The term habitat is species-specific, and describes the resources and conditions occurring in an area that facilitate that species’ occupancy, including survival and reproduction (Hall et al. 1997, Dettki et al. 2003). One important habitat feature for elk, mule deer, and white-tailed deer in western Canada is the rich forage resources within privately owned cropland (Irby et al. 1996, Fagerstone and Clay 1997, Brook 2009). Common crops in western Canada such as cereals, oilseeds, and pulse crops provide an important source of energy and nutrients for free-ranging ungulates (Nixon et al. 1991, Brook 2008). These crops are especially important as supplements before, during, and following harsh prairie winters with extreme cold temperatures, strong winds, deep snow, and low quality native forage that is difficult to access.

Although agricultural crops provide a valuable source of nutritious forage to wildlife, local producers must balance their conservation ethic with the economic decisions of production (Brook 2009). Many farmers benefit from the presence of elk and deer, through the enjoyment of observing wildlife on their land, their use of wildlife for food, or by income gains from hunting and tourism opportunities (Conover et al. 1995, Yoder 2002). However, the costs and benefits from wildlife are rarely distributed equitably over space and time, and individual farmers are burdened by the cost of crop damage done by these ungulates while all of society benefits from the benefits of sustainable wildlife populations (Lacey et al. 1993, Wywialowski 1994). Therefore, in much of North America, insurance programs have been implemented to compensate farmers for damage caused by wildlife (Wagner et al. 1997).

In addition to the influence of crop damage on local producers' wildlife acceptance capacity (Decker and Purdy 1988), use of agricultural crops by ungulates has important implications for disease transmission. Spatio-temporal patterns of diseases are strongly influenced by the life history traits of each host, spatial distribution, and population dynamics, as well as their surrounding biotic and abiotic community (Wobeser 2005, Whiteman et al. 2006, Sorensen et al. 2013). Free-ranging cervids are frequently attracted to agricultural products, such as standing crops or hay bales, in higher densities not normally occurring under natural conditions (Thorne and Herriges 1992, Fischer et al. 1997). Large concentrations of wildlife activity centered around feeding sites have been widely implicated as a mechanism that can increase the risk of inter- and intra-specific transmission of infectious diseases (Miller et al. 2003, Cross et al. 2007, Brook 2010a). In areas of dense forage, bait sites or artificial feeding stations, contact rate often increase substantially as animal density increases (Baker and Thompson Hobbs 1985, Donohue et al. 2013). If an individual animal is infectious, organisms or prions may be transmitted to uninfected individuals by increased contact rates at a food source (Miller et al. 1998). Depending on the nature of the disease and the agricultural product, this can facilitate disease transmission within or between species (Schmitt et al. 1997, Smith 2001).

In North America, chronic wasting disease (CWD) is an important current issue in the management of elk, mule deer, and white-tailed deer, with the potential for long-term population reductions as well as significant socio-economic impacts (Bollinger et al. 2004, Williams 2005, Sigurdson 2008). Chronic wasting disease is both contagious and self-sustaining (Miller et al. 1998, 2000) and evidence suggests that infectious prions may be transmitted to uninfected individuals by the exchange of saliva, mucous, blood, urine or faeces in shared feeds (Sigurdson et al. 2001). In addition to direct lateral transmission, it has been suggested that individuals can be infected indirectly from contaminated environments, as CWD prions may be sequestered near the soil surface, and remain infectious for upwards of two years (Miller et al. 1998, 2004). Since deposition of feces and bodily fluids increases with concentration of ungulate activity, the contamination of communal feeding areas frequently used by overlapping ungulate species, coupled with conditions that facilitate high animal densities, have been shown to increase the rate of CWD transmission (Miller et al. 2000).

Given the important implications of the use of agricultural crops by ungulates to both wildlife conservation and agricultural production, I examined the spatial and temporal patterns of crop selection by elk, mule deer, and white-tailed deer in all Saskatchewan cropland based on damage claims paid by Saskatchewan Crop Insurance Corporation to farmers for losses to annual crops (cereals, oilseeds, pulses) from 2000-2012. My objectives were to *a)* determine if and how temporal variation in crop availability in Saskatchewan influences selection of that crop type by elk, mule deer, and white-tailed deer, *b)* quantify the strength of selection for specific annual crops types by cervids, *c)* identify the key environmental variables that determine selection of annual crops by each of my study species, and *d)* identify the habitat variables that influence overlap in species' selection of annual crops.

3.3 Study area

The study area consists of all annual cropland within Saskatchewan; that is cropland re-seeded annually to cereals, oilseeds, or pulse crops (Fig. 3.1). The area contains vast expanses of highly productive annual cropland. In total, 20.6 million hectares are seeded to crops or are summer fallowed annually (Statistics Canada 2011). Within this study area, the majority of cropland is seeded to four major crop types: wheat (spring, durum, and winter, 31%), oilseeds (canola and flax, 28%), pulse crops (field peas, chick peas, and lentils, 9%), and barley (6%; Statistics Canada 2011).

The area occurs within the Prairie Ecozone and southern transition into the Boreal Plain Ecozone (Wiken 1986). The dry mixed grass and mixed grass prairie regions of southern Saskatchewan are part of a semi-circular extension of North America's Great Plains, stretching from the western edge of Alberta to the eastern edge of Manitoba, and south to northern Texas (Coupland 1961, Wiken 1986). Along the northern edge, grasslands and agricultural lands transition into the aspen parkland and boreal transition, dominated by broadleaf trees such as trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), interspersed with jack pine (*Pinus banksiana*), white spruce (*Picea glauca*), and black spruce (*Picea mariana*;

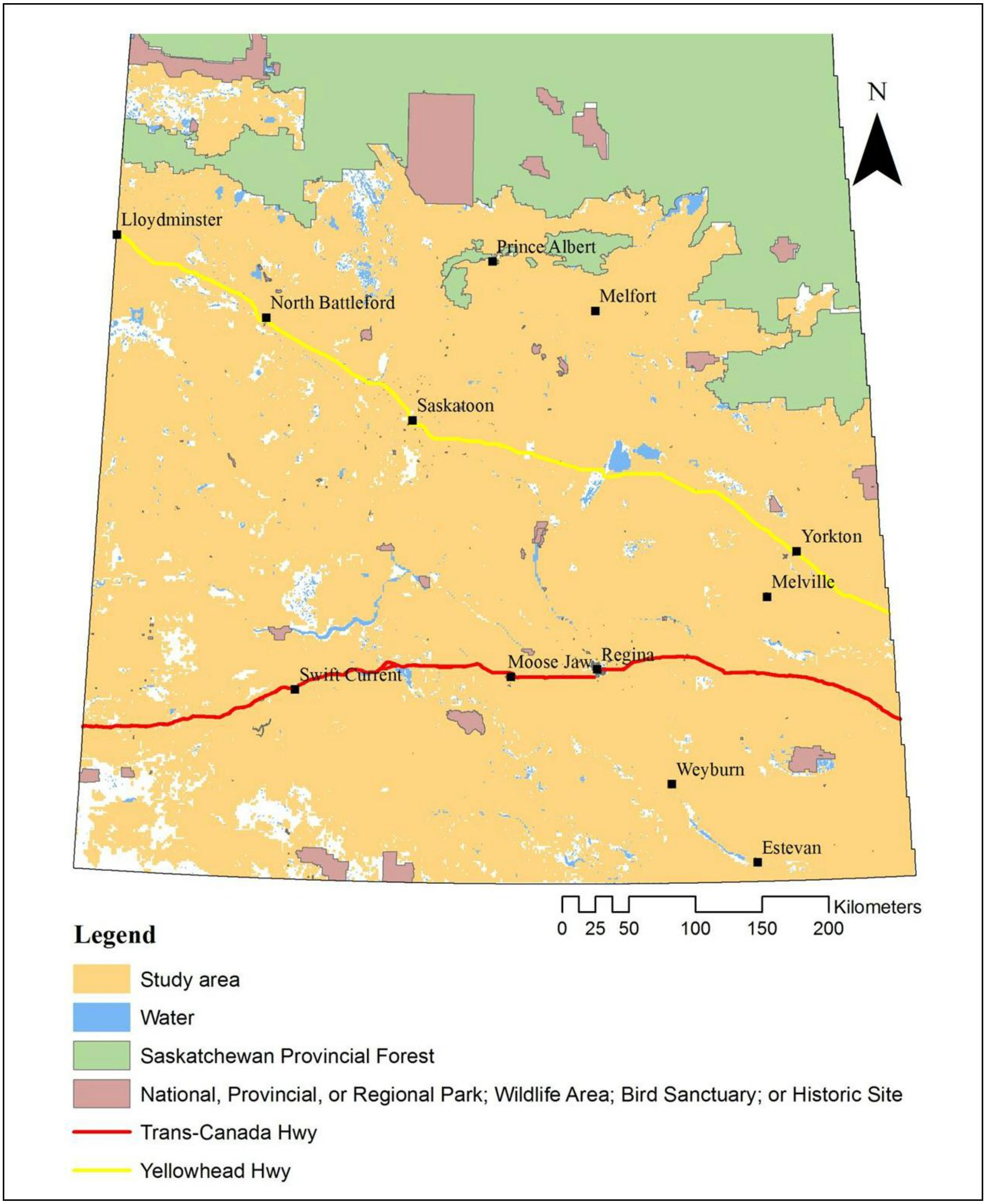


Figure 3.1. Study area consisting of agricultural lands in southern and central Saskatchewan, Canada, 2000 (Geobase Landcover, 2000; Geosask, Sask Admin, 2012).

Johnson et al. 1995). While much of the native grassland, forest, and wetlands on the prairies have been replaced by agriculture, an estimated 20% of Saskatchewan's native prairie remains, though largely as fragments in an otherwise agriculture-dominated landscape (Hammermeister et al. 2001).

Within Saskatchewan, chronic wasting disease (CWD) has been detected in elk, mule deer, and white-tailed deer. After the initial introduction of CWD to Saskatchewan with infected farmed elk in the 1980s (Williams and Miller 2002, Bollinger et al. 2004, Kahn et al. 2004), the disease has now been detected in wild and farm-raised mule deer, white-tailed deer, and elk. While accurate prevalence data is particularly challenging to obtain due to restricted sample sizes and spatio-temporal bias in the collection of samples, within Saskatchewan, prevalence rates in free-ranging cervids are currently highest in mule deer (281 confirmed positives in Saskatchewan, 1997-2011), followed by white-tailed deer (66), and finally elk (4; Saskatchewan Ministry of the Environment 2008, Bollinger et al. 2013). Within Saskatchewan, CWD is likely endemic in four key geographic areas: south of Lloydminster in the Manitou Sand Hills, northeast of Lloydminster along the Bronson forest, along the South Saskatchewan River valley near Saskatchewan Landing Provincial Park, and near the town of Nipawin (Bollinger et al. 2013; Fig. 3.2).

3.4 Methods

3.4.1 Dataset

To identify spatiotemporal patterns in damage to agricultural crops by cervids, I used the Saskatchewan Crop Insurance Corporation (SCIC) crop damage claim database. Saskatchewan Crop Insurance Corporation, funded through the federal and provincial government, operates a wildlife damage program that provides compensation payments in order to offset financial losses incurred by agricultural producers who experience damage to their agricultural crops through consumption, trampling, or excretion by 14 wildlife species. Over 30 crop types are eligible for compensation, with payments based on the amount of lost or spoiled production appraised within the reported damage area, multiplied by a crop price determined by annual average price surveys conducted by the provincial insurance agency. Claim payments are only made to producers if there is a minimum of $150 appraised damage. There is no maximum payment amount and no

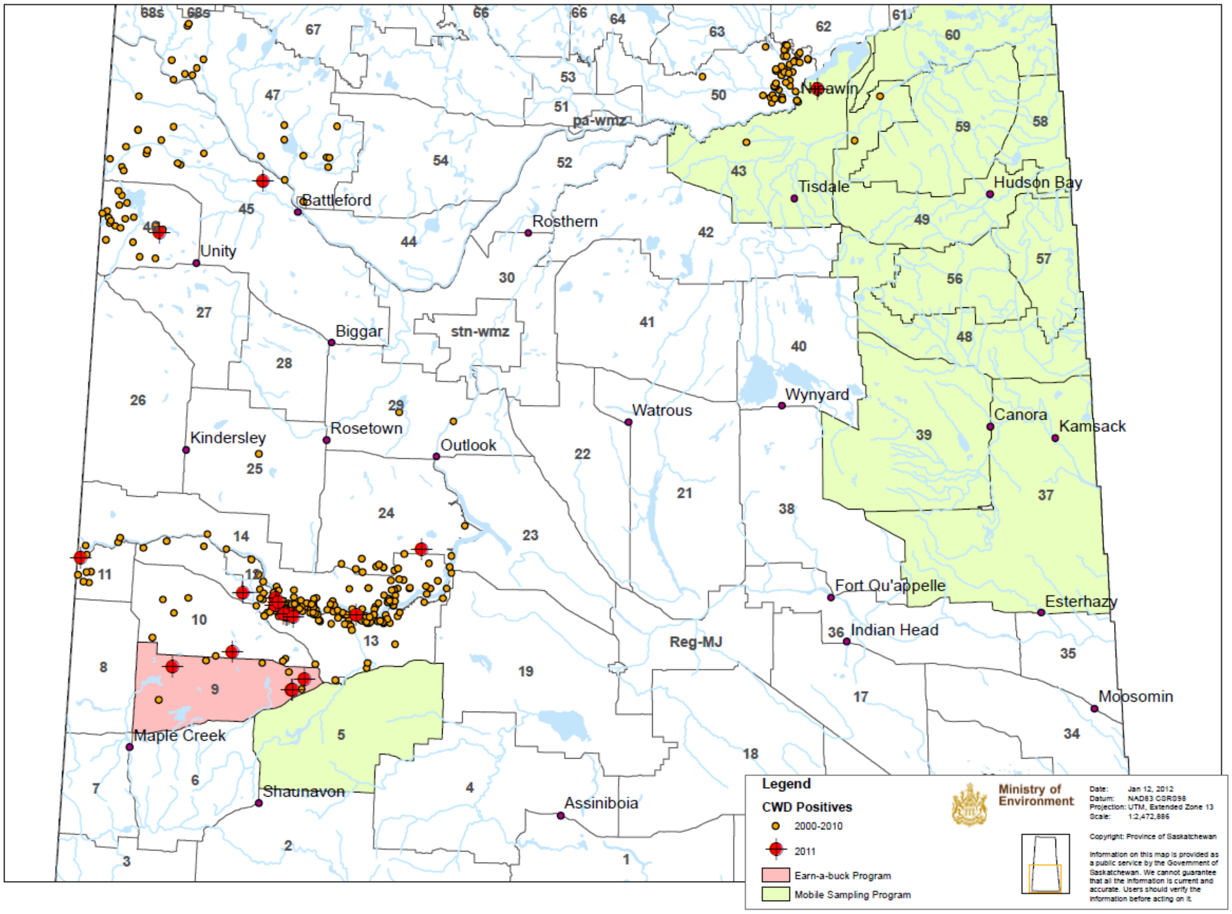


Figure 3.2. Chronic wasting disease distribution in free ranging elk, mule deer, and white-tailed deer populations in Saskatchewan as of January 12, 2012 (Saskatchewan Ministry of Environment, 2012. Reproduced with permission from Saskatchewan Ministry of Environment).

premiums or administrative fees are required of producers in order to receive coverage under the SCIC wildlife damage program.

Through data sharing agreements with Saskatchewan's provincial agricultural departments, I was granted access to SCIC wildlife damage claims from 2000 to 2012. This detailed long term dataset includes appraised and compensated claims for white-tailed deer, mule deer, and elk damage to crops. In some cases (46.8%), individual damage claims included two concurrent species (white-tailed deer and mule deer, white-tailed deer and elk, mule deer and elk). In order to identify the species-specific patterns of crop damage by elk, mule deer, and white-tailed deer, claims for damage caused by two-species combinations were excluded. Only annual crops were examined, that is, cereals (wheat, barley, oats), oilseeds (canola and flax), and pulse crops (field peas, chick peas, and lentils), while perennial forage crops such as alfalfa, clover, native pasture, or tame grass hay were excluded due to discrepancies in the dataset. All claims were screened to ensure they fell within cropland. As a result, 19,069 claims were retained for analysis (white-tailed deer n=12,558; mule deer n=1,700; elk n=4,811)

3.4.2 Selection of annual crops by elk, mule deer, and white-tailed deer

In order to determine whether damage to annual crops occurred in proportion to their availability on the landscape, I used data from the Statistics Canada Census of Agriculture. Every five years, Statistics Canada conducts a census of agriculture which, by law, any person responsible for managing a farm or an agricultural operation must complete (Statistics Canada 2011). Statistics Canada summarizes these data to provide seeded acreage data by reporting the total seeded area of each crop type, within each census region, which vary in size from 558 km^2 to 1,945 km^2. I examined seeded acreage data across Saskatchewan from 2001, 2006, and 2011 censuses, and then interpolated these values to determine values for each of the years between census periods.

Total area of appraised damage by elk, mule deer, and white-tailed deer was reported in acres for each SCIC crop damage record from 2000-2012. Crop types with the greatest overall frequency of damage claims and highest values of reported losses were examined for each species. In the statistical program R (version 2.14.1, R Development Core Team 2011), I compared the proportion of area damaged for these main crop types with the overall availability of the respective crops across Saskatchewan using chi-squared tests for each year. To determine if crop availability changed over time, and if temporal variation in crop type availability influenced selection of that crop type by cervids, I analyzed the data over three separate time periods (2000-2003, 2004-2008, 2009-2012), binned to correspond with availability data from the Statistics Canada Census of Agriculture. To establish a broader overview of selection patterns, I pooled the damage claims for the entire time period for which I had data, and used seeded acreage reports averaged over that time period. Any chi-squared values >26.2 were considered significant given 12 degrees of freedom (n=13 years of data-1) at a 99% confidence interval.

3.4.3 Variables influencing selection of annual crops by elk, mule deer, and white-tailed deer

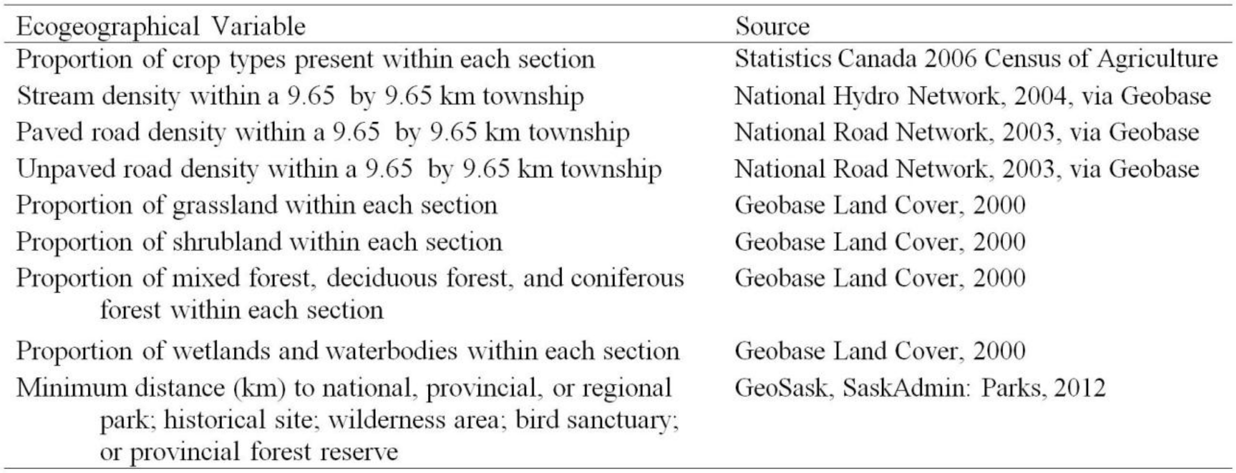
An important limitation in traditional studies of habitat use or selection is the lack of absence data (Hirzel et al. 2002). Ecological-niche factor analysis (ENFA) is designed to circumvent this difficulty of “false absences”. By using only confirmed presence locations as input, ENFA allows for multivariate analysis of eco-geographical variables (EGVs) within the species distribution in relation to that of the surrounding landscape (Austin 2007). Constructed after Hutchinson’s (1957) concept of the ecological niche, ENFA assesses two separate measurement factors. Marginality is expressed as the difference between the “global” mean of an EGV within the scale of interest, and the “species” mean (mean EVG value within the sites used by the focal species). Therefore, higher marginality values indicate that a species’ niche deviates farther from the average conditions of the available habitat (Calenge et al. 2005, Basille et al. 2008). Secondly, specialization can be evaluated by examining the ratio of the standard deviation of the global distribution to the distribution of the focal species (Hirzel et al. 2002). Specialization values can, therefore, be interpreted as a measure of how restricted a species niche is in relation to the whole available study area (Hirzel et al. 2002, Reutter et al. 2003). In this manner, ENFA is able to address two fundamental questions in ecological research: where can a species establish, and which factors is a species searching for (Basille et al. 2008). The resulting multivariate niche of the focal species can be defined on its axes by an index of marginality and specialization. Outputs thus have intuitive ecological meaning, and allow direct comparisons with the niche of different species within the same geographic area and temporal period.

In order to determine the key habitat variables that influence selection of annual crops by each of my study species, I conducted a separate ENFA for each elk, mule deer, and white-tailed deer. First, to extract my study area, agricultural lands, I relied on the 2000 Geobase Land Cover data (www.geobase.ca). These raster data originate from Landsat 5 and Landsat 7 ortho-images, for agricultural and forest areas of Canada. The accuracy of this land cover data was independently assessed by terrestrial surveying, and comparisons of ground-referenced sites to information on the digital map data (Dugal 2012). Within each of four primary land cover classes (deciduous forest, grassland, forage cropland and wetland) 100 random point were ground-referenced, and upon calculating an error matrix, an overall accuracy level of 84% was identified for all four land cover classes (Dugal 2012). This accuracy was consistent with other studies, and deemed acceptable (Congalton and Green 2008).

Using the software programs ArcGIS 10.1 (ESRI, Redlands, CA, USA) and associated Geospatial Modelling Environment (Beyer 2012), I calculated the proportional values for different land cover types (forest, crop land, grassland, water) within each cell of a 1.61 by 1.61 km (section; 1 mile by 1 mile) grid. The spatial scale of analysis was selected as the section because this is the spatial scale at which most land ownership is designated within the study area based on the Canadian Dominion Land Survey. Any section within Saskatchewan containing at least 20% cultivated annual cropland was included in the study area, while sections comprised exclusively of native habitats (forest, shrublands, grassland, wetlands, or water) were excluded.

Once my study area was established, the first step to computing each ENFA was the selection of ecogeographical variables (EGVs) to include in my analysis. In this study, EGVs included were a variety of predictor variables predicted to influence the selection of agricultural crops by elk, mule deer, and white-tailed deer, as derived from a review of the literature (see Table 3.1). All EGV data were projected in the form of raster maps using the software programs ArcGIS10.1, and Geospatial Modelling Environment. Ecogeographical variables were measured at the scale of section or township (see Table 3.1.). Variables such as forest, canola, or water bodies were quantified as a proportion (0.0 to 1.0) of the total land cover within a section. Features such as streams or paved roads were quantified by total density within a 9.66 by 9.66 km (6 mile by 6 mile) township.

Table 3.1. Ecogeographical variables included in ecological niche factor analyses of elk, mule deer, and white-tailed deer crop damage claims in Saskatchewan (2000-2012).



Ecogeographical Variable	Source
Proportion of crop types present within each section	Statistics Canada 2006 Census of Agriculture
Stream density within a 9.65 by 9.65 km township	National Hydro Network, 2004, via Geobase
Paved road density within a 9.65 by 9.65 km township	National Road Network, 2003, via Geobase
Unpaved road density within a 9.65 by 9.65 km township	National Road Network, 2003, via Geobase
Proportion of grassland within each section	Geobase Land Cover, 2000
Proportion of shrubland within each section	Geobase Land Cover, 2000
Proportion of mixed forest, deciduous forest, and coniferous forest within each section	Geobase Land Cover, 2000
Proportion of wetlands and waterbodies within each section	Geobase Land Cover, 2000
Minimum distance (km) to national, provincial, or regional park; historical site; wilderness area; bird sanctuary; or provincial forest reserve	GeoSask, SaskAdmin: Parks, 2012

The various functions required to compile ecological maps, conduct descriptive statistics, compute an ENFA, and analyze output, were conducted in the statistical program R (version 2.14.1, R Development Core Team 2011). Prior to any analysis, I screened all pairs of variables for correlations using a Spearman's rank correlation matrix, with no strong correlations (r_s>0.7) detected. The centroid UTM coordinates of sections where crop damage occurred from 2000-2012 were loaded as presence points for each species, and separate EGV maps were compiled to define a detailed representation of the available habitats for each section. ENFA biplots were constructed for each species, values for species' marginality and specialization were calculated, and coefficient scores were computed for each variable in order to quantify their contributions to marginality and specialization. Any marginality or specialization value greater than 0.20 indicated selection for that variable, less than −0.20 indicated selection against that variable, and values between 0.20 and −0.20 indicate proportional use of that variable (Lande et al. 2010). Species tolerance values were also calculated as the inverse of specialization (Valle et al. 2011), with larger tolerance values indicating a greater capacity for a species to adjust to fluctuations in habitat features, and thus, a wider niche (Valle et al. 2011).

In order to validate the accuracy of my ENFA for each species, and determine if species show non-random habitat selection, 1000 sets of random locations were generated for each species over the study area. Each set consisted of the same sample size as actual crop damage observations for that species. For each set, the marginality and specialization were calculated. Species' actual marginality and specialization values based on SCIC claims were then compared to marginality and specialization values calculated from the random location sets.

3.4.4 Overlap in the selection of annual crops by elk, mule deer, and white-tailed deer

Similar to ENFA, K-select analysis is a geometric method for characterizing habitat use, relying on the concept of ecological niche (Hutchinson 1957). K-select analysis consists of a Principle Component Analysis (PCA) performed on a table containing the relative position of the used habitat, centered on the average available habitat in multivariate space (Calenge et al. 2005). Typically used to identify the habitat variables selected by animals, and examine difference in habitat selection between individuals or groups of individuals (Bremset Hansen et al. 2009, Pellerin et al. 2010), K-select has also been shown to be an effective tool to examine differences in habitat selection between sympatric species (Rauset et al. 2012). K-select analysis specifically focuses on vectors of marginality (Dolédec et al. 2000, Hirzel et al. 2002) which measure the distance between the habitat used by an organism and the habitat available to it in a multidimensional ecological space (Calenge et al. 2005).

In order to compare habitat selection, specifically similarities and differences in selection of annual agricultural crops by elk, mule deer and white tail deer, I conducted a K-select analysis. All functions to compile the eco-geographical variables (Table 3.1), compute the K-select analysis, and analyze output, were conducted in the statistical program R (version 2.14.1, R Development Core Team 2011). The center UTM coordinates of sections where crop damage occurred by elk, mule deer, and white-tailed deer were loaded as presence points, and separate EGV maps were amalgamated to define a detailed representation of the available habitats across the study area.

3.5 Results

In total, the number of compensated claims for damage to standing annual crops by elk, mule deer, and white-tailed deer in the study area from 2000-2012, was 19,069 (12,558 claims for white-tailed deer; 1,700 for mule deer; 4,811 for elk; Fig. 3.3). Over the 13 years examined, compensation payments for standing crop damage by elk, mule deer, and white-tailed deer totalled 30.987 million dollars. From 2000 to 2012, the monetary value of elk damage to annual crops increased significantly (r^2=0.689, p=0.002), while mule deer (r^2=0.053, p=0.725) and white-tailed deer (r^2=0.025, p=0.858) showed no significant trends (Fig. 3.4). Compensation payments to producers were made in all years for all cervid species but actual level of damage for each crop type showed temporal variation (Fig. 3.5).

3.5.1 Selection of annual crops by elk, mule deer, and white-tailed deer

Analysis of seeded acreage proportions and crop damaged hectares demonstrated that while seeded area of some crop types changed over the time period of 2000-2012 (specifically wheat, that declined by 60.6%, and canola, that increased by 207.4%), selection ratios (crop use in relation to availability) did not change significantly (see Appendix A). Therefore, crop damage data were pooled for each species and selection were analysed over the entire time period of the dataset (2000-2012), using seeded acreage reports averaged over that time period. The proportion of observed elk, mule deer, and white-tailed deer use of cereals, oilseeds, and pulse crops were all significantly different from the proportion of crops' respective availability, given 12 degrees of freedom (n=13 years of data−1) at a 99% confidence interval (Fig. 3.6). Elk (Fig. 3.6A) selected (from most selected to least selected based on chi-squared values) oats, peas, wheat, and canola. Mule deer (Fig. 3.6B) showed greatest selection for chickpeas, peas, lentils, and oats, while white-tailed deer (Fig. 3.6C) selected for oats, flaxseed, peas, and barley.

3.5.2 Variables influencing the selection of annual crops by elk, mule deer, and white-tailed deer

Histograms of specialization eigenvalues for elk (Fig. 3.7), mule deer (Fig. 3.8), and white-tailed deer (Fig. 3.9), all indicate that for each species, only the first axis (ie x axis) accounted for 20.24%, 17.13%, 16.49% of specialization, respectively. Therefore, biplots for each species were presented on just two axes: the first axis of specialization (Y axis) and the axis of marginality (X axis).

Biplots for the elk (Fig. 3.7.), mule deer (Fig. 3.8), and white-tailed deer (Fig. 3.9) visually display trends in resource selection for each species. For each biplot figure, the polygons delineate the minimum convex polygons enclosing the projections for all available (light colored polygons) and used points (dark colored polygons), respectively. Secondly, the white circle defines the centroid of the species' niche, with the distance to the centroid of available habitat graphically presenting a measure of marginality. Thirdly, eco-geographical variables are denoted by vectors on each species' biplot. The length of the vector indicates that variable's importance in establishing the position and volume of the ecological niche within the available habitat. The longest vectors represent those variables which are most important in terms of habitat selection (Basille et al. 2008). The direction of the vector measures that variable's relative contribution to the marginality (X axis) or specialization (Y axis). The contributions of each variable to marginality and specialization are also quantified numerically by species. Any marginality or specialization value greater than 0.20 indicated selection for that variable, less than −0.20 indicated selection against that variable, and values between 0.20 and −0.20 indicate proportional use of that variable (Table 3.2; Lande et al. 2010).

Elk selected (in order from most to least selected) deciduous forest, oats, and canola, while areas with a higher proportion of open native grassland and pea crops, farther from protected areas, with higher road densities were avoided (Fig. 3.7). Mule deer selected for peas and areas with greater stream density, while oats, canola, flaxseed, wheat, and barley were avoided (Fig. 3.8). White-tailed deer showed greatest selection for deciduous forest, oats, canola, mixed forest, and coniferous forest, while areas with a high density of pea crops, farther from protected areas, with a high density of wheat crops and paved roads were increasingly avoided (Fig. 3.9).

Marginality values for elk, mule deer, and white tailed deer were all statistically different from those calculated using the random presence locations ($p<0.001$), indicating that each species was occupying specific areas. Marginality values for elk, mule deer, and white-tailed deer were 6.07, 1.99, and 2.51, respectively. Tolerance values for elk, mule deer, and white-tailed deer were 15.09, 14.55, and 16.96, respectively.

3.5.3 Overlap in the selection of annual crops by elk, mule deer, and white-tailed deer

The initial barplot of the K-select shows that the first two principle component axes from the K-select analysis accounted for 90.5 and 6.6% of the mean selection (Fig. 3.10B).

Marginality decreased substantially after the second axis; therefore two axes were retained for visual representation and biological interpretation.

The ecogeographic variables deciduous forest, oats, alfalfa, barley and canola had positive loadings for the first principal component axis (X axis), whereas grassland, shrubland, water bodies, and peas had negative loadings. The second principal component axis (Y axis) had a high positive loading for stream density; whereas distance to park, flaxseed, wheat, paved road density, unpaved road density, coniferous forest, and, to a lesser extent, mixed forest had a negative loading (Fig. 3.10A).

Both elk and white-tailed deer exhibited similar habitat selection patterns, with positive selection along the first axis (X axis), with little substantial selection along the second axis(Y axis; Fig. 3.10C). The length of the elk vector demonstrates the greater strength of selection, compared to white-tailed deer. Mule deer demonstrated a different pattern of habitat selection, with a strongly negative selection along the first axis, and a positive selection along the second axis (Fig. 3.10C).

3.6 Discussion

Patterns in seeded acreage have changed dramatically across Saskatchewan from 2000-2012, however patterns of selection remained largely unchanged, with elk and white-tailed deer showing greatest selection for cereal crops such as oats, while mule deer showed selection for pulse crops such as peas and lentils.

Ecological-niche factor analyses were consistent with the finding of the chi-squared tests. The selection or avoidance of vegetative or anthropogenic features was found to influence species selection of cropland. For instance elk were found to select annual crops in areas with a higher proportion of deciduous forest cover, with lower densities of paved roads, in close proximity to protected areas. This selection of foraging sites is consistent with previous studies of elk habitat selection in western Canada (Gooding and Brook 2011, Dugal et al. 2013), and demonstrates a security strategy, as roads often function as a proxy for increased human presence, hunting risk, and urban development (Conner et al. 2001, McCorquodale 2003, Dugal et al. 2013).While agricultural lands provide nutritious forage, parks or protected areas may offer refuge from hunting and human disturbance. This trade-off has been well documented in parturient elk within western Canada (Brook 2010b).White-tailed deer exhibited similar selection pattern to that of elk, selecting areas with a high proportion of deciduous forest, oats, and canola, while avoiding crops in areas with a higher seeded proportion of peas, or areas farther from protected areas. However, as indicative of their generalist nature and association with forest cover (Côté et al. 2004), white-tailed deer also showed selection for crops in areas containing mixed forest and coniferous forest. Mule deer demonstrated a unique pattern of selection of the cervids, by avoiding oats and canola, while strongly selecting for areas rich in peas and, to a lesser degree, areas with a high stream density. Unlike white-tailed deer and elk that are closely associated with forest (Geist 1998), mule deer showed no selection for cropland in areas with a higher proportion of deciduous, coniferous, or mixed forest.

K-select analysis for all three cervid species further illustrate similarities and differences in species' niche, while identifying the variables influencing overlap in species selection of annual crops. This analysis revealed that elk and white-tailed deer are selecting for annual crops in areas where a high proportion of farmland is seeded to oats, barley, canola, and alfalfa, while avoiding areas farther from protected areas with a high density of paved or unpaved roads and a high proportion of open grassland. Again, this likely reflects an anti-predator strategy in terms of avoiding hunting pressure, as roads and highways are an effective proxy for hunting pressure in general. Mule deer exhibited different annual crop selection patterns, favouring open grasslands, shrublands, and areas with a greater density of streams or water bodies.

When examining the marginality and tolerance values of elk, mule deer, and white-tailed deer, all three species had marginality values higher than that obtained from random sets, indicating clear habitat selection, rather than random occupation of available sites. The high marginality value of elk demonstrates the higher difference between their optimal habitat and the available landscape. This distinction in selecting habitat indicates that elk are exhibiting greater specialist behavior, in comparison to generalists like mule deer and white-tailed deer. Alternately, mule deer were found to have the lowest tolerance value of the three species, reflecting their lower acceptance to deviations from their optimal habitat. White-tailed deer, frequently described as generalists or opportunists (Garrott et al. 1993, Geist 1998, Côté et al.

2004), were found to have the highest tolerance value, reflecting their adaptive capacity to tolerate diverse habitats.

Although each crop damage claim was evaluated by a trained and experienced adjustor, some potential areas of bias in the data are possible, due to unreported damage or misidentification of the species causing the damage. Since the reporting and appraisal procedure is conducted at no cost to the producer, the potential for financial compensation encourages producers to report all cases of damage. While some producers may actively choose to not report damage due to personal principles such as wildlife appreciation or privacy concerns regarding the appraisal process, these cases are rare (Brook 2008). According to one SCIC adjustor, identification of the cervid species responsible for damage is typically reported to the adjustor by the producer who incurred losses (Dan Baber, Saskatchewan Crop Insurance Corporation, personal communication, 2013). Previous studies have shown agricultural producers to be accurate observers and chroniclers of cervid activity on their property (Brook and McLachlan 2006, 2009, Brook 2008), with great ability to recall relevant details over long time periods, especially when the event is of high personal importance (Huntington 2000, Brook and McLachlan 2008, 2009). Nevertheless, small scale damage incidents may go unnoticed, unreported, or misidentified; however, I assumed the effects the low monetary value of these minor and rare events to be minimal. Evaluating reported crop damage claims has proven to be a useful tool in identifying patterns of wildlife use of cropland (Naughton-Treves 1998, Sitati et al. 2005, Gooding and Brook 2011). By examining thousands of damage reports, meaningful spatial and temporal commonalities can be established, and when compared to the characteristics of the available damage-free landscape, it is possible to generate estimates of the relative strength of selection of resources by wildlife.

From 2000-2012, the monetary value of damage done by elk in Saskatchewan increased significantly, while mule deer and white-tailed deer remained unchanged. Damage to standing crops by elk has long been a source of wildlife-agriculture conflict in western Canada and is likely an important risk factor in disease transmission at the livestock-wildlife interface (Brook 2008, 2009, Brook et al. 2013). Important differences in management objectives between farmers and different government agencies (wildlife and agriculture) have historically hindered any attempts to mitigate this conflict and jointly develop long-term elk management solutions (Brook

2009). With the increase in ungulate damage in Saskatchewan, and indeed in many other areas of North America, the need for innovative and co-operative cervid management strategies in Saskatchewan is evident.

My findings provide an important step in evaluating the potential of disease transmission in an agricultural landscape by characterizing areas of high crop use, which is known to be a potential fomite, and identifying factors influencing high spatial overlap and niche overlap. Chronic wasting disease (CWD) is a seriously threat to elk, mule deer, and white-tail deer in western Canada. From 1997, ending in 2012, the Government of Saskatchewan monitored wild cervid populations for CWD using samples collected from hunter harvest (Rees et al. 2012). While accurate prevalence data has been challenging to obtain due to insufficient sample sizes, declining hunter participation, and spatio-temporal bias in the distribution of sampling, within Saskatchewan, prevalence rates are currently estimated to be highest in mule deer (1.0 % province-wide), followed by white-tailed deer (0.43% province-wide; Bollinger et al. 2013). While only four wild elk in the Nipawin region have tested positive for the disease (0.26% prevalence province-wide), wild elk populations in Rocky Mountain National Park in Colorado and some areas in Wyoming have experienced prevalence rates as high as 10% (Saunders et al. 2012). Indeed, findings here demonstrate minimal shared forage and habitat features among elk and mule deer, and this may at least partially provide insight into the low CWD prevalence rates in elk in Saskatchewan thus far. Similarities in cervid selection for particular habitat features such as shrubland, forest cover, protected areas, water features and annual cropland may result in higher densities and increase disease transmission by both direct (Joly and Messier 2004, Walter et al. 2009) and indirect (Silbernagel et al. 2011) transmission routes (Rees et al. 2012).

Through the characterization of sites most likely to experience damage or facilitate species overlap, preventative measures can be efficiently applied based on local environmental conditions. For instance, by providing producers with insight into landscape attributes that influence damage occurrence, crop seeding patterns could be adjusted to mitigate losses and address areas of high overlap of cervid species and associated potential for CWD transmission. Existing hunting efforts may also be targeted toward the areas at highest risk of crop damage and disease transmission. Incorporating these findings into targeted disease management and damage prevention strategies could prove useful in addressing both the critical disease threat to Saskatchewan cervid populations and the ongoing economic burden of crop damage.

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3.8 Figures and Tables

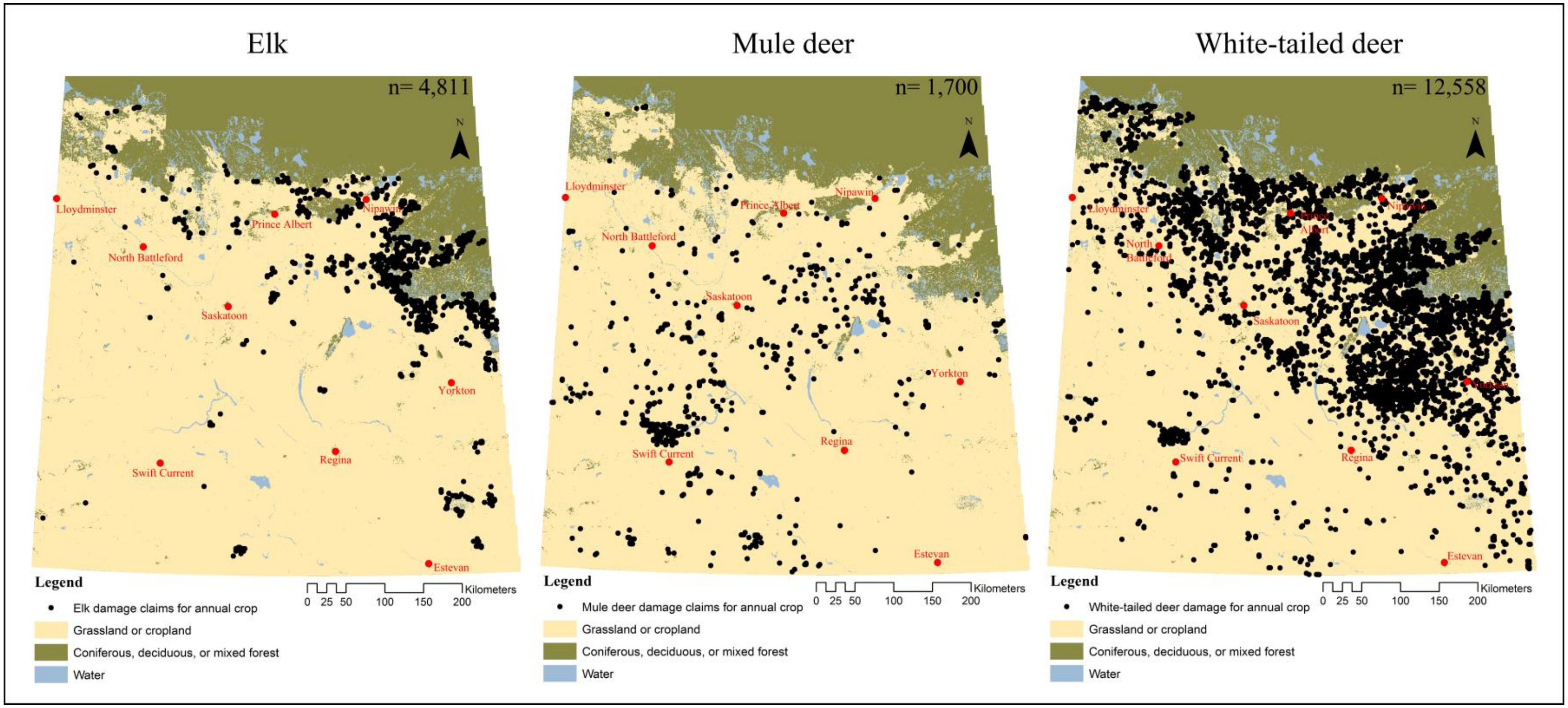


Figure 3.3. Confirmed sites of damage to annual crops caused by elk, mule deer, and white-tailed deer in Saskatchewan (2000-20012).

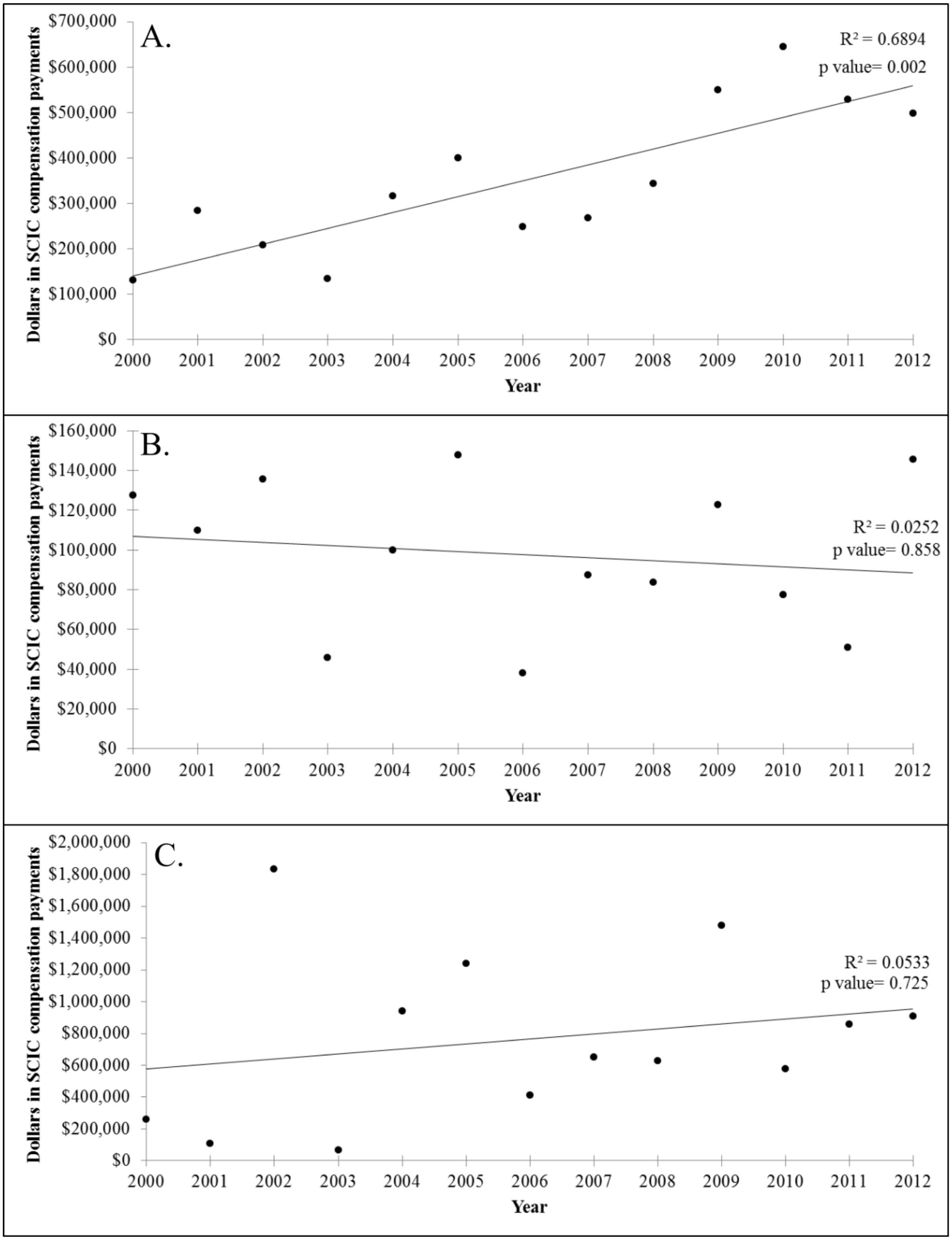


Figure 3.4. Saskatchewan Crop Insurance Corporation compensation payments to producers for all annual standing crop damage by A) elk, B) mule deer, and C) white-tailed deer in Saskatchewan (2000-20012).

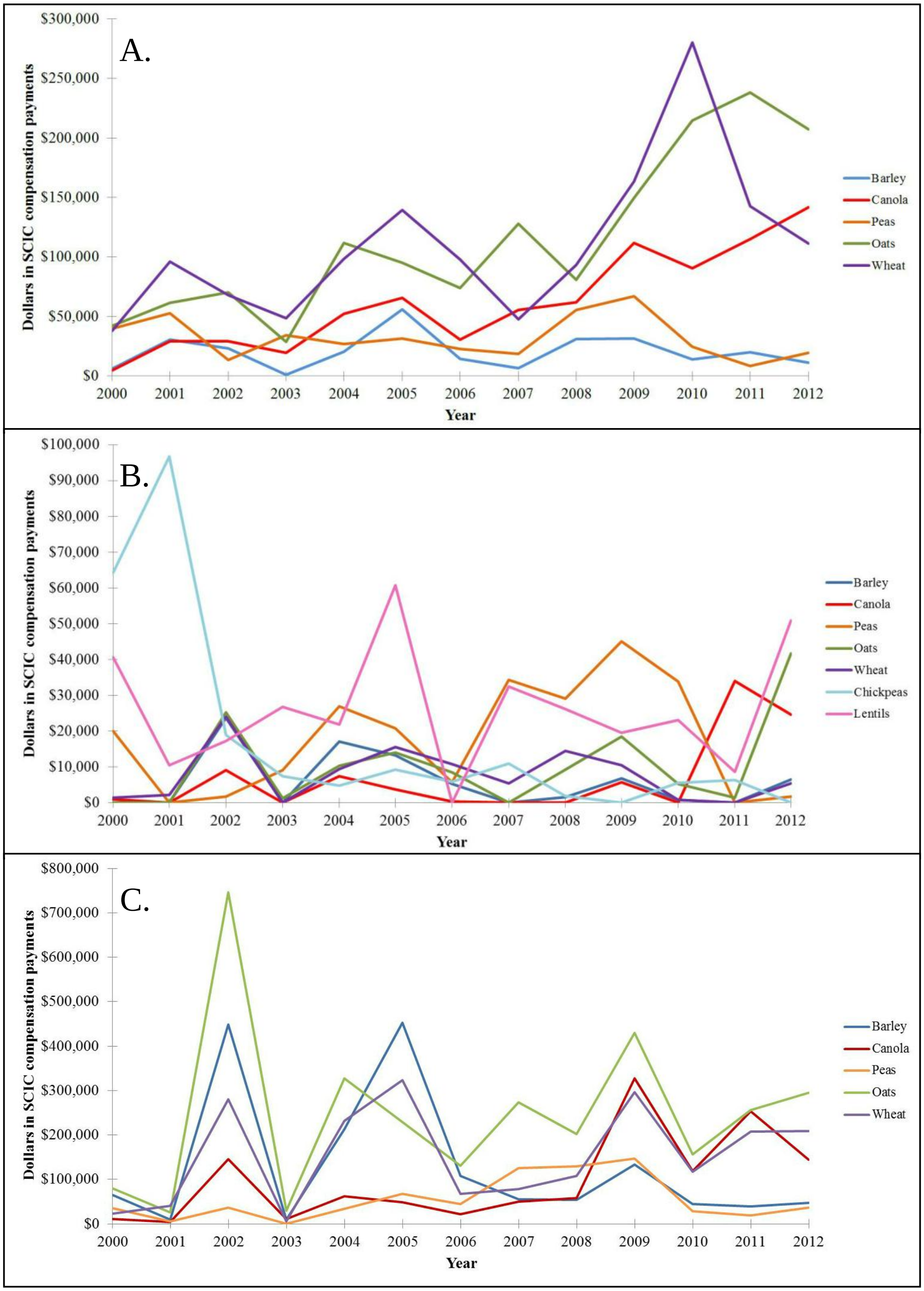


Figure 3.5. Saskatchewan Crop Insurance Corporation compensation payments to producers for annual standing crop damage by A) elk, B) mule deer, and C) white-tailed deer in Saskatchewan (2000-20012).

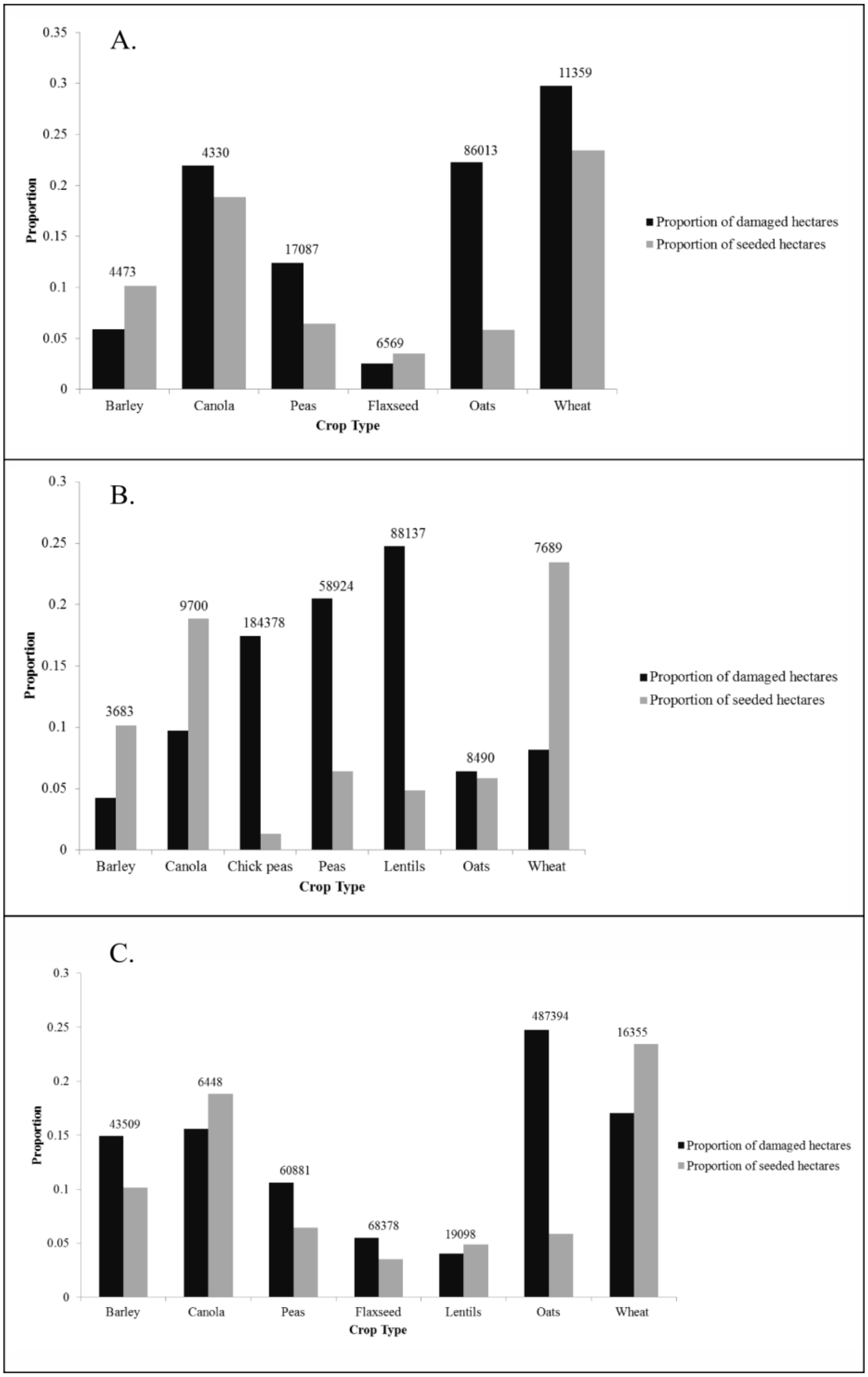


Figure 3.6. Proportion of damaged hectares in relation to the proportion of seeded hectares of the primary crop types in Saskatchewan for A) elk; B) mule deer; and C) white-tailed deer from 2000-2012. Chi-squared values, above each bar, >26.2 indicate the proportion of observed crop damage differs significantly from the proportion of the respective crop availability, given 12 degrees of freedom at a 99% confidence interval.

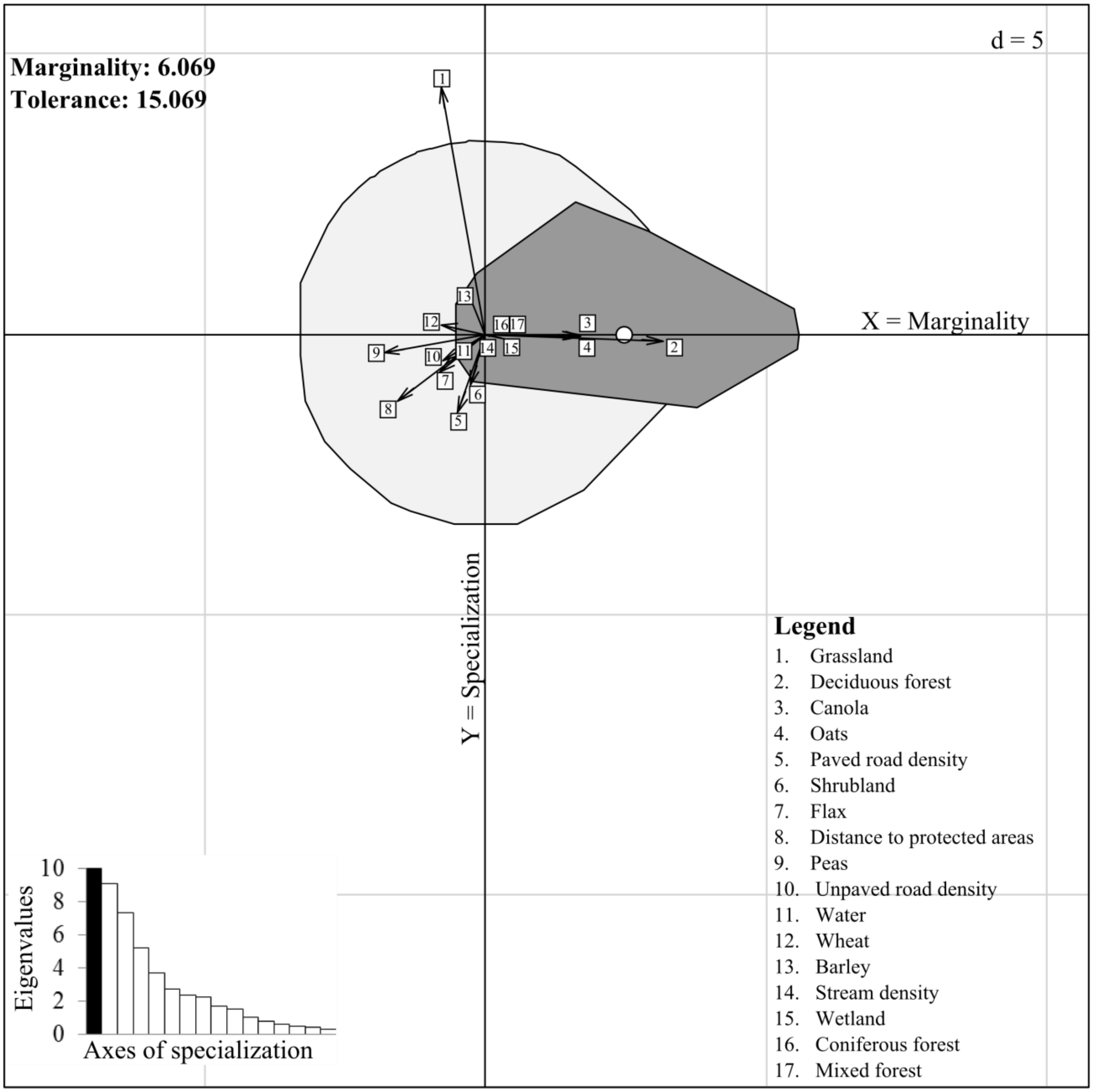


Figure 3.7. Biplot of the ENFA for elk based on standing crop damage claims paid to farmers in Saskatchewan, Canada (2000-2012), formed by the marginality axis (X-axis) and the first specialization axis (Y-axis). The light and dark areas represent the projections of the available and used regions, respectively. The white point denotes the centroid of the used habitat. Vectors display projections of eco-geographical variables. The histogram displays the eigenvalues of specialization, with one axis explaining most of the specialization.

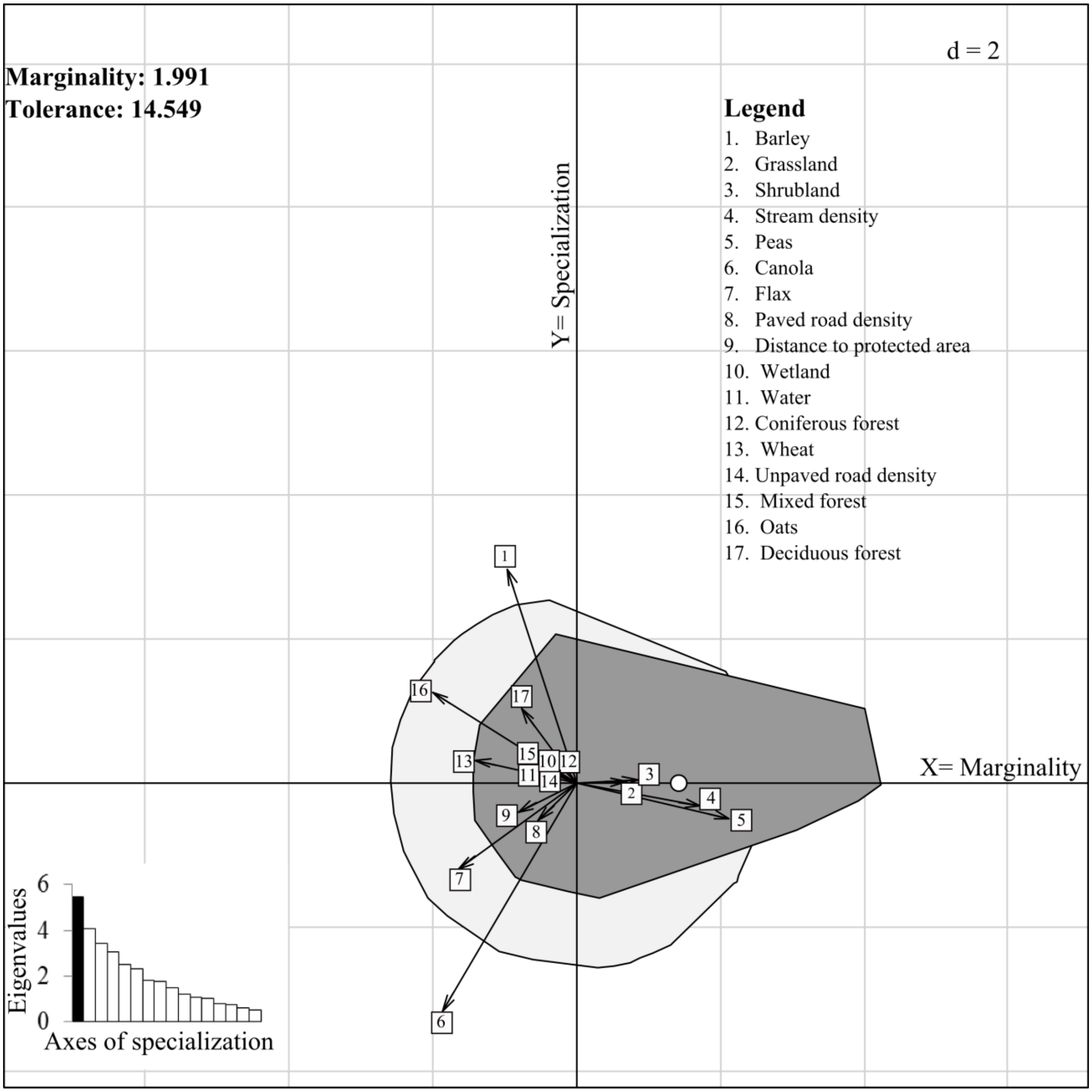


Figure 3.8. Biplot of the ENFA for mule deer based on standing crop damage claims paid to farmers in Saskatchewan, Canada (2000-2012), formed by the marginality axis (X-axis) and the first specialization axis (Y-axis). The light and dark areas represent the projections of the available and used regions, respectively. The white point denotes the centroid of the used habitat. Vectors display projections of eco-geographical variables. The histogram displays the eigenvalues of specialization, with one axis explaining most of the specialization.

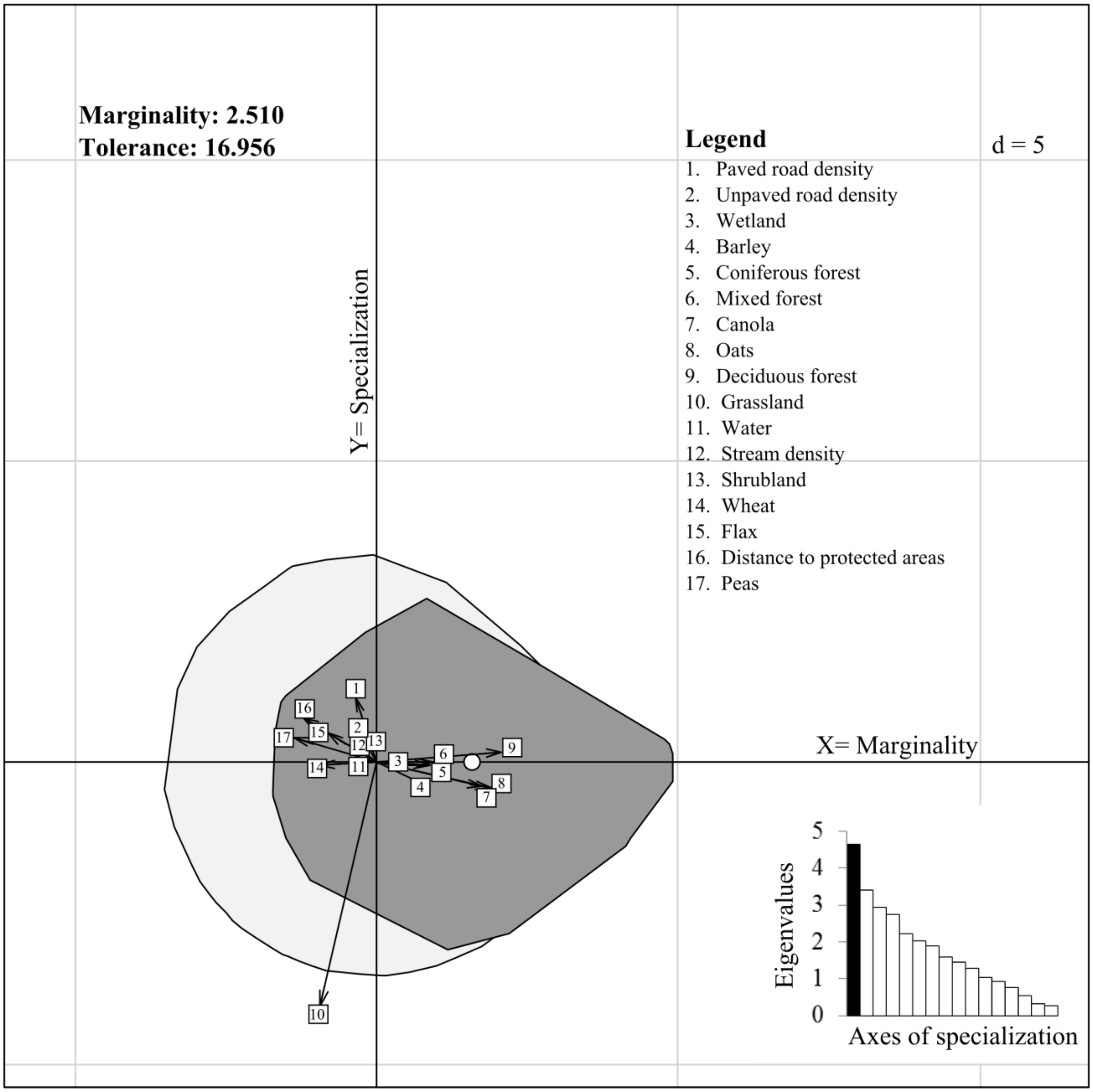
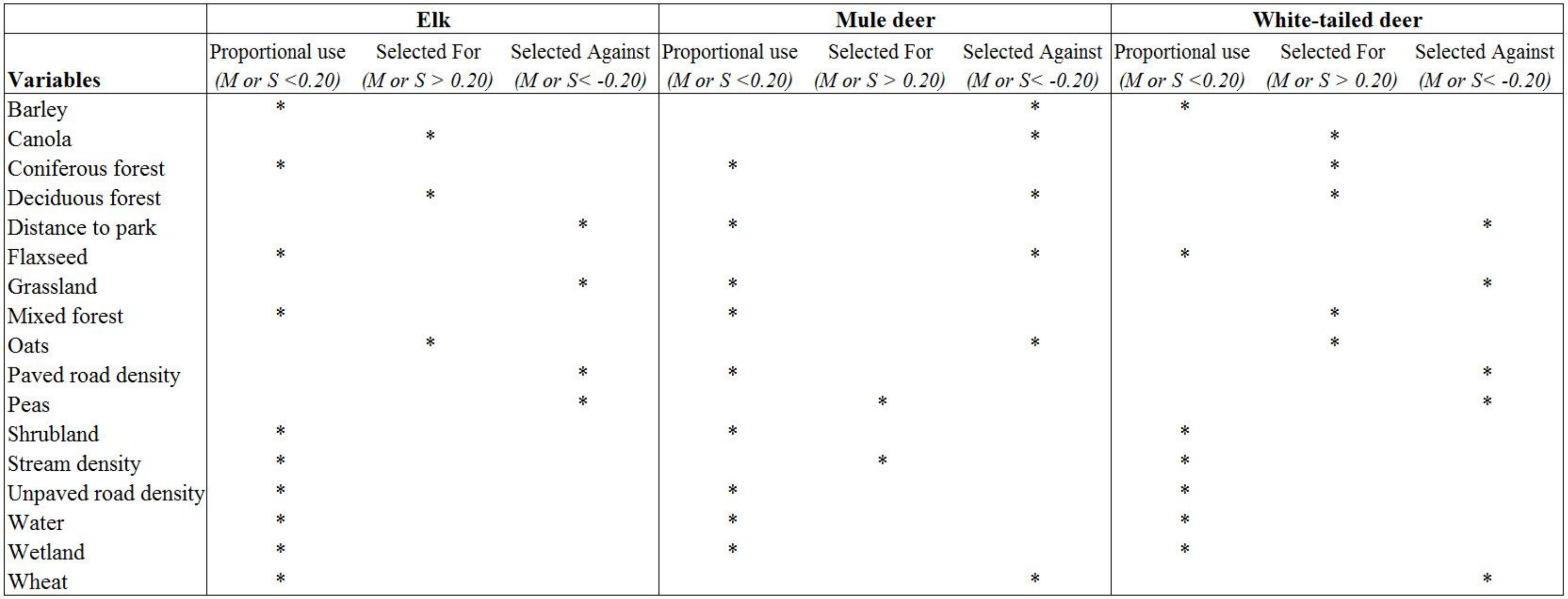


Figure 3.9. Biplot of the ENFA for white-tailed deer based on standing crop damage claims paid to farmers in Saskatchewan, Canada (2000-2012), formed by the marginality axis (X-axis) and the first specialization axis (Y-axis). The light and dark areas represent the projections of the available and used regions, respectively. The white point denotes the centroid of the used habitat. Vectors display projections of eco-geographical variables. The histogram displays the eigenvalues of specialization, with one axis explaining most of the specialization.

Table 3.2. Selection of eco-geographical variables by elk, mule, deer, and white-tailed deer based on significant ENFA values of marginality and specialization. Any marginality or specialization value greater than 0.20 indicates selection for that variable, less than −0.20 indicates selection against that variable, and values between 0.20 and −0.20 indicate proportional use.



	Elk			**Mule deer**			**White-tailed deer**		
Variables	Proportional use *(M or S <0.20)*	Selected For *(M or S > 0.20)*	Selected Against *(M or S< -0.20)*	Proportional use *(M or S <0.20)*	Selected For *(M or S > 0.20)*	Selected Against *(M or S< -0.20)*	Proportional use *(M or S <0.20)*	Selected For *(M or S > 0.20)*	Selected Against *(M or S< -0.20)*
Barley	*					*	*		
Canola		*				*		*	
Coniferous forest	*			*				*	
Deciduous forest		*				*		*	
Distance to park			*	*					*
Flaxseed	*					*	*		
Grassland			*	*					*
Mixed forest	*			*				*	
Oats		*				*		*	
Paved road density			*	*					*
Peas			*		*				*
Shrubland	*			*			*		
Stream density	*				*		*		
Unpaved road density	*			*			*		
Water	*			*			*		
Wetland	*			*			*		
Wheat	*					*			*

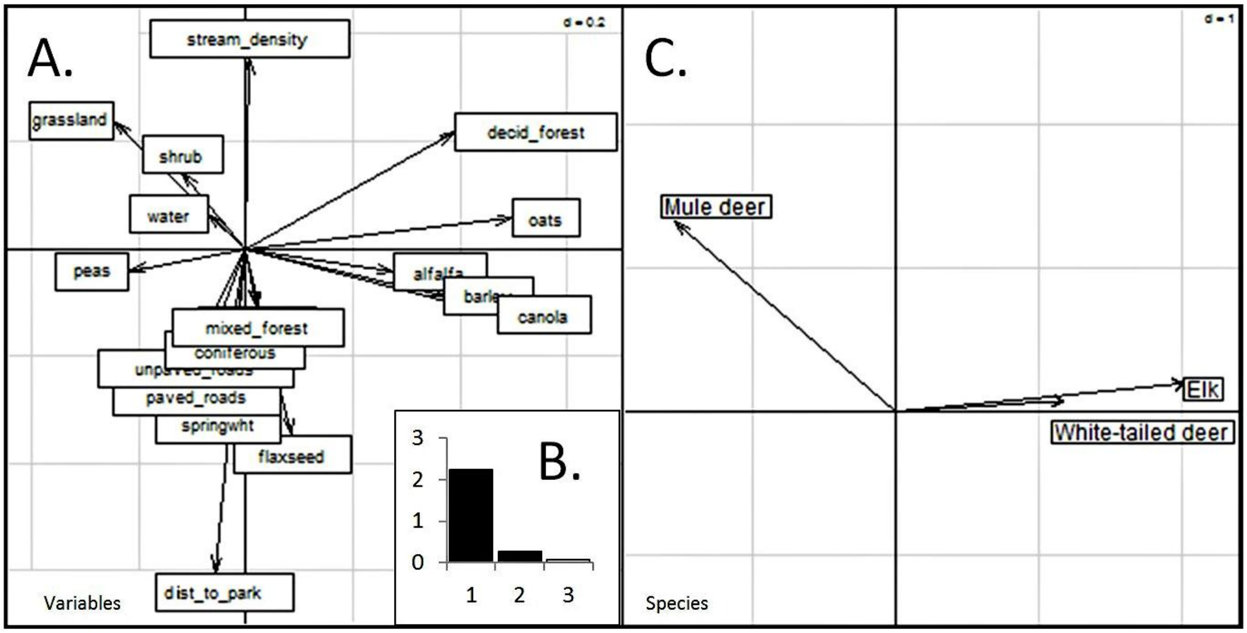


Figure 3.10. K-select analysis carried out to highlight habitat selection by elk, mule deer, and white-tailed deer based on standing crop damage claims paid to farmers in Saskatchewan, Canada (2000-2012). A) variable loadings on the first two factorial axes; B) bar chart of the eigenvalues, measuring the mean marginality explained by each factorial axis; C) projection of the marginality vectors of elk, mule deer, and white-tailed deer

CHAPTER 4: SPATIAL MODELLING OF CROP DAMAGE RISK BY ELK, MULE DEER, AND WHITE-TAILED DEER IN SASKATCHEWAN

4.1 Abstract

As areas of agricultural production expand worldwide, complex zones of wildlife-agriculture interface present numerous benefits and challenges to farmers and wildlife managers. Crop damage has long been a source of wildlife-human conflict, with negative impacts on producers’ tolerance for local wildlife populations, and thus conservation efforts. Furthermore, while many compensation programs alleviate the economic impacts on producers, such reactive measures do not address the cause of damage in the long-term, and indeed may eliminate incentives to implement proactive measures. In western Canada, free-ranging elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*), make frequent use of cereal, oilseed, and pulse crops, which provide a relatively high source of dietary protein and digestible energy. As a result, many producers are faced with economic losses, as their crop production is compromised by free ranging cervids. Given these important considerations, I examined damage claims paid by Saskatchewan Crop Insurance Corporation for losses to annual crops incurred by farmers due to elk, mule deer, and white-tailed deer from 2000-2012. In order to evaluate the risk of annual crop damage by each of the three species across all agricultural lands in Saskatchewan, two metrics were calculated: the probability of damage occurring, and the local financial impact should damage occur. Damage probability values were calculated through species specific resource selection probability functions (RSPFs), and historical values of regional crop production provided a measure of impact. Areas at highest risk for annual crop damage by elk bordered the northern edge of the study area; mule deer risk was highest in south-western and central Saskatchewan; while white-tailed deer risk was highest in north-eastern and north-central areas of the province. By identifying the environmental variables influencing the probability and risk of crop damage, preventative measures may be allocated efficiently, and deliberate and localized management practices may be applied to minimize losses.

4.2 Introduction

Human-wildlife conflicts are a significant obstacle for regional wildlife conservation efforts worldwide and are associated with important costs for agricultural production (Dublin and Hoare 2004, Wang et al. 2006). These interactions have increased across the world as humans continue to transform natural habitats and landscapes through agricultural, urban, and industrial development (Thirgood et al. 2005). As a result of this widespread landscape modification, the complex areas of wildlife-human interface present numerous benefits and challenges to local communities. While many landowners appreciate the aesthetic and intrinsic values of wildlife, or opportunities to harvest food or other wildlife products, local farmers are often faced with the struggle to mitigate or eradicate the impact of crop damage by wildlife to their standing, stored, or baled crops (Conover et al. 1995, Yoder 2002, Osborn and Hill 2005).

During the 1880's, western Canada's prairies and parklands were systematically converted to agricultural lands by arriving European settlers (Knopf 1992, Samson and Knopf 1994). As a result, by the 1990's, Saskatchewan's native prairie had declined by an estimated 80% (Hammermeister et al. 2001). In areas especially well-suited for crop production, <0.1% of the original native prairie communities remain, and any residual native grassland, forest, or shrublands are highly fragmented (Riemer et al. 1997, Laliberte and Ripple 2004). Thus, contemporary conservation efforts in western Canada often focus on preserving large tracts of remaining native habitat, while private lands are considered working landscapes altered into a matrix of cropland, grazing lands, industrial development and patches of native vegetation (Gehlbach 1975, Bender and Fahrig 2005). However, in western Canada, agricultural regions offer highly productive functional habitat for free-ranging elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*), which make frequent use of the rich forage resources within privately owned cropland and grazing pastures (Irby et al. 1996, Fagerstone and Clay 1997, Brook 2009). Compared to native vegetation, common crops in Saskatchewan, such as cereals (wheat, barley, oats), oilseeds (canola and flax), and pulse crops (field peas, chick peas, and lentils) offer wild cervids a relatively high source of dietary protein and digestible energy (Burcham et al. 1999). However, as a result of ungulate crop use, many Saskatchewan farmers are burdened by the cost of crop damage.

In Canada, as with many countries worldwide, programs have been implemented to compensate agricultural producers for damage caused by wildlife. An individual’s susceptibility to economic losses, such as vulnerability to crop damage, has been shown to be a significant contributor to their tolerance of wildlife populations in their area (Decker and Purdy 1988). By minimizing the financial burden for local producers coexisting with wildlife, conservationist and compensation program coordinators aim to lessen the negative consequences of human-wildlife conflict (Nyhus et al. 2005, Bulte and Rondeau 2005). However, few quantitative studies have demonstrated the efficiency of compensation programs in increasing tolerance for wildlife in agricultural communities (Sillero-Zubiri and Laurenson 2001, Nyhus et al. 2005).

Given the important role of crop damage in establishing and maintaining local communities’ conservation ethic, and it impacts on sustainability of agricultural production, I examined the spatial distribution of crop selection by elk, mule deer, and white-tailed deer in all cropland in Saskatchewan. This research was based on damage claims paid by Saskatchewan Crop Insurance Corporation to farmers for losses to annual crops (cereals, oilseeds, pulses) from 2000-2012. My objectives were to a) predict the spatial distribution of crop damage by elk, mule deer, and white-tailed deer, and each possible dual species combination, based on local habitat variables, and b) incorporate economic and environmental measures to map the risk of annual crop damage by elk, mule deer or white-tailed deer for annual cropland in Saskatchewan.

4.3 Study Area

The study area includes all of Saskatchewan’s cropland, situated predominately in the southern half of the province. Saskatchewan accounts for 38.5% of the total agricultural area of Canada, and contains highly productive annual cropland (Statistics Canada 2011). Indeed, Saskatchewan produces 99% of the chickpeas, 95% of the lentils, 86% of the durum wheat, 65% of the dry peas, and 42% of the canola in Canada (Statistics Canada 2011). Each year, 20.6 million hectares are seeded to crops (94%) or left in summer fallow (6%; Statistics Canada 2011). The majority of Saskatchewan cropland is primarily seeded to four main crop types: wheat (spring, durum, and winter, 31%), oilseeds (canola and flax, 28%), pulse crops (field peas, chick peas, and lentils, 9%), and barley (6%; Statistics Canada 2011).

The study area exists within two ecozones, the Prairie Ecozone and the southern edge of the Boreal Plain Ecozone at the forest fringe (Wiken 1986). North America's Great Plains extend into southern Saskatchewan's semi-circular prairie and mixed grassland region, reaching from the western edge of Alberta to the eastern edge of Manitoba, and south to northern Texas (Coupland 1961, Wiken 1986). The northerly edge of this region marks the beginning of the aspen parkland and boreal transition, where broadleaf trees such as trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) begin to emerge, interspersed with jack pine (*Pinus banksiana*), white spruce (*Picea glauca*), and black spruce (*Picea mariana*; Johnson et al. 1995). The majority of Saskatchewan's native grassland (estimated 80%) has now been replaced by farmland, resulting in isolated and fragmented small patches of wetland, grassland, shrubland, and forest (Hammermeister et al. 2001).

4.4 Methods

4.4.1 Dataset

In order to identify areas with the highest probability of risk of crop damage by elk, mule deer, or white-tailed deer, and each possible dual species combination, I used a database of existing damage claims made to Saskatchewan Crop Insurance Corporation (SCIC) from 2000-2012. With joint funding through the provincial and federal government, SCIC offers a wildlife damage program that provides compensation payments to agricultural producers who experience losses of their agricultural crops through consumption, trampling, or excretion by wildlife. Fourteen wildlife species, including white-tailed deer, elk, and mule deer, are covered by this program, and over 30 crop types are eligible for compensation. Additionally, claims for damage caused by two cervid species concurrently at the same site are also listed within the dataset, coded by primary and secondary cause of loss. Compensation payments are calculated based on the appraised quantity of damaged product within the reported area, multiplied by that crop's price, as determined by SCIC's annual average price surveys based on market pricing. There is no maximum payment amount; however, compensation payments will only be made to producers if there is a minimum of $150 appraised damage. No premiums or administrative fees are required of producers in order to receive coverage, and since 2010, compensation payouts have increased from 80% of the crops' market value to its current rate of 100% of the crop value (Dan Baber, Saskatchewan Crop Insurance Corporation, personal communication, 2013).

4.4.2 Predicting probability of damage to annual crops

To predict the probability of annual crop damage by elk, mule deer, and white-tailed deer in Saskatchewan, as well as the probability of species overlap in crop damage, I used resource selection probability functions (RSPFs). Resource selection probability functions are predictive models based on binary logistic regression, that determine the probability of an individual animal selecting a resource based on comparing used and unused sample units as a function of availability of those resources (Boyce and McDonald 1999, Manly et al. 2002). RSPFs are highly effective in associating animal distribution with spatial heterogeneity in resource distribution when comparing sites used by a study species to unused locations (Manly et al. 2002). Therefore, I used wildlife damage claims for annual crops provided to me by Saskatchewan Crop Insurance Corporation as a measure of species presence at each crop damage location. The centroid UTM coordinates of sections where annual crop damage occurred from 2000-2012 served as presence points for elk (n= 4,811), mule deer (n= 1,700), and white-tailed deer (n= 12,558) RSPF models. In some cases (46.8%), individual damage claims included two concurrent species. These combination damage claims were used in order to generate separate multispecies crop damage models (white-tailed deer and mule deer n= 3,367; white-tailed deer and elk n= 13,082; mule deer and elk n=309) using the same analytical approach used for the single species models where the dependent variable was the presence/absence of damage by each two species combination. In total, 35,827 claims were used in this analysis, once all claims were screened to ensure they fell within cropland.

Since RSPF models rely on used and unused sites as the dependent variable, I identified sets of absence points for each of my study species. Sites of confirmed SCIC crop damage claims (presence locations) were removed from the existing study area of agricultural lands in order to prevent "zero contamination", i.e. inclusion of sites used by study species in the unused sample (Johnson et al. 2006). All locations where no damage claims were recorded were assumed to be unused, and sets of absence points for the model were then randomly selected from all unused areas for each study species (and combination of species for the overlap maps) across the study area with a sample size matching the respective species presence locations.

Sets of environmental covariates predicted to determine elk, mule deer, and white tailed deer damage to crops were selected *a priori* as independent variables for the RSPFs based on the results of separate ecological niche factor analyses (ENFA) conducted on each species (see Chapter 3). The ENFA results quantified the contributions of different eco-geographical variables to each species' niche through two measures, marginality and specialization. Marginality values provide a measure of the difference between the habitat used by an organism and the habitat available to it in a multidimensional ecological space (Hirzel et al. 2002, Calenge et al. 2005), while specialization measures of how restricted a species niche is in relation to the whole available study area (Hirzel et al. 2002, Reutter et al. 2003). Any marginality or specialization value for a given variable greater than 0.20 indicated a species' selection for that variable, while values less than −0.20 indicated selection against that variable (Table 4.1; Lande et al. 2010). Values between 0.20 and −0.20 indicate proportional use of that variable, and were not included as RSPF covariates while all others were retained for the RSPF analysis.

Table 4.1. Environmental covariates predicted *a priori* to determine elk, mule deer, and white-tailed deer damage to conduct resource selection probability function models of annual crop damage within Saskatchewan, Canada (2000-2012) based on ecological niche factor analyses.

Elk		**Mule deer**		**White-tailed deer**	
Selected For	Avoided	Selected For	Avoided	Selected For	Avoided
Canola Deciduous forest Oats	Distance to park Grassland Paved road density Peas	Peas Stream density	Barley Canola Deciduous forest Flaxseed Oats Wheat	Canola Coniferous forest Deciduous forest Mixed forest Oats	Distance to park Grassland Paved road density Peas Wheat

All covariate data were projected in the form of raster maps using the software programs ArcGIS10.1, and Geospatial Modelling Environment (Beyer 2012). The proportions of each agricultural crop type (Statistics Canada 20006 Census of Agriculture), as well the proportion of forests, grasslands, shrublands, wetlands, and water bodies (Geobase Land Cover, 2000) present on the landscape were measured at the scale of 1.6 km by 1.6 km (section), using 100m by 100m resolution rasters. The accuracy of Geobase land cover data was independently assessed by comparing 400 random ground-referenced sites to the digital map data, and determined to be 84% accurate across the four primary land cover classes (deciduous forest, grassland, forage cropland and wetland; Dugal 2012). Variables such as stream density (National Hydro Network, 2004, via Geobase), paved road density, and unpaved road density (National Road Network, 2003, via Geobase) were measured within every 9.65 km by 9.65 km (6 mile by 6 mile) township. The distance to large protected areas was also included as a covariate by creating a map presenting the minimum distance of every section to a national, provincial, or regional park, historical site, wilderness area, bird sanctuary, or provincial forest (Geosask, Sask Admin: Parks, 2012).

All statistical analyses, including the development of logistic regression models, were conducted in the statistical program R (version 2.14.1, R Development Core Team 2011). Following the selection of covariates using the ENFA technique, all variables were screened for inter-correlations using a Spearman's rank correlation matrix (R Development Core Team 2010). No significant correlations ($r_s>0.7$) were detected, therefore, no variables were removed. Sets of candidate *a priori* models were generated for each species including variables identified as being significant by ENFA, as well as all possible additive combinations of independent variables (Appendix B, Table B. 1 and Table B. 2). The following model structure was used:

$$W(x) = \frac{exp(\beta_1\chi_1 + \beta_2\chi_2 + \ldots + \beta_z\chi_z)}{1 + exp(\beta_1\chi_1 + \beta_2\chi_2 + \ldots + \beta_z\chi_z)}$$

where $W(x)$ is the RSPF value for each section, and β_1 is the coefficient for the predictive habitat variable χ_1 of z covariates (Manly et al. 2002). The most parsimonious model for each species was identified using Akaike's Information Criterion (ΔAIC), with the model having the lowest ΔAIC considered to be the best model (Burnham and Anderson 2002). Once the best model was selected for each species, predictive mapping was conducted in the software programs ArcGIS10.1 based on each best models' equation.

Ninety percent of the crop damage claims were used to develop each RSPF model, while a randomly selected ten percent of claims were withheld from the initial model creation for independent validation purposes (Boyce et al. 2002). Receiver Operating Characteristic (ROC) curves were used to measure the predictive accuracy of all RSPF models (Harrell et al. 1996, Fielding and Bell 1997). Area under the curve (AUC) values produce estimates of accuracy, with AUC>0.5 indicating adequate model predictive capacity and AUC values approaching one are extremely accurate (DeLeo 1993).

4.4.3 Mapping risk of damage to annual crops

While RSPF modeling provides a measure of how the combination of environmental factors within a given area influences the distribution of crop damage by each study species, this measure alone does not estimate the true risk of agricultural crop damage (Enari and Suzuki 2010). Risk colloquially refers to the probability that an undesirable outcome will happen, and risk assessment involves the quantification of this probability (Rowe 1977). However, based on the risk triplet concept (Kaplan and Garrick 1981), risk assessment must include not only an estimate of the likelihood of an adverse endpoint (L), but also an approximation of the economic impacts should that endpoint occur (I). Thus, the risk for endpoint x (Ex) may be calculated by multiplying Lx and Ix (Kaplan and Garrick 1981).

The RSPF maps for each cervid species provided a measure of likelihood (L) of damage (Peterson and Vieglais 2001, Enari and Suzuki 2010). Economic impact was calculated using data from the Statistics Canada Census of Agriculture (2001, 2006, 2011), which reports production averages (metric tonnes) for each crop type per census region, as well product prices (dollars per metric tonne) for the same time period of the study (2000-2012). Using these data, I created a raster map depicting the dollar value of annual crop production within each census region, then divided these totals down to the section level, based on the area of each region. The previously produced species specific RSPF values for each section (L) were multiplied by the spatially corresponding crop dollar value (I) in order to produce maps of the risk of annual crop damage by elk, mule deer or white-tailed deer for every section of cropland in Saskatchewan.

4.5 Results

4.5.1 Probability of damage to annual crops in Saskatchewan

In determining the best models to predict the probability and spatial distribution of crop damage by elk, mule deer and white-tailed deer in Saskatchewan, I found great differences in selection patterns among the three study species. Best models were identified for each study species and multispecies combination using ΔAIC, (Table 4.2) and these differed markedly between species. Elk avoided areas with a high density of paved roads, open grassland, peas, and areas increasingly farther from protected areas, while selecting for oats, canola, and areas with greater deciduous forest cover (Fig. 4.1). Mule deer avoided barley, flaxseed oats, wheat, and deciduous forest, and selected for canola, peas, and higher stream density (Fig. 4.1). White-tailed deer avoided open grasslands, wheat, areas increasingly farther from protected areas, and areas with higher densities of paved and unpaved roads, while selecting for canola, oats, and deciduous forest (Fig. 4.1). Mapping the best RSPF models for crop damage by each species and combination of species provided a graphic representation of the probability of crop damage for each section of agricultural land in Saskatchewan for elk, mule deer, white-tailed deer, white-tailed deer and mule deer, white-tailed deer and elk, and mule deer and elk (Fig. 4.2).

Receiver Operating Characteristic (ROC) curves measured the predictive accuracy of each RSPF models, with area under the curve (AUC) values approaching one indicating high model accuracy. All models were deemed acceptable (DeLeo 1993), with the elk model and white-tailed deer and elk combination model exhibiting the highest model accuracy (AUC= 0.915) and the white-tailed deer and mule deer model displaying the lowest accuracy (AUC= 0.658; Fig. 4.3).

4.5.2 Risk of damage to annual crops in Saskatchewan

RSPF probability maps were transformed into true measures of risk for annual crop damage by elk, white-tailed deer, and mule deer by incorporating the associated crop production values of each section (Fig. 4.4). Maps depicting areas the distribution of crop damage risk by the three study species highlighted important spatial differences and similarities (Fig. 4.5). Areas at highest risk for annual crop damage by elk were found bordering the northern edge of the study area, along Saskatchewan's forest fringe. Risk of annual crop damage by mule deer was highest in south-western and central Saskatchewan, while white-tailed deer annual crop damage risk was highest in north-eastern and north-central areas of the province.

4.6 Discussion

Maps depicting regional risk of annual crop damage identified similarities and difference in the spatial distribution of risk for elk, mule deer, and white-tailed deer. These risk maps are a useful tool for producers to assess risk in their region and evaluate mitigation options and cropping patterns. Patterns of selection and avoidance of eco-geographical variables revealed by species- specific RSPFs also provide valuable insight to producers looking to minimize annual crop damage on their property. Additionally, this research could prove to be a valuable asset for Saskatchewan Crop Insurance Corporation (SCIC) to prioritize their efforts. Like many compensation programs, SCIC remains heavily dependent on federal and provincial funding sources, raising concerns of the long-term sustainability and practicality of such programs (Bulte and Rondeau 2005). Currently, if an SCIC adjuster recommends constructing a fence to prevent recurring losses to standing or stored crop, a producer can receive funding to offset the material costs (Saskatchewan Crop Insurance Corporation 2013). Maps depicting the economic risk of annual crop damage, based on species-specific selection patterns and crop values, highlight those areas of greatest concern, and could function as an initial assessment tool to prioritize the distribution of these funds.

Selection and avoidance patterns of my three study species and multispecies combinations corroborates prior ENFA findings (see Chapter 3.0), as demonstrated by the inclusion of covariates previously deemed significant in the best models identified using ΔAIC. Elk selected annual cropland foraging sites in areas with greater deciduous forest cover, located near protected areas, while avoiding areas with a high density of paved roads and a high density of open grassland. This selection of foraging sites is consistent with previously established studies of elk habitat selection in western Canada (Gooding and Brook 2011, Dugal 2012). Individuals in closer proximity to roads often experience increased hunting risk, while parks or protected areas may offer refuge from hunting and human disturbance (Conner et al. 2001, McCorquodale 2003, Dugal 2012). Similarly, white-tailed deer avoided open grasslands, areas farther from protected areas, and areas with higher densities of paved and unpaved roads, while selecting deciduous forest. White-tailed deer have been shown to thrive in agricultural areas interspersed with early successional forest habitat, containing woody and herbaceous forage (Halls et al. 1984, Desmarais et al. 2000). Widespread agricultural activities have arguably improved deer habitat in areas of North America throughout the twentieth with the increase in forage quality (Alverson et al. 1988, Porter and Underwood 1999, Côté et al. 2004).

Alternately, mule deer avoided the selection of annual crops in areas with deciduous forest, and selected for areas with canola, peas, and sites with a higher stream density. Unlike the more forest adapted white-tailed deer and elk (Geist 1998), mule deer are typically found in more open landscapes, utilizing topographic cover associated with river drainages (Mackie et al. 1982). Within southern Saskatchewan, mule deer have been shown to select habitat such as rugged terrain adjacent to large river drainages and upland agricultural land, presumably as such sites offer the combination of thermal cover and nutritious forage (Rees et al. 2012). The RSPF models of each species delineate these selection patterns described, and thus are a useful tool to visually present the probability of crop selection by my three study species.

In order to assess regional risk of crop damage by elk, mule deer, or white-tailed deer, I relied on past damage claims made to Saskatchewan Crop Insurance Corporation (SCIC) from 2000 to 2012. RSPF models rely on used and unused sites, thus sets of absence points were generated for each of my study species. I used this approach under the important assumption that the lack of an SCIC crop damage claim indicates little to no use of annual crops on a given section by my study species. While cases may exist where producers actively choose not report cervid damage due to wildlife appreciation or privacy concerns, these circumstances are likely rare. All SCIC reporting and appraisal processes are conducted at no cost to the producer; therefore the potential for financial gains presumably encourages producers to report any and all potential cases of damage. Small scale damage incidents may go unnoticed or unreported; however, the low monetary value of these minor events likely would not alter my findings to any degree of significance. Therefore, I deemed this assumption acceptable. Additionally, concerns have been raised regarding the strength of species identification in the crop damage claims data. According to an SCIC adjustor, producers typically report the identification of the cervid species responsible for damage to the adjuster upon appraisal (Dan Baber, Saskatchewan Crop Insurance

Corporation, personal communication, 2013). Agricultural producers have been shown to be accurate observers and chroniclers of cervid activity on their property (Brook and McLachlan 2006, 2009, Brook 2008), with great ability to recall pertinent information over long time periods, especially when the event is of high personal importance (Huntington 2000, Brook and McLachlan 2008, 2009). One of the great strengths of this research lies in the large sample size of the SCIC dataset, spanning a thirteen year period across the entire province of Saskatchewan. The examination of crop damage claims has been shown to be an effective method in identifying patterns of wildlife cropland selection (Naughton-Treves 1998, Sitati et al. 2005, Gooding and Brook 2011). Through the analysis of thousands of damage claims, spatial similarities can be established, and when compared to the attributes of available damage-free sites, it is possible to estimate the relative strength of selection of resources by wildlife.

Common annual crops in Saskatchewan provide a relatively high source of dietary protein and digestible energy to wild cervids, compared to native vegetation (Burcham et al. 1999). However, many farmers are burdened by the cost of crop damage done by these ungulates (Lacey et al. 1993, Wywialowski 1994), and local producers must balance the economic decisions of production with their conservation ethic (Brook 2009). The concept of wildlife acceptance capacity (WAC) reflects the maximum wildlife population level in an area that is tolerated by the local community (Decker and Purdy 1988). The publics' concern for their individual economic security and tolerance for wildlife damage can greatly influence their WAC. For instance, producers growing high-value crops that are susceptible to damage have a lower WAC than other farmers (Decker and Brown 1982). Therefore, better understanding wildlife species' selection patterns and quantifying damage risk is a crucial step in order to mitigate losses, maintain communities' wildlife appreciation, and pursue co-operative management and conservation objectives. Secondly, by understanding factors influencing species-specific crop selection, the risk of crop damage may be proactively managed, rather than reactively compensated through insurance programs. Not only are such programs economically draining to operate (Naughton-Treves 1998, Terborgh 2002, Bulte and Rondeau 2005), but they also present a problem which economists refer to as moral hazard (Rollins and Briggs 1996). By offering 100% monetary coverage on production losses, compensation program sponsors remove the incentive for producers to take preventive actions in protecting crops (Nyhus et al. 2005). Alternately, the aforementioned method of risk mapping provides an applied ecologic and economic approach to allocating damage prevention resources. Through the calculated management of wildlife populations and agricultural practices, mutually beneficial wildlife-human coexistence can be achieved.

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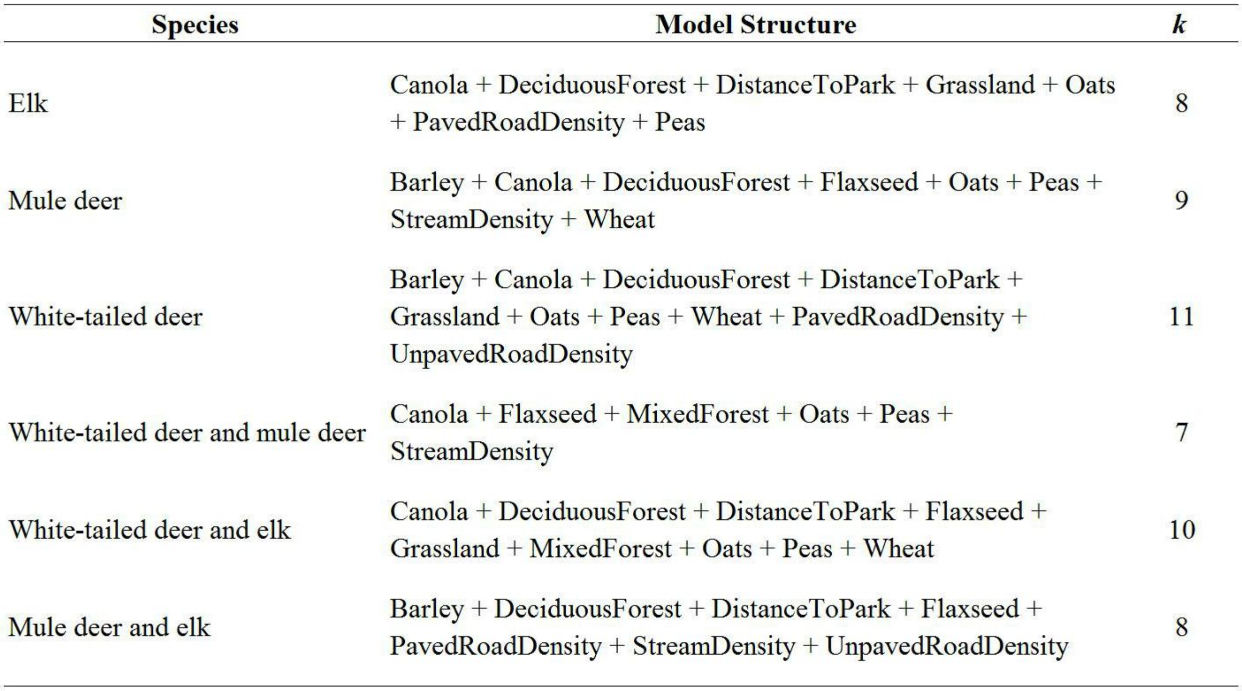
4.8 Figures and Tables

Table 4.2. Best RSPF models comprised of habitat variables hypothesized to determine annual crop damage (Saskatchewan, 2000-2012), based on Akaike's Information Criterion equal to zero. *K* indicates the number of parameters within each model.



Species	**Model Structure**	***k***
Elk	Canola + DeciduousForest + DistanceToPark + Grassland + Oats + PavedRoadDensity + Peas	8
Mule deer	Barley + Canola + DeciduousForest + Flaxseed + Oats + Peas + StreamDensity + Wheat	9
White-tailed deer	Barley + Canola + DeciduousForest + DistanceToPark + Grassland + Oats + Peas + Wheat + PavedRoadDensity + UnpavedRoadDensity	11
White-tailed deer and mule deer	Canola + Flaxseed + MixedForest + Oats + Peas + StreamDensity	7
White-tailed deer and elk	Canola + DeciduousForest + DistanceToPark + Flaxseed + Grassland + MixedForest + Oats + Peas + Wheat	10
Mule deer and elk	Barley + DeciduousForest + DistanceToPark + Flaxseed + PavedRoadDensity + StreamDensity + UnpavedRoadDensity	8

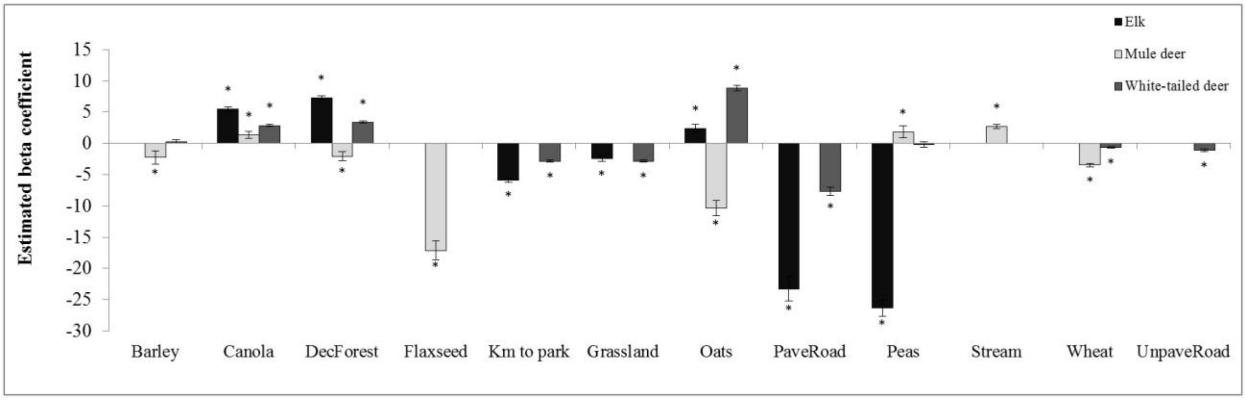


Figure 4.1. Strength and direction of relationship (±S.E.) for variables hypothesized to determine crop damage, from logistic regression resource selection probability function models for annual standing crop damage by elk, mule deer, and white tailed deer in Saskatchewan, Canada (2000-2012).Variables significantly different from zero are presented with an asterix.

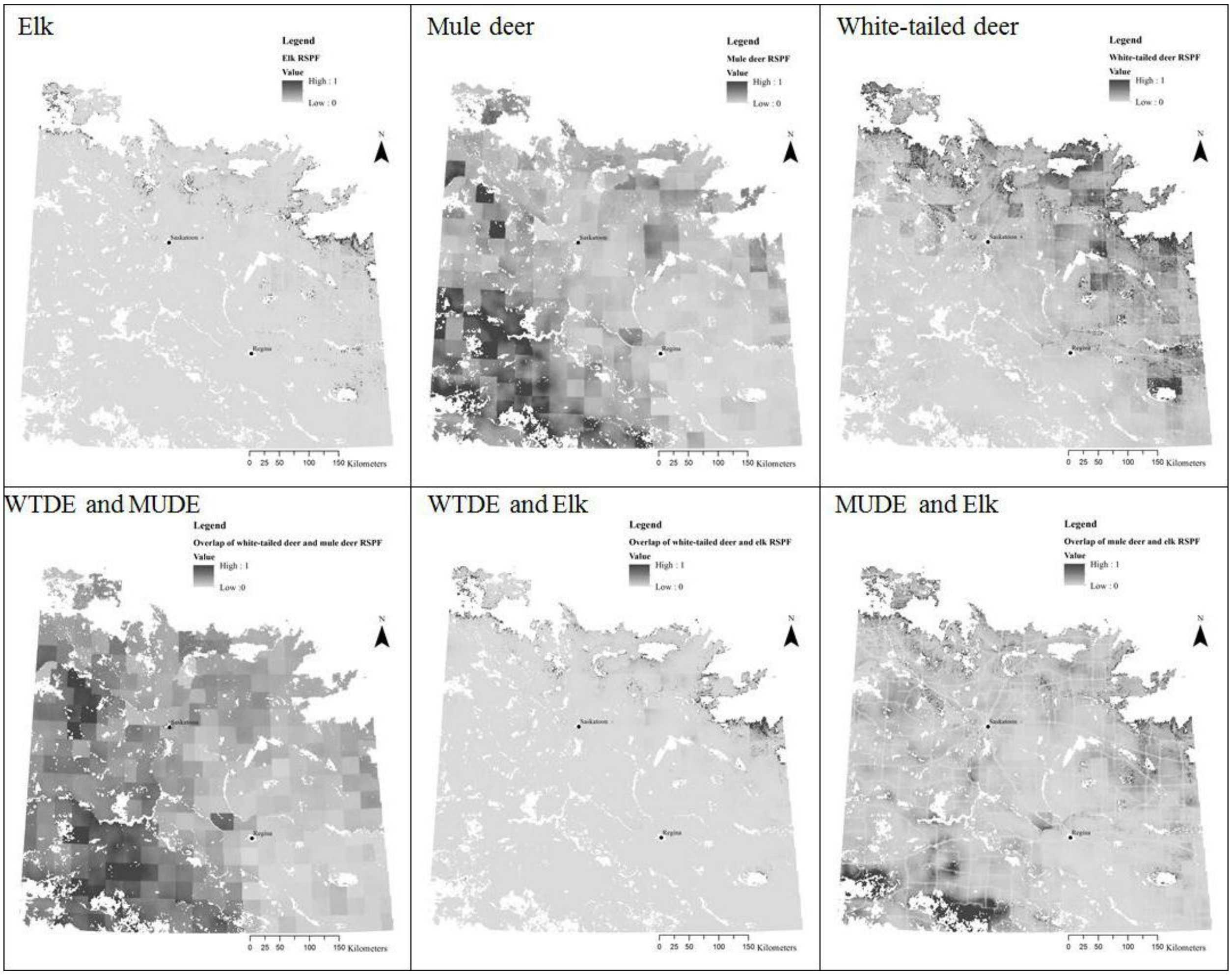


Figure 4.2. Interpolated map surface representing resource selection probability function models for annual crop damage in Saskatchewan, Canada by A) elk, B) mule deer, C) white-tailed deer, D) white-tailed deer and mule deer, E) white-tailed deer and elk, and F) mule deer and elk (2000-2012). Darker shaded sections represent areas of high probability for annual standing crop damage whereas lighter shaded sections represent areas of low probability of annual standing crop damage.

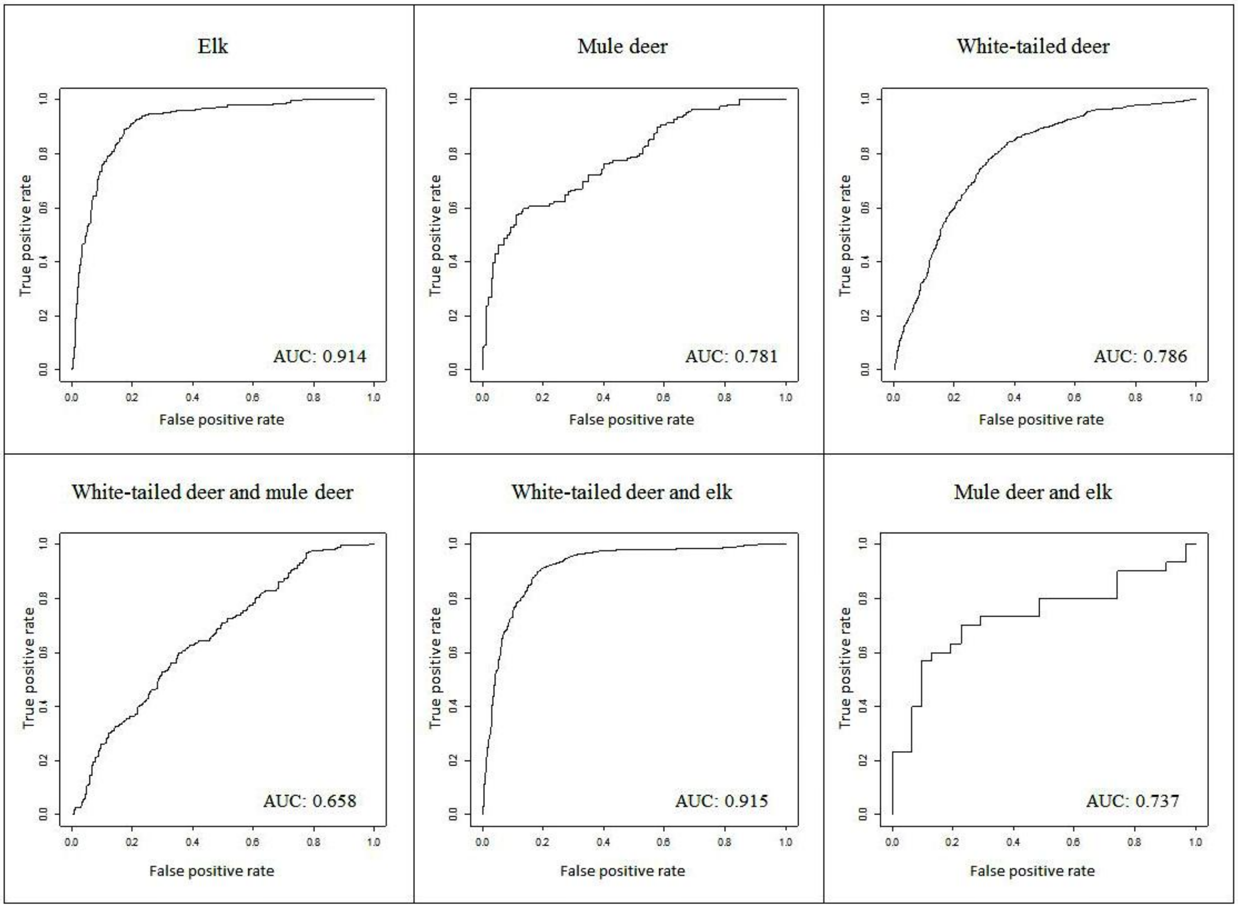


Figure 4.3. Receiver operator characteristic (ROC) curves for the RSPF models of elk, mule deer, and white-tail deer crop damage and the RSPF models of combined species crop damage in Saskatchewan, Canada (2000-2012). Area under the curve (AUC) values approaching one indicate very high model accuracy.

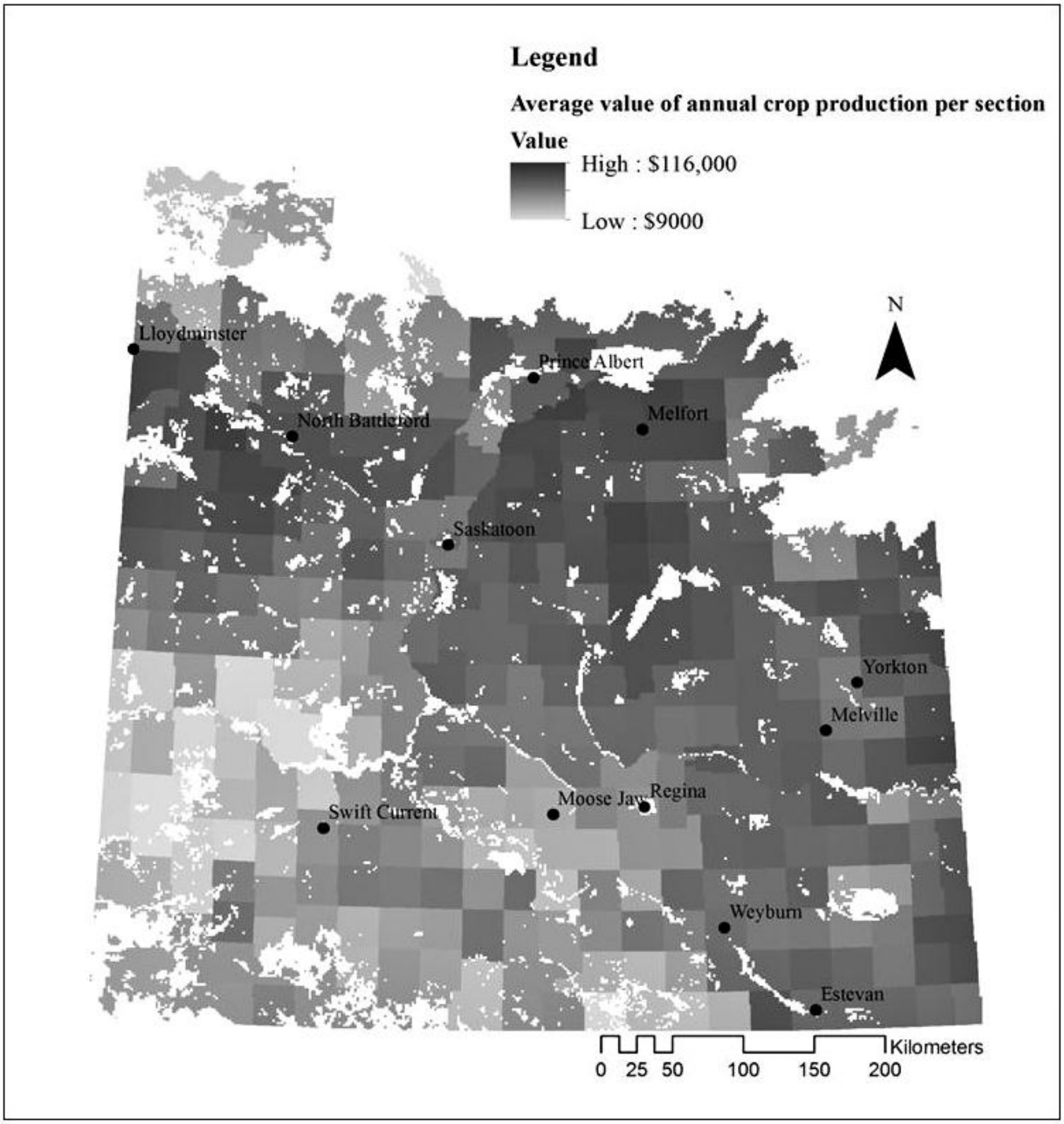


Figure 4.4. Dollar value of crop production per year, per section, in Saskatchewan, Canada, based on production averages (tonne) and averaged prices per metric tonne (2000-2012)

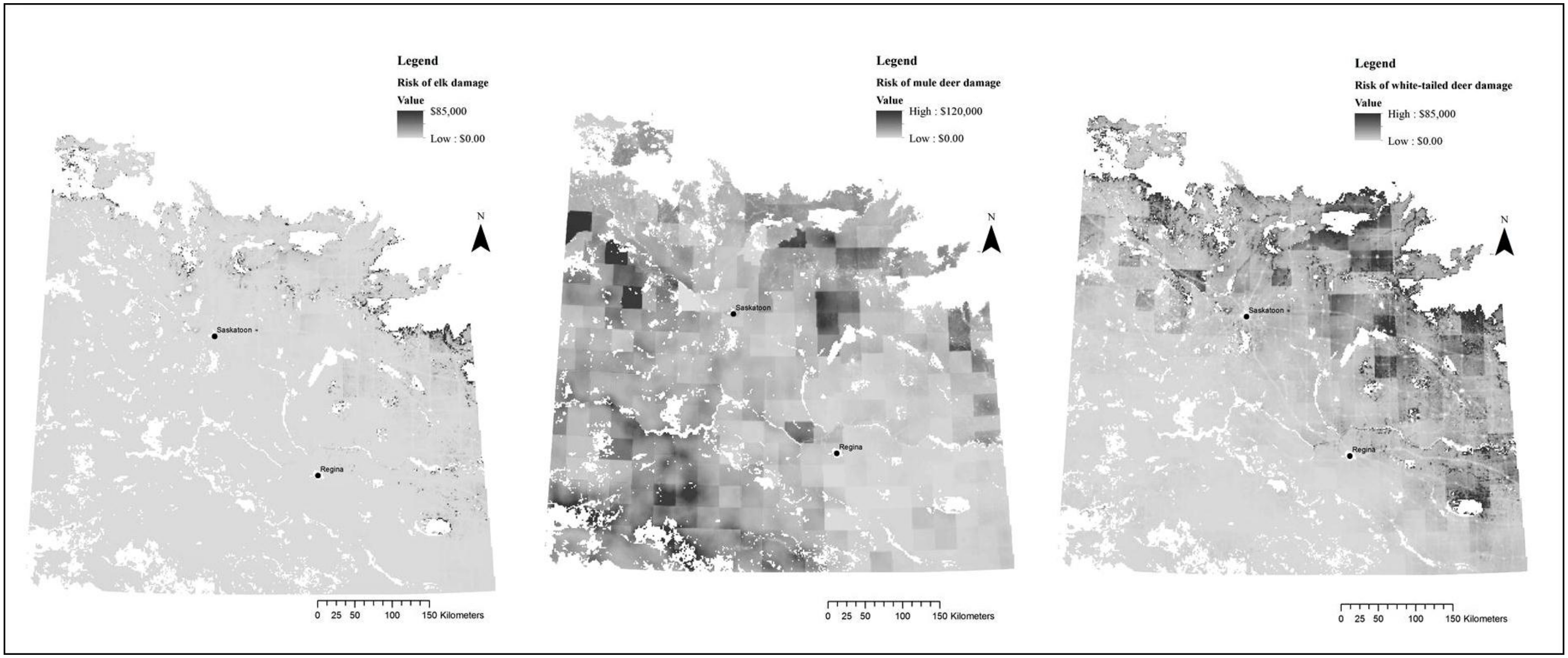


Figure 4.5. Areas of highest risk of annual crop damage by elk, mule deer, and white-tailed deer in Saskatchewan, Canada, based on species' RSPF values for crop damage, regional crop production averages, and averaged crop prices (2000-2012; Statistics Canada Census of Agriculture 2001, 2006, 2011).

CHAPTER 5: GENERAL DISCUSSION

5.1 Review and Synthesis

Damage to standing crops by cervids has long been a significant source of human-wildlife conflict in western Canada (Lee 1979, Brook 2009), and the issue continues to be a major obstacle in maintaining local support for wildlife conservation efforts (Hegel et al. 2009). While wildlife damage compensation programs like Saskatchewan Crop Insurance Corporation (SCIC) offer producers relief from the financial losses of crop damage, these programs often do little to repair the underlying causes of crop selection by wildlife (Rollins and Briggs 1996, Bulte and Rondeau 2005) and are economically draining to operate (Naughton-Treves 1998, Terborgh 2002, Bulte and Rondeau 2005). Additionally, contamination of communal feeding areas frequently used by multiple ungulate species, coupled with conditions that facilitate concentrations of animals in high densities, have been shown to increase the rate of chronic wasting disease (CWD) transmission (Miller et al. 2000, 2006, Sorensen et al. 2013). Developing predictive models of resource selection at the local and landscape level has also proven an effective method in mitigating wildlife-agriculture conflicts (Naughton-Treves 1998, Sitati et al. 2005, Retamosa et al. 2008). Furthermore, understanding animal ecology and behaviour, including feeding patterns and habitat selection, is a crucial first step in managing disease spread (McCallum and Dobson 1995, Knust et al. 2011, Brook et al. 2013).

The examination of resources selection patterns by three sympatric cervids established here could also provide an opportunity for more theoretical –based future research. Agricultural products, such as standing or baled crops, may provide a relatively novel forage resource to co-existing cervid species. Since high levels of interspecific competition and niche overlap between cervids can result in decreased performance of one or both species, theories have emerged implying that resource partitioning occurs in natural environments to relive the pressures of competitive exclusion (Hudson 1976, Schwartz and Ellis 1981, Jenkins and Wright 1988, Stewart et al. 2010). Resource partitioning among co-existing species can be defined as divergence in resource use between species which once had greater overlap in their requirements, and is often thought to result from “the ghost of competition past” (Connell 1980, 1983, Walter 1991). Alternatively, partitioning of resources may reflect independent responses of populations to environmental gradients, rather than strictly a response to competition (Jenkins and Wright 1988).The introduction of a novel food source may shift niche overlap, and alter patterns of resource partitioning (Schoener 1974, Stewart et al. 2002).

Hofmann's 1983 classification of Cervidae by feeding type described both mule deer and white-tailed deer as concentrate selectors, based on their by their poor capacity to digestive fibre and their high metabolic rate. Highly selective feeding behaviours allow these cervids to target only herbaceous material rich in digestible inner cell components, with only a small portion of easily degradable cell wall portions (Hofmann 1985). Elk, alternately, are classified as intermediate feeders, with a higher tolerance for fibrous components in their diet, and thus greater flexibility to feed opportunistically on a wider variety of forages (Hofmann 1985). However, my research raised two points that seemingly contradict Hofmann's classification (1983). The high marginality value of elk, in comparison to the values of mule deer and white-tailed deer, indicate that elk are exhibiting greater specialist behavior, and are most particular in selecting very specific resources, as opposed to more generalist species such as white-tailed deer. Secondly, K-select analysis demonstrated great similarities between elk and white-tailed deer in the selection of annual crops. Based on Hofmann's classification, one would expect similarities between two concentrate selector species, mule deer and white-tailed deer. However, mule deer demonstrated the most unique pattern of resource selection of the three species examined. The various influences of factors such as competition, resource partitioning, digestive tract adaptations and feeding behaviours have yet to be established for species in this region, and may aid in further understanding the relationships between these sympatric species.

5.1.2 Study Limitations

Reported crop damage claims have been shown to be a useful tool in identifying resource selection patterns of wildlife in cropland regions (Naughton-Treves 1998, Sitati et al. 2005, Gooding and Brook 2011). One common concern in such studies, however, may be the effect of damage incidents which are not reported. For instance, the SCIC claims database identifies thousands of confirmed locations where cervids were present. However, the lack of a claim report on a given quarter section is not definitive evidence of species absence. Cervids may have in fact been present on that site, but producers actively chose not to file a report due to wildlife appreciation, privacy concerns regarding the SCIC appraisal procedure, or time constraints.

Additionally, small scale damage incidents may go unnoticed and unreported. However, the thousands of claims which are reported and verified across my entire study region, over the 13 year study period, provide a substantial source of valuable data with which to establish spatial commonalities and selection patterns. While some annual crop damage sites are certainly absent from this dataset, it is unlikely that there would be any significant consistency in the types of claims which are unreported. Any common spatial or temporal biases in producer's reporting behaviour over 13 years, and across such a large study area, does not seem probable. Therefore, the claims I used from the SCIC database were assumed to be an accurate representation of crop selection patterns by cervids across Saskatchewan.

Additionally the examination of crop damage claims from SCIC, only claims for damage to annual crops by elk, mule deer, and white-tailed deer were examined. For the purpose of this study, annual crops were defined as cereals (wheat, barley, oats), oilseeds (canola and flax), and pulse crops (field peas, chick peas, and lentils) which are reseeded each year. Perennial forage crops such as alfalfa, clover, native pasture, or tame grass hay were excluded due to discrepancies in the dataset. The SCIC claims database does not differentiate between damage to standing crops and damage to stored crops such as baled and stacked forage. Resource selection patterns for cervids would likely differ in instances of standing crop selection as opposed to the selection of densely stored crop products. The degree of selection or avoidance of habitat variables could vary if including both standing and stored crops in this analysis. Therefore, perennial forage crops, which are frequently harvested and stored in open sites accessible to cervids, were completely excluded from this analysis in order to prevent such inconsistencies. Claims for cereal, oilseed, and pulse crops were assumed to be damage occurring in standing crop fields. While instances may occur when annual crop damage claims were reported for stored forage crops such as "greenfeed" bales for livestock, it can be assumed that this would represent a small portion of the 35,827 claims annual crop claims. The benefits and strengths of research using the SCIC dataset lays not only in this large sample size, but also the 13 year time period it spans, and the large spatial scale it covers.

5.2 Key Findings

The purpose of this thesis research was to understand the selection of annual crops by elk, mule deer, and white-tailed deer in agricultural lands across Saskatchewan in order to assess potential for chronic wasting disease transmission, and predict the spatial distribution of crop damage risk. This research provides valuable insight into the primary environmental traits influencing resource selection by these three cervid species, thus highlighting important factors that impact intra- and inter-specific disease transmission. The implementation of these findings in the development of disease management strategies would not only help mitigate the spread of CWD, but also benefit producers aiming to minimize cervid damage to standing crops.

Chapter 3: Selection of agricultural crops by elk, mule deer, and white-tailed deer in Saskatchewan: Implications for agricultural production and disease transmission

The examinations of SCIC damage claims for annual crop damage by elk, mule deer, and white-tailed deer revealed that while patterns in seeded acreage have changed dramatically across Saskatchewan from 2000-2012, patterns of cervid crop selection (use in relation to availability) remained largely unchanged. Elk and white-tailed deer both show the greatest selection for oats, followed by wheat, peas and canola (elk) and flax, peas, and barley (white-tailed deer). Mule deer showed greatest selection (in order) for chickpeas, lentils, and peas. Examining the influence of both crop types and environmental characteristics on crop use by each cervid species revealed similar patterns by elk and white-tail deer both selecting for canola, oats, and deciduous forest, while avoiding areas with a high density of paved roads, farther from protected areas. Mule deer exhibited visually different annual crop selection patterns, favouring open grasslands, shrublands, and areas with a greater density of streams or water bodies.

Chapter 4: Spatial modelling of crop damage risk by elk, mule deer, and white-tailed deer in Saskatchewan

The importance of particular eco-geographical variables, established through their inclusion in the most parsimonious model identified using Akaike's Information Criterion (ΔAIC), corroborated prior ENFA findings (Chapter 3). RSPF maps highlighted areas with the greatest probability of experiencing crop damage by each cervid species, or dual species combinations. These maps provide a valuable representation of species distribution, overlap, and thus potential areas of disease transmission concern, as well as potential insight into the differential CWD prevalence rates among cervid species in Saskatchewan. The further transformation of these probability maps into risk assessment maps determined that areas at highest risk for annual crop damage by elk were found bordering the northern edge of the study area, along Saskatchewan's forest fringe. Risk of annual crop damage by mule deer was highest in south-western and central Saskatchewan, while white-tailed deer annual crop damage risk was highest in north-eastern and north-central areas of the province.

5.3 Recommendations and Conclusions

Efforts to reduce the selection of cereal, oilseed, and pulse crops by free ranging elk, mule deer, and white-tailed deer in Saskatchewan could prove to be a valuable step in not only minimizing crop damage and maintaining wildlife tolerance in rural communities, but also in managing the spread of CWD throughout western Canada. Based on localized, species-specific risk values, a wide variety of preventative measures may be efficiently allocated to benefit both producers and wildlife managers. Crop damage prevention techniques may be summarized in three broad categories: crop protection devices, wildlife population reduction, or habitat modification.

5.3.1 Crop protection devices

The use of frightening devises aimed to prevent or lessen the damage to crops by grazing cervids is a non-lethal method of crop protection frequently supported by the public in urban and rural communities (Reiter et al. 1999). This technique is based on the principle that unnatural tactile, visual, or auditory stimuli reduces the desire of grazers to enter or stay in an area where a valuable crop resource is located (Koehler et al. 1990, Nolte 1999). While devises such as firecrackers, alarms, or flashing lights may be effective over short periods, most cervid species quickly habituate to these measures (Gilsdorf et al. 2002). Additionally, many auditory devises can irritate nearby human residents or have negative effects on non-target species (Matschke et al. 1984). While frightening devices may be an effective method in hazing migrating animals along, they are generally not effective in resolving chronic damage problems (Gilsdorf et al. 2002).

One of the most common techniques to reduce damage to agricultural products is the use of fences. While properly installed and maintained fences can be a very effective in protecting small areas of valuable agricultural product from cervids (Caslick 1980, Brook 2010), the economical investment can be considerable (VerCauteren et al. 2006).Fencing aimed to prevent cervids from crossing or jumping into a field requires great material and labour cost, and may simply funnel damage effects onto adjacent property (Isleib 1995). Temporary fencing that is quickly assembled and moved can be an effective method in lessening the effects of high intensity, short term wildlife movement (VerCauteren et al. 2006) but larger scale permanent structures are often impractical or economically infeasible when examined in a cost-benefit analysis.

The crop protection techniques described above certainly do not offer one ideal economical or practical method to wholly eradicate crop use by cervids. However, in combination with other methods, based on local risk levels identified in my maps, these techniques may be incorporated into producers' efforts in minimizing damage.

5.3.2 Population reduction

Lethal control methods have been a commonly used tool to mitigate local wildlife damage for centuries (Woodroffe et al. 2005) and vary widely in public acceptability by region (Treves et al. 2004). Worldwide, retributive lethal control of crop raiding species such as chimpanzees (*Pan troglodytes*), baboons (*Papio Anubis*), and African elephants (*Loxodonta africana*) have resulted in serious declines in wildlife populations and concerns for species conservation (Naughton-Treves 1998, Woodroffe et al. 2005, Tweheyo et al. 2005). One of the common criticisms of lethal control methods is that they ignore the underlying causes of wildlife –agriculture interactions (Hegel et al. 2009). In regions inherently supportive of grazing wildlife, population reductions will, at best, minimize damage problems for a short time. However as species with high site fidelity, such as white-tailed deer, recover, damage problems may continue to reoccur (Vercauteren and Hygnstrom 1998). Localized hunting efforts may also disperse animals that cause problems, simply moving the crop damage issues elsewhere, and may further increase the probability of disease spread.

In Saskatchewan, given the threat of chronic wasting disease to cervid population, deliberate and targeted hunting efforts may reduce the risk of disease spread (Dugal et al. 2013), however further research is needed to examine the potential negative impacts of hunting in facilitating species dispersal. Co-operative efforts among landowners, urban and rural hunters, and First Nation communities to direct existing hunting efforts at areas identified as high risk for crop damage, may serve as one option to reduce losses to annual crops.

5.3.3 Habitat modification

Given the demonstrated influence of specific environmental factors on cervids' selection of annual crops (Chapter 3), one option for preventing or minimizing crop damage is the modification of the agricultural landscapes which provides functional habitat for elk, mule deer, and white-tailed deer in Saskatchewan. Such efforts rely on substantial knowledge of the target species' ecology and behaviour. Altering land use patterns by planting highly attractive crops farther away from forest edges or protected areas, where elk or white-tailed deer are less likely to cause damage, has been suggested as an option to minimize losses (Hegel et al. 2009). This research offers farmers insight into landscape attributes influencing damage occurrence by elk, white-tailed deer, and mule deer. This influence may then be considered when devising crop seeding patterns, as one way to decrease crop damage.

In conclusion, no one damage prevention approach alone is effective in entirely eliminating the selection of annual crops by grazing cervids in Saskatchewan. However the integration of several different approaches, tailored to local conditions and the cervid species of damage concern, increases the chance of success. My thesis has provided essential insight and an effective framework for allocating these proactive measures. Co-operative efforts to implement these findings into the planning and policies of producers and resource managers may prove to be a valuable step in not only minimizing crop damage and maintaining wildlife tolerance, but also in managing the spread of chronic wasting disease throughout western Canada.

5.4 Literature Cited

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APPENDIX A

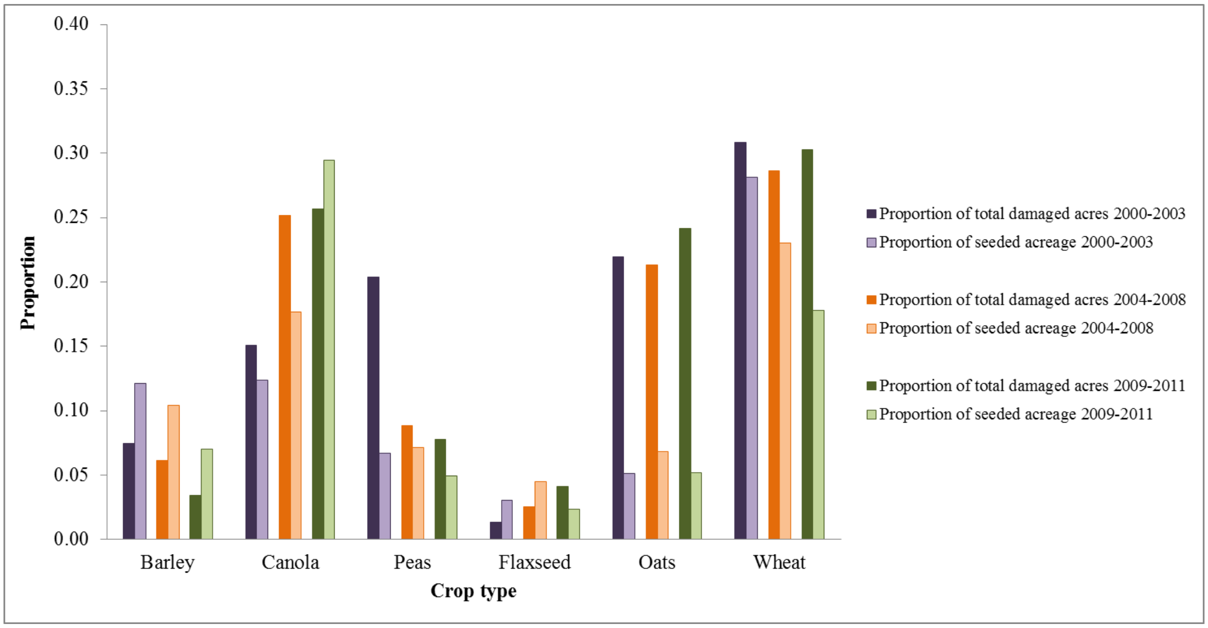


Figure A.1. Proportion of annual crop acres damaged by elk versus the proportion of seeded acres of the primary crop types in Saskatchewan over three time periods: 2000-2003, 2004-2008, 2009-2011.

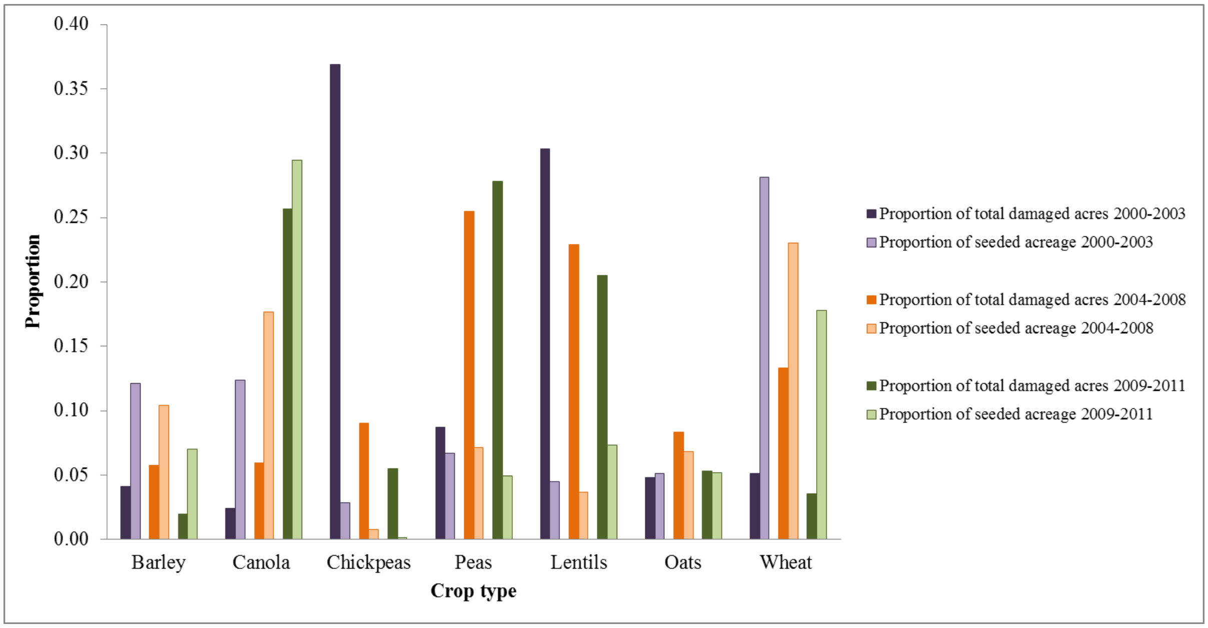


Figure A.2. Proportion of annual crop acres damaged by mule deer versus the proportion of seeded acres of the primary crop types in Saskatchewan over three time periods: 2000-2003, 2004-2008, 2009-2011.

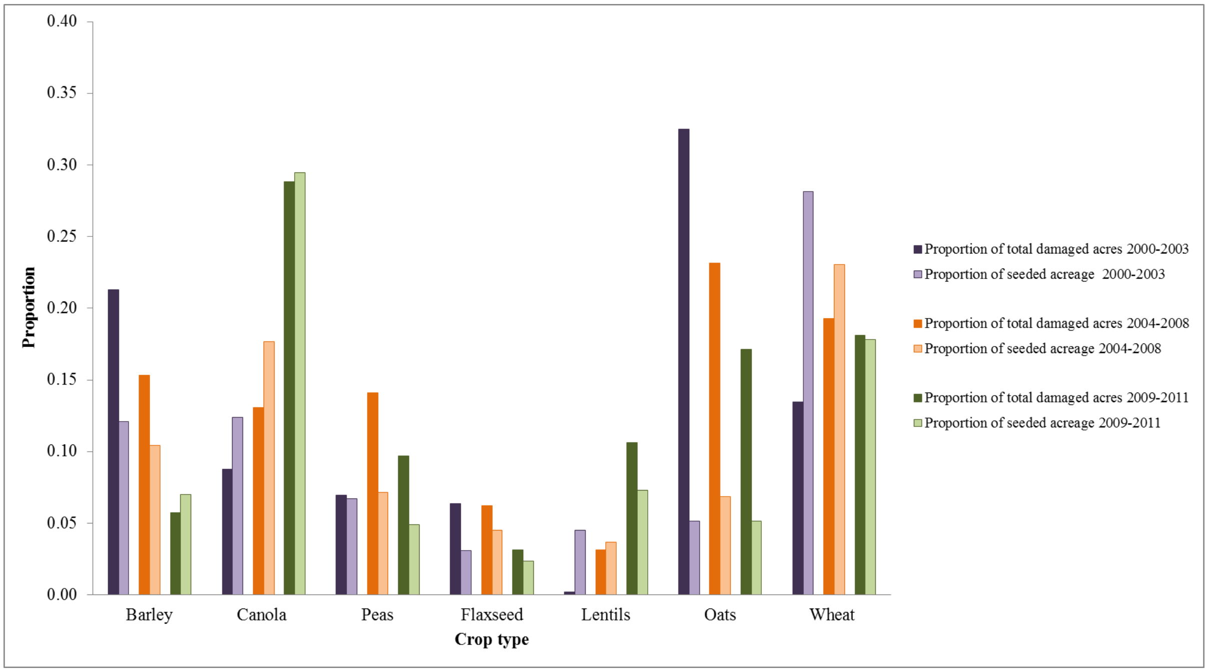
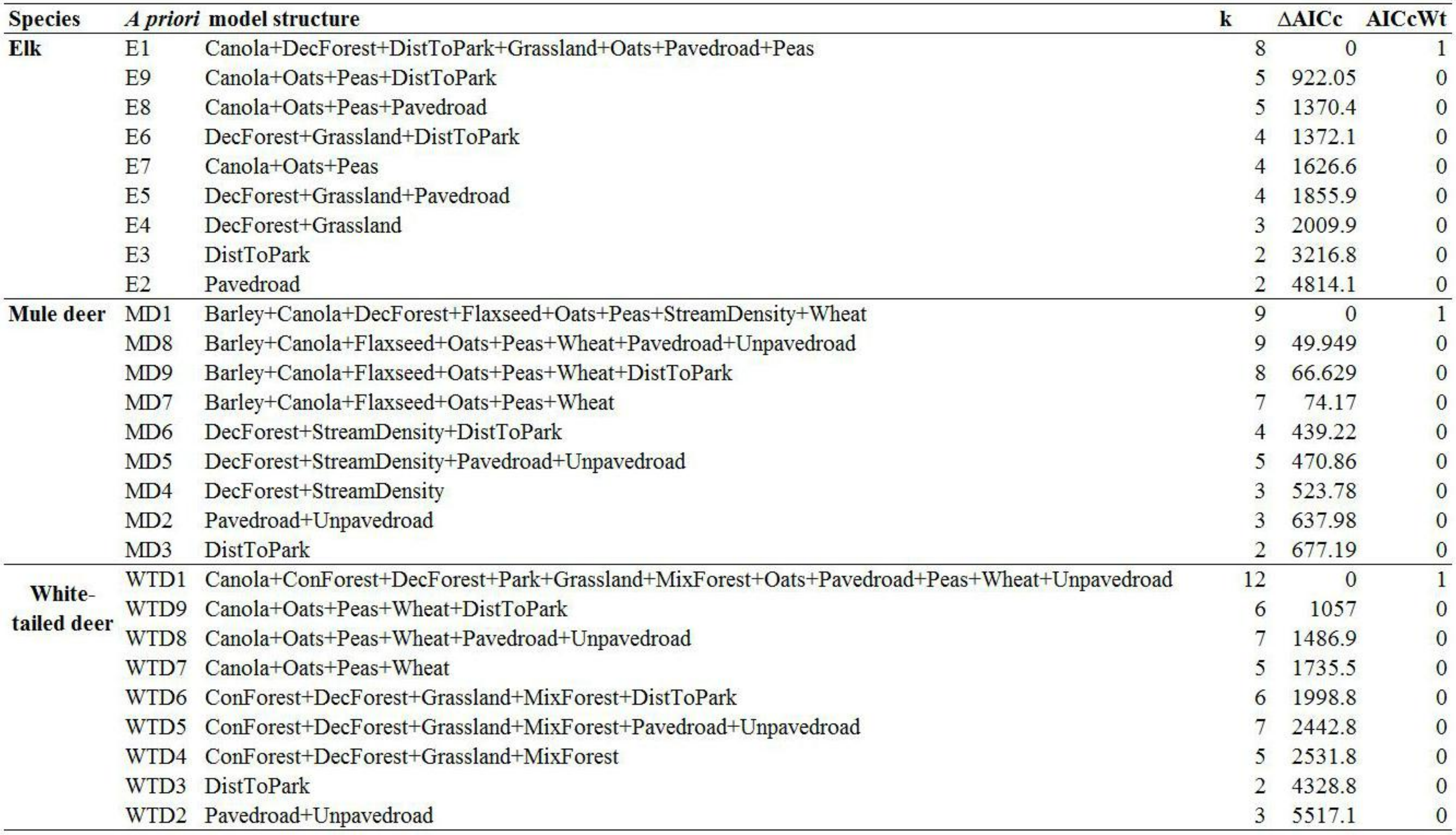


Figure A. 3. Proportion of annual crop acres damaged by white-tailed deer versus the proportion of seeded acres of the primary crop types in Saskatchewan over three time periods: 2000-2003, 2004-2008, 2009-2011.

APPENDIX B

Table B.1. Number of parameters (k), Akaike information criterion (Δ AICc), and AICc weights (AICcWt) for candidate RSPF models for elk, mule deer, and white-tailed deer annual crops selection in Saskatchewan, Canada (2000-2012).



Species	***A priori***	**model structure**	**k**	**ΔAICc**	**AICcWt**
Elk	E1	Canola+DecForest+DistToPark+Grassland+Oats+Pavedroad+Peas	8	0	1
	E9	Canola+Oats+Peas+DistToPark	5	922.05	0
	E8	Canola+Oats+Peas+Pavedroad	5	1370.4	0
	E6	DecForest+Grassland+DistToPark	4	1372.1	0
	E7	Canola+Oats+Peas	4	1626.6	0
	E5	DecForest+Grassland+Pavedroad	4	1855.9	0
	E4	DecForest+Grassland	3	2009.9	0
	E3	DistToPark	2	3216.8	0
	E2	Pavedroad	2	4814.1	0
Mule deer	MD1	Barley+Canola+DecForest+Flaxseed+Oats+Peas+StreamDensity+Wheat	9	0	1
	MD8	Barley+Canola+Flaxseed+Oats+Peas+Wheat+Pavedroad+Unpavedroad	9	49.949	0
	MD9	Barley+Canola+Flaxseed+Oats+Peas+Wheat+DistToPark	8	66.629	0
	MD7	Barley+Canola+Flaxseed+Oats+Peas+Wheat	7	74.17	0
	MD6	DecForest+StreamDensity+DistToPark	4	439.22	0
	MD5	DecForest+StreamDensity+Pavedroad+Unpavedroad	5	470.86	0
	MD4	DecForest+StreamDensity	3	523.78	0
	MD2	Pavedroad+Unpavedroad	3	637.98	0
	MD3	DistToPark	2	677.19	0
White-tailed deer	WTD1	Canola+ConForest+DecForest+Park+Grassland+MixForest+Oats+Pavedroad+Peas+Wheat+Unpavedroad	12	0	1
	WTD9	Canola+Oats+Peas+Wheat+DistToPark	6	1057	0
	WTD8	Canola+Oats+Peas+Wheat+Pavedroad+Unpavedroad	7	1486.9	0
	WTD7	Canola+Oats+Peas+Wheat	5	1735.5	0
	WTD6	ConForest+DecForest+Grassland+MixForest+DistToPark	6	1998.8	0
	WTD5	ConForest+DecForest+Grassland+MixForest+Pavedroad+Unpavedroad	7	2442.8	0
	WTD4	ConForest+DecForest+Grassland+MixForest	5	2531.8	0
	WTD3	DistToPark	2	4328.8	0
	WTD2	Pavedroad+Unpavedroad	3	5517.1	0

Table B.2. Number of parameters (k), Akaike information criterion (Δ AICc), and AICc weights (AICcWt) for candidate RSPF models of dual cervid species selection of annual crops in Saskatchewan, Canada (2000-2012).

Species combination	***A priori***	**model structure**	**k**	**ΔAICc**	**AICcWt**
White-tailed deer and mule deer	WTMU1	Canola+Flaxseed+MixForest+Oats+Peas+StreamDensity	7	0.000	0.9998
	WTMU8	Canola+Flaxseed+Oats+Peas+Pavedroad+Unpavedroad	7	17.505	0.0002
	WTMU9	Canola+Flaxseed+Oats+Peas+DistToPark	6	29.702	0
	WTMU7	Canola+Flaxseed+Oats+Peas	5	59.550	0
	WTMU6	MixForest+StreamDensity+DistToPark	4	607.200	0
	WTMU5	MixForest+StreamDensity+Pavedroad+Unpavedroad	5	620.642	0
	WTMU4	MixForest+StreamDensity	3	681.014	0
	WTMU2	Pavedroad+Unpavedroad	3	693.079	0
	WTMU3	DistToPark	2	737.777	0
White-tailed deer and elk	WTE1	Canola+DecForest+Park+Flaxseed+Grassland+MixForest+Oats+Peas+Whea	10	0.000	1
	WTE9	Canola+Flaxseed+Oats+Peas+Wheat+DistToPark	7	1411.836	0
	WTE8	Canola+Flaxseed+Oats+Peas+Wheat+Pavedroad+Unpavedroad	8	3358.322	0
	WTE7	Canola+Flaxseed+Oats+Peas+Wheat	6	4261.759	0
	WTE6	DecForest+Grassland+MixForest+DistToPark	5	3714.460	0
	WTE5	DecForest+Grassland+MixForest+Pavedroad+Unpavedroad	6	6843.472	0
	WTE4	DecForest+Grassland+MixForest	4	7183.829	0
	WTE3	DistToPark	2	7603.524	0
	WTE2	Pavedroad+Unpavedroad	3	13816.567	0
Mule deer and elk	MUE1	Barley+DecForest+Park+Flaxseed+Pavedroad+StreamDensity+Unpavedroad	8	0.000	1
	MUE8	Barley+Flaxseed+Pavedroad+Unpavedroad	5	33.167	0
	MUE5	DecForest+StreamDensity+Pavedroad+Unpavedroad	5	33.199	0
	MUE6	DecForest+StreamDensity+DistToPark	4	36.104	0
	MUE4	DecForest+StreamDensity	3	40.197	0
	MUE7	Barley+Flaxseed	3	43.782	0
	MUE9	Barley+Flaxseed+DistToPark	4	45.781	0
	MUE2	Pavedroad+Unpavedroad	3	74.691	0
	MUE3	DistToPark	2	94.893	0