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MODELING PRONGHORN RESPONSES TO LANDSCAPE VARIABLES ON CFB SUFFIELD

by

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The undersigned certify that they have read, and recommend to the Faculty of Environmental Design for acceptance, a thesis entitled "MODELING PRONGHORN RESPONSES TO LANDSCAPE VARIABLES ON CFB SUFFIELD" submitted by TOBIN SEAGEL in partial fulfilment of the requirements of the degree of MASTER OF ENVIRONMENTAL DESIGN.

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Abstract

Modeling pronghorn responses to landscape variables on CFB Suffield.

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Prepared in partial fulfilment of the requirements of the degree in the Faculty of Environmental Design, The University of Calgary.
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Forty-three percent of the Grassland Natural Region of Alberta remains in a predominantly native state. However, development continues to alter and fragment this landscape. At the scale of pronghorn management units in Alberta, pronghorn density is positively related to the proportion of native grass prairie. Elsewhere, pronghorn distribution has responded negatively to structures associated with energy development. Therefore pronghorn are a useful indicator species for assessing the cumulative effects of human activities in grasslands. Given the increased activity in Alberta's grasslands there is a need to better understand and quantify the effects on pronghorn. Animal distribution patterns are a fundamental question of ecology that is typically an important aspect of environmental effects assessment. Animal distribution data can be obtained from aerial surveys or from radio relocation (GPS) studies. The purpose of my research was to compare pronghorn resource selection models built from aerial survey and GPS survey techniques and to determine the effects of specific anthropogenic disturbances on seasonal resource selection by pronghorn on Canadian Forces Base Suffield. Aerial survey data and GPS data produced similar distribution probability models. However, GPS location data provided higher resolution, and can be used to analyse short term movement responses to disturbances.

Key Words: pronghorn, habitat model, density distribution, aerial survey, GPS, RSF, CFB Suffield.

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Dedication

My thesis is dedicated to my Mom and Dad.

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Chapter One: Introduction

1.1 Introduction

The Grassland Natural Region of Alberta occupies 97,125 km^2 or 14% of the province, extending from the Saskatchewan border to the Rocky Mountains and from the southern edge of the Parklands to Montana (Downing and Pettapiece 2006). Currently, only about 43% (40,468 km^2) remains in a native state (PCF 2000). Anthropogenic development of this landscape continues to alter and fragment native grassland. The primary cause of habitat loss has been conversion of grassland through cultivation (PCF 2006). Pressures on remaining native grassland include additional conversion for cultivation or tame pasture, oil and gas field development, roads and pipelines, rural acreage development and urban expansion. The Grasslands Natural Region of Alberta provides habitat for numerous species of native plants and animals, including 75% of Alberta's 'species at risk' (PCF 2006). Among the diversity of prairie wildlife, the pronghorn is considered the most representative large mammal, and is an obligate grassland species (Barrett 1982, Wood 1989). Analysis of 2004 Alberta Sustainable Resource Development pronghorn survey data revealed that pronghorn density is positively related to the proportion of native grass prairie in survey units (Sheriff 2006). In addition to being an iconic element of prairie biodiversity, the pronghorn is a highly valued game species (AFWD 1990).

Severe winters, unrestricted hunting and the conversion of native grassland to agricultural land nearly extirpated the pronghorn in western Canada in the early 1900's (Riddle and Oakley 1973, Barrett 1987). In 1915, 140 km^2 of Dominion Rangeland were designated a pronghorn sanctuary on part of what is now Canadian Forces Base Suffield

(Barrett 1987). By 1922, the Pronghorn Reserve was officially designated as the Wawaskesy National Park (Barrett 1987). This era marked the beginning of pronghorn management in Alberta (Barrett 1987). The first management plan was written in 1972; and the most recent plan was released in 1990 (AFWD 1990). Over the past 30 years management has focused on stabilizing fluctuations in the pronghorn population and minimizing conflict with agricultural land use. Managing for population stability is challenging since the species is at the northern limit of its historic range and the population is sensitive to climatic fluctuations, particularly winter severity. In this northernmost area of the species distributional range, human disturbance to land cover and disturbance sources can be expected to influence population dynamics, movements, and distribution patterns. Given the rate of anthropogenic development in southern Alberta, particularly by energy resource development and to a lesser extent to transportation and residential development, revisions to the province's Pronghorn Management Plan are being considered to ensure that land and resource management processes are able to meet the goals of the management plan.

1.2 History of landscape change in the northern prairies

Grasslands are the most threatened ecosystem in the world (CEC 2003). Prior to European settlement, North America's northern prairies were a sea of grass stretching from the Rocky Mountains east to the Appalachians. In 1830, they covered 1/6th of the continent (Hoth 2001); however intensive agricultural development, urbanization and mineral exploration have changed the prairies considerably. Today, only 1% of the tall grass and 20-30% of the mixed and short grass prairies remain (Hoth 2001). The northern prairies today are a monoculture of engineered grains, a patchwork of intensive agriculture fragmented by roads and communities, and remnant tracts of native prairie (Hoth 2001).

1.3 CFB Suffield

After Texas and North Dakota, Alberta has the third largest area of remnant native prairie (PCF 2006). These areas of native prairie are located largely in south-eastern Alberta, including Palliser's Triangle (PCF 2006). Cattle ranching is the predominant agricultural land use (PCF 2006).

Canadian Forces Base (CFB) Suffield is a 2690km^2 area of predominantly native grassland and wildlife in an intensively developed landscape. Originally settled in the late 1800's by homesteaders, the area has a rich history as it transformed from Blackfoot First Nation Territory, to Pronghorn Reserve, to National Park, to its current designation as a military training area. CFB Suffield differs from the surrounding landscape in that it is not cultivated, it experiences periodic fire, disturbance by military training, and cattle are grazed in part of the area. Parts of CFB Suffield have been cultivated in the past, but over time the fields have regenerated to native prairie (Environment Canada 2006). The area has experienced restricted access, including access for recreation, since expropriation by the Federal Government in 1941 (Environment Canada 2006). The result is a relatively intact native prairie landscape and a refuge for wildlife from hunting and land use pressures experienced outside its boundaries.

1.3.1 CFB Suffield in the context of the Dry Mixed Grass Sub Region and pronghorn

At 2600 km^2,CFB Suffield is one of the largest remaining contiguous parcels in the Grasslands Natural Region of Alberta. It is located entirely in the Dry Mixedgrass Natural Subregion. The Grasslands Natural Region is critical habitat for many Alberta native flora and fauna including 75% of Alberta's species at risk (Gates et al. 2006). The pronghorn is one of the iconic large mammals representative of the prairies and is an obligate grassland species. Pronghorn range in Alberta is almost entirely within the Grasslands Natural Region and more specifically the Dry Mixedgrass Subregion (Barrett 1982, Wood 1989, Sheriff 2006). Pronghorn density is positively related to the proportion of native grass prairie in Alberta Antelope Management Areas (AMAs) ($R^2 = 0.82$, $p > 0.001$) (Sheriff 2006). The lowest densities of pronghorn identified in Alberta were on highly cultivated areas, and the highest densities were observed in large tracts of continuous prairie, notably on CFB Suffield (Sheriff 2006). This study suggests that given the pronghorn's wide distribution in the prairies and the close relationship to native grassland, pronghorn are likely a suitable indicator species for native grassland management.

CFB Suffield is a significant landscape for pronghorn because of its size, quality of habitat, and its geographic location relative to other patches of native grassland amidst a heavily developed landscape. The extent, seasonality, and direction of historical pronghorn movement in Alberta are not well documented. In Wyoming pronghorn move north-south seasonally to reach suitable habitat when winter conditions are severe (O'Gara and Yoakum 2004). Similar patterns were reported by Barrett in Alberta (Barrett 1982). Studies by Sawyer (Sawyer et al. 2006) and Berger (Berger et al. 2006) have shown that pronghorn movements in Wyoming were negatively affected by the cumulative impact of oil and gas development and roads on the landscape. Research on this topic in Alberta is currently being undertaken by the University of Calgary, Alberta Sustainable Resource Development, and the Alberta Conservation Association (www.albertapronghorn.com).

1.3.2 History of CFB Suffield

In response to substantial pronghorn population declines at the beginning of the 20th century, 140km^2 of Dominion Rangeland was designated the Canyon Antelope Reserve in 1915. This refuge, located in the Murphy's Horn area of present day CFB Suffield, was designated to speed the recovery of pronghorn. In 1922, the area was re-designated Wawaskesy National Park, though the land continued to be grazed by cattle and horses. Following the recovery of pronghorn numbers in 1938, Wawaskesy National Park was dissolved in a land exchange with the Province of Alberta to expand the area of Elk Island National Park located in central Alberta. In 1941, lands in the CFB Suffield area were expropriated by the Dominion Government to secure the area as a defence research and experimental proving ground. In 1971 CFB Suffield was commissioned to support training by armoured battle groups. At that time, sensitive land on CFB Suffield's east side bordering the South Saskatchewan River were declared out of bounds to military training activities based on recommendations by the Canadian Wildlife Service. Protection from hunting pressure afforded by CFB Suffield benefited pronghorn recovery efforts, and this protection continues today under the authority of the CFB Suffield National Wildlife Area (NWA). In 1992, a memorandum of understanding was signed by the Minister of Environment and the Department of National Defence towards developing the NWA. The NWA was officially created June 12, 2003.

The Province of Alberta and the Federal Government reached an agreement in 1975 that allowed for the development of oil and gas reserves on CFB Suffield (Environment Canada 2006). CFB Suffield has been heavily developed by the oil and gas industry. The majority of wells and all pipelines on CFB Suffield are buried to protect them from military activities (EnCana 2007). Above ground infrastructure is limited to a low density road network (EnCana 2007). Exceptions include the AEC Oil Access Area in the north-west section of the Base where above ground structures dominate, and the Suffield NWA where there is an assortment of above and below ground oil and gas infrastructure (EnCana 2007). Light grazing by cattle continues to take place June through September in two areas of CFB Suffield managed and administered by the Prairie Farm Rehabilitation Association (PFRA) (EnCana 2007). The Suffield Grazing Advisory Committee (SGAC) inspects the pastures annually and provides recommendations to the Base commander, who in turn directs the PFRA on implementation of SGAC recommendations (Environment Canada 2006). The native prairie ecosystem and the Suffield viewshed remain largely intact in contrast to the surrounding landscape, which is characterized by intensive agriculture and grazing.

1.3.3 Lands adjacent to CFB Suffield

Land use surrounding CFB Suffield is predominantly cattle grazing or cultivation. The east border of CFB Suffield adjoins the Drowning Ford Grazing Co-op and the BT-Grazing Co-op. The Pipeline Grazing Co-op borders the south of CFB

Suffield. To the north of the base are extensive grazing lands including the Buffalo Atlee Community Pasture and the Remount Community Pasture. To the west are grazing land, cultivated lands and intensive oil and gas development.

1.4 Pronghorn in Alberta

1.4.1 History of pronghorn in Alberta

Pronghorn historically existed in the grasslands of North America, from Alberta and Saskatchewan to Mexico, including grasslands west of the Cordillera (O'Gara and Yoakum 2004). Pre-settlement population estimates range widely from 40-100 million pronghorn. Intensive hunting coupled with high winter mortality decimated the pronghorn population in the early 1900's (O'Gara and Yoakum 2004). By 1920 roughly 20,000 remained, triggering management efforts to preclude extinction (O'Gara and Yoakum 2004). Pronghorn have experienced an approximately 64% range reduction from their pre-European range (Laliberte and Ripple 2004). They continue to exist throughout their historical range, but its continuity has been greatly fragmented by settlement and agriculture. Today, there are approximately 400,000 pronghorn (O'Gara and Yoakum 2004) but increasing settlement and resource development could once again threaten the pronghorn of North America. The impact of such development has received little study.

Pronghorn in Alberta are at the northern limit of their range and are limited in their population growth by severe winters, low recruitment and/or kid survival following difficult winters and/ or wet springs (Barrett 1982). Historically, pronghorn in Alberta have experienced major population crashes owing to severe winter weather (DCL 1998). The Alberta pronghorn population varied from 6,000 to 32,000 individuals during the period 1975 to 2005 (Sheriff 2006). Severe winters in 1906-07, 1964-65, 1965-66, 1966-67, 1974, and 1995-96 as well as severe droughts in 1948, 1949 and 1957-1962 decimated pronghorn populations and shaped the species management efforts in Alberta.

Pronghorn are listed as *sensitive* in Alberta because they are highly susceptible to extreme climatic conditions and because loss of native prairie to cultivation and development threatens their habitat (ASRD 2005).

Pronghorn in Alberta are managed by Alberta Sustainable Resource Development (ASRD) in accordance with the 1990 "Management Plan for Pronghorn Antelope in Alberta". The management plan has a number of goals:

- maintaining a viable population of pronghorn in Alberta, to ensure a commercially harvestable population;
- mitigating property damage to landowners (with a target of less than $25,000 damage annually) (AFWD 1990);
- a winter population target of 15,500 animals and a resulting pre-season fall target of 20,010 pronghorn excluding Suffield, and 22,460 including Suffield.

Management objectives include:

- A harvestable surplus 3,410 animals that is anticipated to produce 1,740 trophy antelope and 1,670 non-trophy antelope annually;
- 25,900km^2 of natural grassland maintained as summer habitat of which 3,290km^2 is maintained as winter habitat in 12 known wintering areas, one of which is located in the CFB Suffield NWA (AFWD 1990).

1.4.2 Pronghorn response to vegetation

Eighty-five to ninety percent of pronghorn in Alberta occupy native grassland and/or sagebrush throughout the year (Barrett 1982), and pronghorn distribution is correlated with food distribution (Dirschl 1963). Their diet is predominantly graminoids (40-60%), forbs (10-30%) and browse (5-20%) (Barrett 1982, Howard 1995). O'Gara and Yoakum determined that pronghorn prefer a heterogeneous mix of native vegetation rather than a single vegetation type (O'Gara and Yoakum 2004). Resource availability for pronghorn in Alberta varies seasonally as a function of availability, palatability and succulence of vegetation (Dirschl 1963, Hoover 1966); pronghorn switch to browse such as sagebrush (*Artemisia cana*) when most forbs are less available (possibly snow covered) or low in nutrients (Barrett 1982, Howard 1995, O'Gara and Yoakum 2004). Studies suggest that pronghorn select for high protein food sources year-round and succulent vegetation in dry climates (Dirschl 1963, O'Gara and Yoakum 2004). Forbs are selected preferentially in spring, summer and fall and when not available, succulent high-protein grasses and browse (e.g.: *Bouteloua gracilis, Stipa comata, Artemisia frigida, and Artemisia cana*) are substituted (Dirschl 1963, Mitchell and Smoliak 1971, Gainer 1991). Grasses are grazed mainly in spring when their water and protein content are high (Dirschl 1963, Sexton et al. 1981). When snow accumulates in winter, browse constitutes the highest proportion of pronghorn diet, although its availability is critically limited (Mitchell and Smoliak 1971).

It has been suggested that pronghorn prefer vegetation in sub-climax condition, where the sub-climax condition is believed to result from fire and grazing by bison, elk and deer (O'Gara and Yoakum 2004). CFB Suffield experiences periodic fire resulting from lightning strikes, artillery fire, heavy machinery use, and prescribed burns though fires are generally suppressed.

Vegetation taller than 25cm and small depressions provide ambush cover for predators but reduce convective heat loss by fawns in winter and/ or especially wet and windy weather (Barrett 1981, O'Gara and Yoakum 2004). Pronghorn are well adapted to open country, having excellent sight and speed to evade predators (O'Gara and Yoakum 2004). Autenrieth (1978) suggested that low rolling expansive terrain provides suitable wintering habitat for pronghorn. Microhabitats produced by topographic relief can increase the quality of habitat during the winter by providing benefits such as lower wind velocities and less snow than the surrounding area in prairie landscapes as well as providing greater lines of sight from hilltops (Bruns 1977).

Wheat has been observed to form a large proportion of pronghorn diet throughout the winter in some areas of Colorado (74%) and Kansas (60%) respectively (Hoover 1966, Sexton et al. 1981). Mitchell (1980) noted that during severe winters in Alberta pronghorn congregated in areas that provided access to both cropland and native vegetation, but where cropland consisted of no more than 25% of the landscape (Barrett and Vriend 1980). Throughout the year, grain fields closer than 0.8km from native prairie received greater use than fields further away (Allen et al. 1984). Although the western portion of CFB Suffield was cultivated prior to 1941 and features remain still visible in satellite imagery, the effects on extant plant communities are negligible (Adams 2007).

1.4.3 Pronghorn populations on CFB Suffield

The pronghorn population in CFB Suffield has varied widely from 3,550 individuals in 1992 to 700 individuals in 1997 following high winter mortality in the winter of 1995-1996 (Figure 3).The current pronghorn population on CFB Suffield is ~1000 individuals. It is one of the highest densities of pronghorn in Alberta (AFWD 1990). In 1992 and 1994 estimates of pronghorn density on CFB Suffield were 1.52 and 1.24 animals/km^2 in comparison to densities of 0.13 to 1.07 animals/km^2 in adjacent management areas in the same years (DCL 1998). The mean density of pronghorn on Suffield between 1967 and 1986 was 0.70 animals/km^2. This highlights the importance of CFB Suffield for pronghorn in Alberta. CFB Suffield may be a source habitat for pronghorn in Alberta (Pulliam 1988, Hanski 1999).

1.4.4 Pronghorn response to disturbance

The following describes the dominant forms of anthropogenic disturbance currently taking place on CFB Suffield to which pronghorn may respond and for which suitable data were attainable. The dominant forms of land use on CFB Suffield are grazing, military activities, and oil and gas development. Fire and grazing affect plant communities, military activities disturb soils, affect fire frequency and provide sensory disturbance, and oil and gas activities fragment the landscape as well as generating sensory disturbance. The following describes these impacts of anthropogenic disturbance in greater detail:

1.4.4.1 Fire

Kindschy et al. (1978) suggest that preferred pronghorn habitat is likely maintained by intermittent fire and grazing wildlife (Kindschy et al. 1978). Historically, fires occurred frequently in the northern prairies (O'Gara and Yoakum 2004). Fires are common on CFB Suffield resulting from prescribed burns and live fire exercises (annually from June to October), however, fire is suppressed in the Suffield NWA. Intermittent fire is beneficial for pronghorn, improving the palatability, digestibility and nutrition of forage following regrowth (Courtney 1989). In the fall, winter and spring following prescribed burns in Alberta, pronghorn have been observed to use burned areas of needle-and-thread grass, thickpsike wheatgrass, and western wheatgrass (Howard 1995). Fires can also increase the availability of succulent forage such as prickly pear cactus, otherwise not palatable before fire removes the spines (Stelfox and Vriend 1977, Courtney 1989). Burned areas with prickly pear cactus were heavily used following fire events (Courtney 1989, Howard 1995). Pronghorn in Alberta have been observed moving onto burned sites within a month following fire to forage new forbs and grass growth (Stelfox and Vriend 1977, Courtney 1989). Benefits of fire have been observed for up to 3-4 years following a fire (Courtney 1989). However, where fire frequency is excessive the benefits of increased forage production can be compromised (O'Gara and Yoakum 2004).

1.4.4.2 Grazing

As mentioned previously, Kindschy et al. (1978) suggest that preferred pronghorn habitat was likely maintained by grazing wildlife and intermittent fire

(Kindschy et al. 1978). O'Gara and Yoakum (2004) suggest that pronghorn are more common on ungrazed or lightly grazed rangeland than on heavily grazed sites (Willms et al. 1986, Brady et al. 1989, O'Gara and Yoakum 2004). Forb abundance was 16% higher on lightly grazed sites in Arizona (Loeser et al. 2005). Cowboys on horseback tending cattle on grazed lands provide a human disturbance component that must be considered when evaluating the effect of grazing on pronghorn. The effects on pronghorn of grazing by other ungulates on CFB Suffield have not been studied.

1.4.4.3 Military activities

The effects of direct military activities on pronghorn have not been studied on CFB Suffield. Previous research has suggested that military disturbance can increase the size of ungulate home ranges, but otherwise have little effect on ungulate species (Reider et al. 1996, Stephenson et al. 1996, Krausman et al. 2005). Research by Krausman and Harris suggests presence of military aircraft did not change behaviour of Sonoran pronghorn (Krausman and Harris 2002). Stephenson et al. suggest that ungulates respond negatively to human disturbance, alteration of security cover, and destruction of forage base resulting from military activities (Stephenson et al. 1996). Disturbance on military weapons ranges resulting from fire can result in increased forage and improved pronghorn habitat (Krausman et al. 2005). In the vicinity of live fire exercises, bears respond more to vegetation than noise zones (Telesco and Van Manen 2006). Some military activities were indirectly included in this study such as fire and major roads. However, direct impact of military training was not included since there were no data available at the time of the study.

1.4.4.4 Oil and gas infrastructure

Oil and gas development has both direct and indirect impact on wildlife (Sawyer and Lindzey 2003). Direct impacts include habitat loss and alteration, whereas, indirect loss may result from behavioural avoidance of areas because of noise, pollution, and human activity (Sawyer and Lindzey 2003, Kaseloo and Tyson 2004). With the exception of the AEC Oil Access Area and the Suffield NWA, wells and pipes are buried on CFB Suffield so as not to interfere with military activities. Despite heavy development of the oil and gas reserves on CFB Suffield, the above ground infrastructure is limited to a low density road network. Consequently indirect impacts on pronghorn on CFB Suffield are limited to increased human activity to wellsites. Fragmentation of previously undisturbed lands by oil and gas infrastructure results in reduced usage and abandonment by pronghorn: particularly a 50% reduction in usage of fragments of less than ~243 ha (Berger et al. 2006). In addition, Berger et al. (2006) noted pronghorn avoided concentrated gas fields. However, as mentioned previously, CFB Suffield is unique in that buried wells reduce the footprint of oil and gas infrastructure considerably and as such direct sensory (visual) impact on pronghorn is reduced and Berger's results need to be re-considered in context of CFB Suffield. Trails comprise a major component of oil and gas infrastructure, but spatial data were not available for inclusion in this study. Therefore, this study is limited in its ability to determine the effects of oil and gas infrastructure on pronghorn. In addition, the impact on pronghorn of increased human traffic on the landscape for exploration, drilling, pipeline construction and periodic well maintenance was not explored.

1.4.5 Resource selection modelling

A resource selection function (RSF) is a model that determines the value of a resource unit in proportion to the relative probability of use of a resource unit (Boyce et al. 2002). The units of land on which an animal is found are assumed to be resources "selected" by the animal, and as such the resource selected is a predictor variable associated with these units of land (e.g.: vegetation type, aspect, etc.) and expressed as an RSF (Manly et al. 2002). Consequently, an RSF built on "presence/absence" sampling design is a type of habitat suitability index (HIS), but provides statistical rigour (Boyce et al. 2002). RSFs built on a "presence/ available" sampling design approach, like those built in this study, are used to provide a foundation for estimating the components of ecosystem function in habitat modelling, not for statistical inference (Boyce et al. 2002). Quantifying and understanding the values of predictor variables identified by RSFs helps resource managers to understand the importance of each variable within the biome and can help to describe the effects of changing land uses on ecosystems (Boyce et al. 2002). As such, RSF is increasingly used as a tool in natural resource management, cumulative effects assessment, land-management planning, and population viability analysis (Boyce et al. 2002, Johnson et al. 2004, Richardson et al. 2005, EnCana 2007). Cumulative effects occur where the impacts of one activity combine with the activities of another in a synergistic manner (CEARC 1988). The Environmental Impact Statement for the EnCana Shallow Gas Infield Development in the CFB Suffield National Wildlife Area used a model I generated as part of a cumulative effects study of the impacts of anthropogenic disturbance on pronghorn (EnCana 2007). The proposed gas field development has the potential to negatively impact pronghorn resulting in reduced usage and/or abandonment of previously undisturbed land by pronghorn if the landscape is fragmented into parcels of land less than ~243 ha in size (Berger et al. 2006). Where there exists seasonal, temporal and/ or geographic variability in resource availability, such as in this study, several RSF models could be necessary to adequately describe the resource selection of pronghorn.

1.5 Purpose

Pronghorn appear to be a useful indicator species for assessing cumulative effects of human activities in grasslands. Animal distribution patterns are a fundamental question of ecology that are useful for addressing cumulative effects. Animal distribution data can be obtained from aerial surveys or from radio relocation studies (Johnson et al. 1991, Manly 2002, Manly et al. 2002). The two-fold purpose of my study was to compare the relative merits and shortcomings of pronghorn distribution models derived from two location data types, GPS collar and aerial surveys, and to evaluate the influence of natural and anthropogenic features on pronghorn distribution in summer and winter.

1.6 Study Approach

First, I determined the study problem and purpose of my research (Chapter 1). Then, with my project collaborators, the two data sets were gathered and processed for this study (Chapter 2). Resource selection models were developed for a summer aerial survey, and two models were developed from the GPS data (Chapter 3). The two model types were compared and the two seasons were compared within the same model type

(Chapter 4). In addition, the effects of anthropogenic disturbance on seasonal resource selection were identified (Chapter 4). Based on the results of the report, I made recommendations on how the models developed herein can be applied in land and wildlife management, and on directions for future research/ considerations towards making better resource selection models in the future (Chapter 5).

Chapter Two: Methods

2.1 Study areas

Canadian Forces Base (CFB) Suffield is located in south-east Alberta 50km north-west of Medicine Hat (Figure 1). It occupies 2690km^2 of grassland used primarily for military training (1700 km^2) and testing (750 km^2) as well as oil and gas development and limited cattle grazing (Environment Canada 2006). Notable on the eastern border is the Suffield National Wildlife Area (NWA) officially designated in 2003 to protect its ecological significance.

The EnCana study area was defined based on the needs of the EnCana EIS cumulative effects assessment based in the Suffield NWA (EnCana 2007). The study area was defined to encompass the Suffield NWA (Figure 1), and a model was designed from pronghorn location data collected using an aerial survey methodology. The second study area was the entire CFB Suffield, including the NWA (Figure 1). A summer habitat selection model and a winter habitat selection model were developed for pronghorn location data obtained from GPS collars in the CFB Suffield study area. The availability of biophysical data sets was limited to CFB Suffield, so the study could not include lands adjacent to the Base.

2.2 Animal location data

2.2.1 Summer aerial data acquisition

A pronghorn (*Antilocapra americana*) survey was conducted August 1-3, 2006 with URSUS Ecosystem Management Ltd. Surveyors included Mike Charlebois, Dave

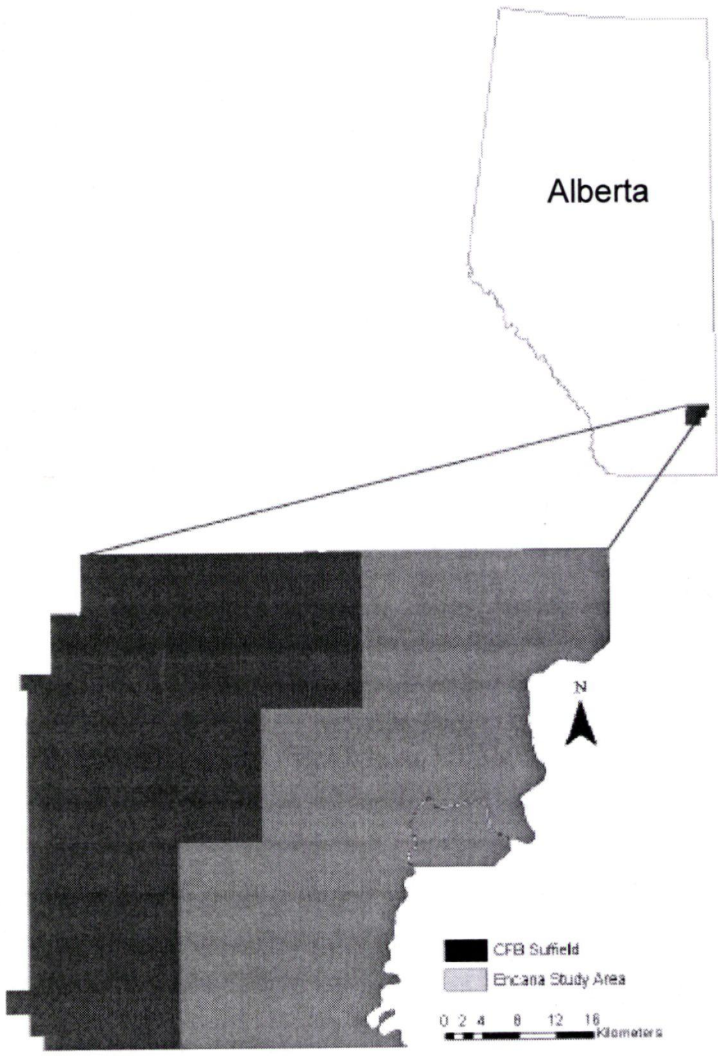


Figure 1: CFB Suffield and EnCana Study Areas.

Almanza, myself and the pilot. Alberta Sustainable Resource Development (ASRD) survey methods (Gudmundson 1985) were adopted with the exception that a 100% coverage survey was chosen to obtain more robust data sets. A helicopter (Bell Jetranger 206B3) was flown instead of fixed winged aircraft for improved safety and greater manoeuvrability during the survey. In addition, transects were flown east-west or west-east in order to improve sightability as flights were required to be flown early and late in the day to minimize impacts from running the study animals in the heat of August. Surveys were conducted between 7am and 11am, and then between 3pm and 7:30pm. Temperatures ranged between 15-24 degrees Celsius and skies were variable, from overcast to sunny and clear. Surveys were flown at 120 km/hr to 160km/hr at an elevation of 60m to 90m. Transect width was 800m.

There were 440 recorded observations representing 867 pronghorn locations. 6,943 random points were established in the study area to represent resource availability sites (Manly 2002, Manly et al. 2002). The number of random points was chosen to be representative of the study area in accordance with procedures proposed by Johnson et al. (Johnson et al. 2006). In order to determine the number of random points that would closely represent the study area, four sets of random points (1500, 3000, 6000, 12000) were generated in the study areas, and the percentage of each that fell in each ecological range category was compared with the percentage of ecological range group in the study area (Manly et al. 2002). The number of random points was selected which best approximated the study area. The random points in the aerial survey model were clipped to fit the spatial extent of the study data.

2.2.2 GPS data acquisition

Pronghorn locations were obtained over two seasons for seven radio collared pronghorn does in the summer and twelve in the winter. Twenty-four does were captured in December of 2003 and another twenty-five were collared March 1-3 2005; ten on CFB Suffield. Four animals were recaptured in July 2004 and refitted with new collars as a result of early collar failure. Initial capture locations for the study animals each season were chosen to be representative of three landscape types in the Grasslands Natural Region. Collars were applied to ten pronghorn captured on the Base, and fourteen pronghorn captured outside the Base. Captures were conducted by a professional netgunning company according to protocol developed by the Alberta Conservation Association and certified by the Alberta Animal Care Committee of the Department of Sustainable Resource Development. Captured animals were equipped with Lotek GPS 3300 collars. Data were provided to me by the Alberta Conservation Association (ACA).

Collar locations were divided into seasonal groups defined by the ACA (P. Jones, personal communication). In brief, seasonal ranges and core areas were constructed for individual pronghorn based on biological and behavioural constraints. Start and end dates for the seasonal ranges were determined using mean four hour movement distances per week for each year. Seasonal ranges and core areas were constructed using the fixed kernel home range estimator method in Home Range Tools for ArcGIS© (Worton 1987, Rodgers et al. 2005). The "user" option was selected to determine the smoothing parameter that resulted in the best fit for each individual pronghorn. The individual seasonal ranges were examined and points were removed if (1) it appeared the animal had began to migrate earlier than the end date of the season, (2) points were associated with short term sallies, (3) points appeared to be outliers, or (4) points were associated with a short term movement from one distinct area to another within the same season. If it appeared that an individual pronghorn used two or more spatially and temporally distinct areas during the same season, we allowed for multiple polygons. Seasonal ranges were constructed at the 95% volume level while core areas were calculated at the 50% volume level (Worton 1987). Area (km^2) was determined for each seasonal and core area using ArcView XTools extension (DeLaune 2003).

In this study, summer and winter were used to develop seasonal RSFs. From the two years of collar data used in the study, 3141 locations were included in the summer model representing seven pronghorn, and 4470 presence points were included in the winter model representing twelve pronghorn. 12,000 random points were generated to represent available area. The number of random points was proportionate to the percentage of each ecological range group in the study areas. The number of random points was chosen to be representative of the study area in accordance with procedures proposed by Johnson et al. (Johnson 1980, Johnson et al. 2006). Briefly, the number of random points was chosen so that the percentage of random points in each ecological range group reflected the relative area of each ecological range group (Johnson 1980).

2.3 Biophysical data

Landscape variables used in evaluating pronghorn habitat selection were chosen *a priori* based on their assumed influence on distribution (Burnham and Anderson 1998). *A priori* selection was informed by pronghorn habitat selection patterns reported in other studies in Alberta and the western United States (Alberta Fish and Wildlife Division

1990, Allen et al. 1984, Mitchell 1980). "Distance to" measures represent the Euclidean distance from the presence/ absence point to the closest selected landscape variable (output cell size was 50m, except for wells, which was 20m).

Eleven biophysical variables were selected in total and can be divided into two classes, landscape and anthropogenic. The following describes the biophysical variables used in this study.

2.3.1 CFB Suffield Ecological Range sites

Agricultural Region of Alberta Soil Inventory Database (AGRASID) ecological range site classification was used as a surrogate for a vegetation-based land cover classification. It represents site potential for plant communities based on soil and moisture conditions on the site (Adams et al. 2005). Soil landscape models were delineated on 1:37,500 stereo aerial photography by LandWise Inc, scanned by DND, and rubbersheeted to existing orthophotos. Polygons were digitized to a 1:50,000 product. Approximately 63% (570) of the 910 polygons have been ground-truthed to varying degrees, including pedon description, landscape, soil texture, vegetation, stoniness, blowouts, and wetlands (Landwise 2006).

Fourteen ecological range site classes exist on Suffield. Each ecological range site is a distinctive kind of land with specific physical characteristics differing in ability to produce a distinctive kind and amount of vegetation (Adams 2007). Disturbed ecological range sites represented less than 1% of CFB Suffield and 0% of the study area of the aerial survey and were excluded from analysis. Water bodies were omitted because they are not used as habitat by pronghorn. The remaining twelve classes were grouped for how they'd be perceived by pronghorn, in accordance with the recommendation of Barry Adams of ASRD (Adams 2007).

2.3.2 Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) was derived from a tasselled cap 4-dimensional transformation on 6 bands of Landsat 5 TM data captured August 1, 2006 by Javier Vargas at URSUS Ecosystem Management Ltd. NDVI refers to the difference between near infrared and red bands normalized by the sum of those bands.

$$NDVI = (NIR-RED)/(NIR+RED)$$

NDVI is the most commonly used vegetation index since it retains the ability to minimize topographic effects while providing a linear measurement scale (Eastman 1999). High NDVI values represent high amounts of vegetation, while lower values represent non-vegetated surfaces.

2.3.3 Brightness

Brightness was derived from the same Landsat imagery used to generate the NDVI variable by Javier Vargas at URSUS Ecosystem Management Ltd. Areas of high brightness represent areas with little vegetation and often represent water surfaces. A tasseled cap 4-dimensional transformation on 6 bands of Landsat 5 TM data (excluding the thermal band) was performed using the Gram-Schmidt orthogonalization process to extract three new index bands (GI, BI, and WI). GI highlights green vegetation cover or biomass above ground; BI refers to soil brightness; and MI refers to vegetation and soil moisture. Detailed information of this transformation can be found in Kauth and Thomas (1976) and Crist and Cicone (1984). The equations used in the transformation are from Mather (1989):

BI = (TM1*0.3037) +(TM2*0.2793) +(TM3*0.4343) +(TM4*0.5585) +(TM5*0.5082) +(TM7*0.1863)

GI = (TM1*-0.2848) +(TM2*-0.2435) +(TM3*-0.5436) +(TM4*0.7243) +(TM5*0.0840) +(TM7*-0.1800)

GM = (TM1*0.1509) +(TM2*0.1793) +(TM3*0.3299) +(TM4*0.3406) +(TM5*-0.7112) +(TM7*-0.4572)

2.3.4 Distance to intermittent water

Pronghorn in the grassland biome require 1.0-5.5L of water per day, and the distribution of water sources needs to be no greater than 1.5-6.5km apart (Allen et al. 1984, O'Gara and Yoakum 2004). This metric represents the distance to water bodies that may be ephemeral or seasonal in nature. For consistency, this variable was included in all three models. It is possible that these water bodies were absent or frozen depending on the season.

2.3.5 Distance to lakes, streams and rivers

As mentioned above, proximity to water is essential for pronghorn survival (Allen et al. 1984, O'Gara and Yoakum 2004). This metric represents the minimum distance to permanent water features including streams, saline lakes, and the South Saskatchewan River.

2.3.6 Terrain Ruggedness Index (TRI)

Low rolling expansive terrain provides suitable wintering habitat for pronghorn (Mitchell and Smoliak 1971, Bruns 1977). Microhabitats produced by topographic relief can increase the quality of habitat during the winter by providing benefits such as lower wind velocities and less snow than the surrounding area in prairie landscapes as well as providing greater lines of sight (Bruns 1977). Pronghorn are not observed for any significant length of time where their view is restricted (Allen et al. 1984). Derived from the digital elevation model, the TRI provides a raster layer that describes the relative degree of variability in the topography on the landscape.

Anthropogenic or human use variables were selected based on the dominant anthropogenic land uses in the area. These include grazing, oil and gas development, and military training activities. Anthropogenic variables included in the analysis are as follows:

2.3.7 Distance to major roads

Roads create edges and if perceived as risky may affect the distance pronghorn use habitat from the edge (Gavin 2006). Pronghorn show higher vigilance and lower foraging times along high traffic roads (Gavin 2006). Increases in densities of high traffic roads can disrupt behaviour, leading to changes in habitat use and potentially reducing population productivity (Gavin 2006). The extensive network of roads and trails throughout CFB Suffield used by the military as well as the oil and gas industry contribute directly and indirectly to habitat loss through habitat fragmentation, traffic disturbance, and introduction of exotic species (Berger et al. 2006, Gavin 2006). Analysis was limited to major roads; however, trails represent a greater linear disturbance on CFB Suffield than major roads. Trails were not available for inclusion in this study.

2.3.8 Area burned in 2003

CFB Suffield experiences periodic fire resulting from lightning strikes, artillery fire, heavy machinery use and prescribed burns. Intermittent fire is beneficial for pronghorn, improving the palatability, digestibility and nutrition of forage following regrowth (Courtney 1989). In the fall, winter and spring following prescribed burns in Alberta, pronghorn have been observed to use burned areas of needle-and-thread grass, thickspike wheatgrass, and western wheatgrass (Howard 1995). Fires also increase the availability of succulent forage such as prickly pear cactus, otherwise not palatable before fire removes the spines (Stelfox and Vriend 1977). This metric quantified pronghorn presence on areas burned in 2003. Data were available for fires in 2003, 2004, and 2005, however, I considered only the fires of 2003 to be of significant magnitude to be included in the study (Table 1).

Table 1: Area burned on CFB Suffield from 2003-2005.

Year	Burn Area (ha)
2003	42799
2004	2632
2005	5076

2.3.9 Grazed area

Pronghorn are more common on ungrazed or lightly grazed rangeland than on heavily grazed sites, since forbs are in higher abundance in the former (Willms et al. 1986, Brady et al. 1989, O'Gara and Yoakum 2004). This metric quantified pronghorn presence on the CFB Suffield grazing leases. This binary measurement identified if pronghorn selected for or against being on a grazed area.

2.3.10 Distance to pipelines

Pipelines are a linear disturbance on the landscape, extending from well pads to processing plants (Berger et al. 2006). Pipelines introduce exotic species during construction and/ or through seed stock used for replanting (Zink et al. 1995). This metric measured the Euclidean distance of pronghorn observations from a pipeline to determine if pronghorn avoid pipelines or areas of higher pipeline density.

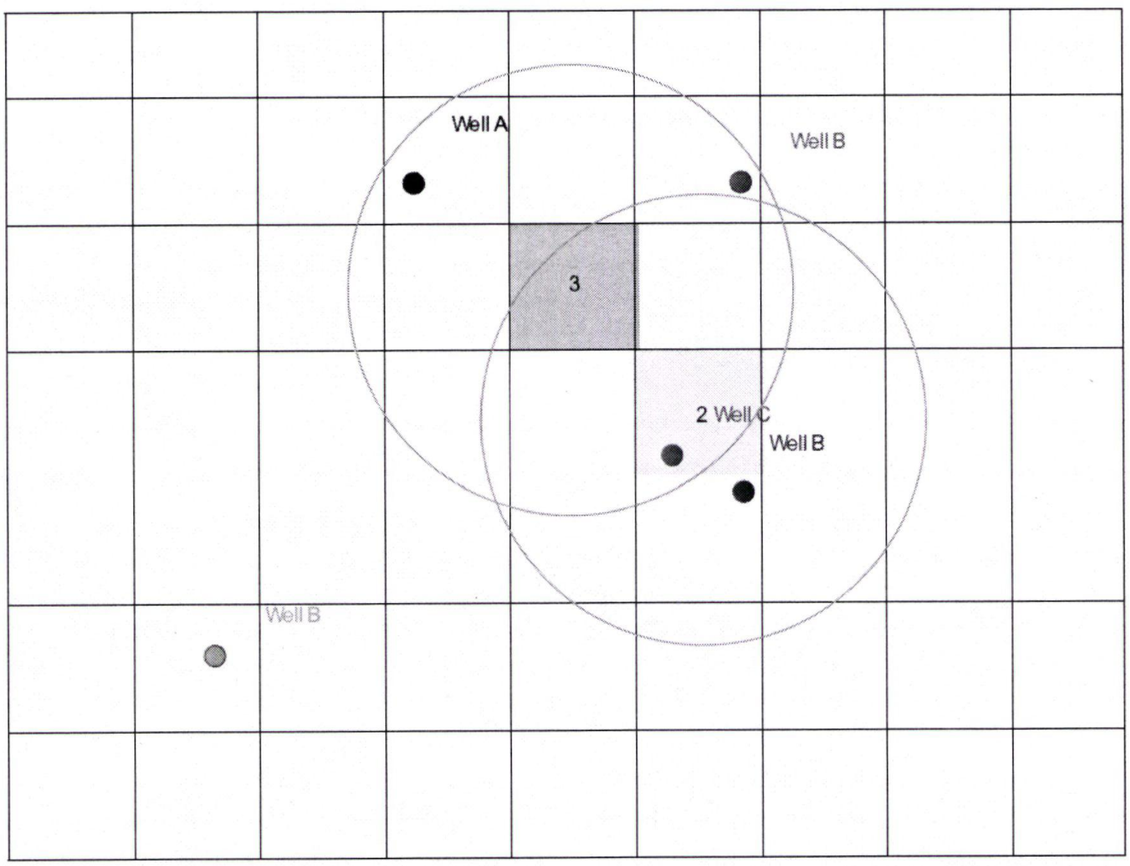
2.3.11 Well nearest neighbour density

Well sites result in direct habitat loss to road, pipeline, wellpads, site degradation and invasive species creep as well as indirect habitat loss where pronghorn habitat use may decline near concentrations of oil and gas infrastructure (Sawyer and Lindzey 2003, Gavin 2006, Sawyer et al. 2006). To quantify the effects of wells on pronghorn as part of the EnCana EIS, it was imperative that a metric be created that represents the cumulative effect of wells on the landscape. In addition, wells on CFB Suffield created a unique problem whereby most active wells were buried although some remained on the surface. In addition, numerous well sites were inoperative or deactivated, some replanted with invasive species (crested wheat grass) and in some areas native vegetation regenerated. Accurate records were not available. I decided to aggregate all oil and gas wells, active or inactive, in order to capture the cumulative effect of the industry, and because indirect habitat loss from deactivated well sites remains long after the well ceases to produce (Sawyer et al. 2006).

The well nearest neighbour density metric was developed in response to shortcoming in density and "distance to" measurements. Well density per quarter section proved too coarse to reflect observed well density, and the "distance to" measurement did not differentiate areas of high and low well density. The "well nearest neighbour density" layer was developed by Spencer Cox at Tesera Systems Incorporated (January 6, 2007). Initially a moving window analysis was performed on each region. Radial windows were used to perform window areas of 0.25km, 1km, and 2.5km. The average distance from each point to its ten nearest points was 862m. Therefore, the 2.5km window, which had a radius of 892m, should have produced the best results. However, the results did not give an accurate representation of well density because the individual wells and their overlapping areas were having too much influence. The flaw with a window based method for identifying density in areas where density is fairly low is shown in Figure 2.

The cell given a value of 3 isn't really near any wells although it is within range of 3. It is assigned a higher density than the cell with a value of 2, which only is within range of 2 wells, even though it is almost right on top of both of them. The problem is for areas with varying densities an appropriate window size is impossible to select. If the density is quite high this works fine, but when the wells are far apart you run into this problem, where the high density areas are defined as being in between the actual features.

Figure 2: Example of a window based density analysis.



To overcome this problem an alternate procedure was used to define density. This method avoids some of the issues of a moving window by avoiding choosing a window size. It simply accumulates the distance to its 10 neighbours. There is still a possibility of under including instances where 2 wells are very near but the rest of the neighbours are very distant.

1. A uniform grid of points 100 m apart was created for the entire NWA area.
2. For each of these points, the distances were calculated to the 10 nearest points in the EnCana well data for each time slice.
3. The 100m x 100m point grid now had a quantitative distance to each of the 10 closest wells.
4. The distances to the 10 nearest wells were averaged.
5. Each point in the 100m x 100m grid now had an average value, which could be compared with that of its neighbours.
6. This 100m x 100m point grid was interpolated to a surface using the average distance to 10 nearest neighbour values.
7. The surfaces were classified using eight natural breaks (Jenks). The densities within a time slice were therefore identified. The well densities between time slices were not compared as the classes were different (necessary because the overall density between each time slice was quite different).

2.4 Distribution analysis

The survey location and GPS location data were independently entered into a GIS (Earth Systems Research Institute's (ESRI) ArcGIS 9.1). Random points were generated using Hawth's tool extension. Using binary logistic regression, the relationship between the dependant variable, the relative probability of pronghorn being present, and independent variables in the study area were analyzed (Manly et al. 2002).

Binary logistic regression is used when the dependant is dichotomous (binary) and the independent variables are of any type (e.g. continuous, categorical, integer). Binary logistic regression was used in my study because it is suited to the dichotomous dependant data sets (e.g. presence/ absence) (Manly et al. 2002). This technique was chosen because it does not have a number of assumptions of ordinary regression analysis such as heteroskedacity, unequal variance in the dependant variable for different values of the independent variables, and normally distributed residual values (Hosmer and Lemeshow 1989). It relies on statistical evidence and empirical relationships, not on subjective opinion. Variables were screened for colinearity using the Spearman rank correlation coefficient (Mladenoff et al. 1995, Mladenoff et al. 1999) and one variable of any correlated pair was removed ($rs > 0.75$, $p<0.001$) from analysis (Mladenoff et al. 1995). Model selection was based on the information theoretic approach using Akaike's information criterion (AIC) (Manly et al. 2002). AIC attempts to evaluate the degree of truth associated with each model in a group of potential models, selecting for the model that best approximates the observed data (Burnham and Anderson 1998). The best model is selected for having the best (lowest) goodness of fit (log likelihood) and complexity (number of parameters: "K") (Burnham and Anderson 1998). Log likelihood (LL) refers to the probability that the observed value of the dependant variable (i.e. pronghorn presence or absence) can be predicted from the independent variables (i.e. wells, distance to water, etc.). The likelihood ratio (-2LL) is used to assess the significance of logistic regression. The use of AIC is considered to be an improvement over traditional hypothesis testing techniques because it ranks models to evaluate the degree of truth and then the user can select for the best fit model that reflects true processes in observed data (Burnham and Anderson 1998).

In terms of parametric assumptions (i.e. normality, homogeneity of variance, and independent errors) AIC minimizes the constraints placed on the interpretation of results because we are more confident that our choice of model reflects reality. One can be more confident in the inferences made about animals or populations; there is more confidence in the probability of an event occurring (p-values).

$$AIC = -2 \text{ logliklihood} + 2K$$

The SPSS version 14.0 statistical package was used to run step-wise binary logistic regression and obtain the –2 logliklihood used as part of AIC for model selection. The AIC values calculated were then modified to correct for sample size of the survey data:

$$AICc = AIC + [(2K(k+1))/(n-K-1)] \text{ where } n = \text{sample size}$$

The corrected AIC values (AICc) could then be ranked according to their relative importance. To determine their relative importance, the AICc of individual models were compared against the lowest AICc value in the group of potential models (Burnham and Anderson 1998).

$$\Delta i = \text{AICc}(i) - \text{minAICc}$$

Where Δi is the difference between the lowest AICc value and model i.

The theoretically best fit model was selected based on the lowest AICc, assigned a Δi of zero. However, Akaike weights (*wi*) were applied to better understand the probability that a model is the best model. If, for instance, the *wi* of the top ranked model is 1 and the *wi* of the second ranked model is two, it can be inferred that the top ranked model is twice as likely to be the best explanation of the truth compared to the second ranked model (Burnham and Anderson 1998).

$$wi = (\exp(-0.5 \text{ x } \Delta i)/(\Sigma r = 1^{r} \exp(-0.5 \text{ x } \Delta r))$$

where Δr is the sum of all candidate models.

Once the best fit model is chosen, the output "*B*" values of the independent variables from binary logistic regression were used to build a fitted logistic regression equation. Logit coefficients aka "*B*" are the natural log of the odds ratio. In dichotomous data sets, a change in an independent variable (B_1) is associated with a (B_1) change in the log odds of the dependant variable. In other words, "*B*" represents the variability in the dependant variable associated with the independent variable. "*B*" in the "Variables in the equation" table represents the percent of variance in the dependant variable explained by the independent variables. The coefficient of determination, Nagelkerke's R^2, was reported and is the proportion of variability in a data set accounted for by a statistical model. Nagelkerke's R^2 is the most reported R^2 value and is a modification of the Cox and Snell R^2 coefficient to ensure it is between 0 and 1 (Nagelkerke 1991). Nagelkerke's R^2 is [1- exp(-LR/n)] where LR is the likelihood ratio chi-square for the whole model and "n" the number of observations (Nagelkerke 1991). Model validation was conducted using K-fold analysis (Boyce et al. 2002, Johnson et al. 2006). K-fold analysis assesses a withheld data set against the model prediction of a training data set using correlations between bin rank of the RSF values and the frequency of independent, withheld observations in the same bin rank standardized for area (Boyce et al. 2002, Johnson et al. 2006). In my analysis, RSF layers were reclassified into ten quantile classes as per Johnson et al. (Johnson et al. 2006). Results of K-fold analysis are reported in Chapter 3.

Top biophysical variables were compared among models. The relative importance of each biophysical variable is indicated by the Wald statistic.

Chapter Three: Results

3.1 Study area

One study area was the entire Canadian Forces Base Suffield (2,650km^2) which encompassed the EnCana study area. The EnCana study area (1371km^2) was defined by EnCana (2007) for an environmental impact assessment for a proposed natural gas field development in the National Wildlife Area (Figure 1). The EnCana study area overlaps 51.7% of CFB Suffield.

3.2 Pronghorn locations

An aerial survey of the EnCana study area was conducted August 1-3, 2006. Pronghorn spatial locations were evenly distributed throughout the EnCana study area (Figure 3). The GPS data were collected from seven pronghorn does in the summer and twelve in the winter. GPS data were censored to locations on CFB Suffield. GPS locations were clumped in the summer and winter (Figures 4 and 5), due in part to the limited number of pronghorn collared in the study. Clumped locations were more pronounced in the summer when pronghorn are not aggregated at their winter range sites. Minimum convex polygons for the summer and winter GPS models show the collared pronghorn did not use 100% of the Base (Figures 6 and 7). Consequently, variables such as the Blowouts ecological range group (ERG) were under-utilized, limiting the effectiveness of the analysis of selection in this study.

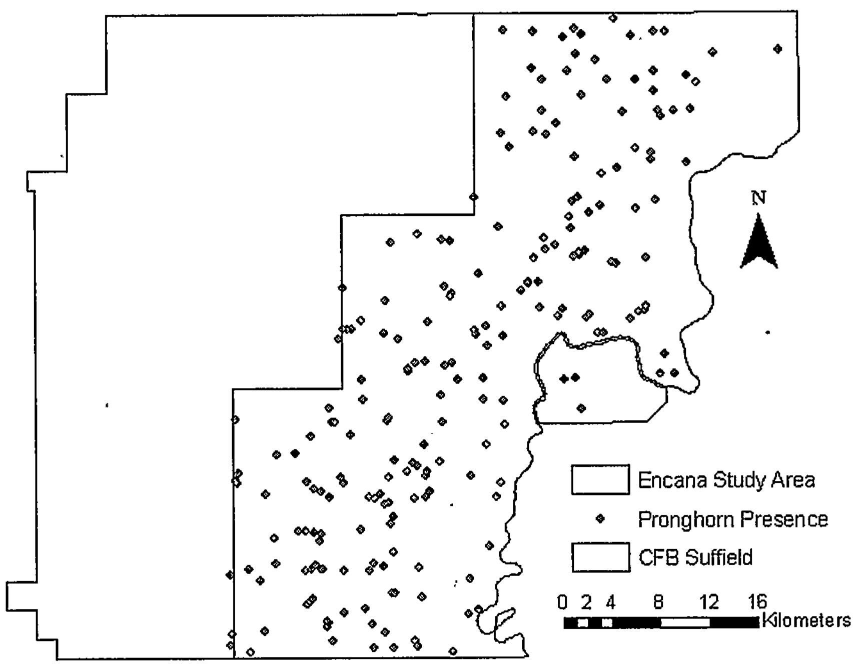


Figure 3: Pronghorn aerial survey location data in the EnCana study area, CFB Suffield. Survey flown August 2-3, 2006.

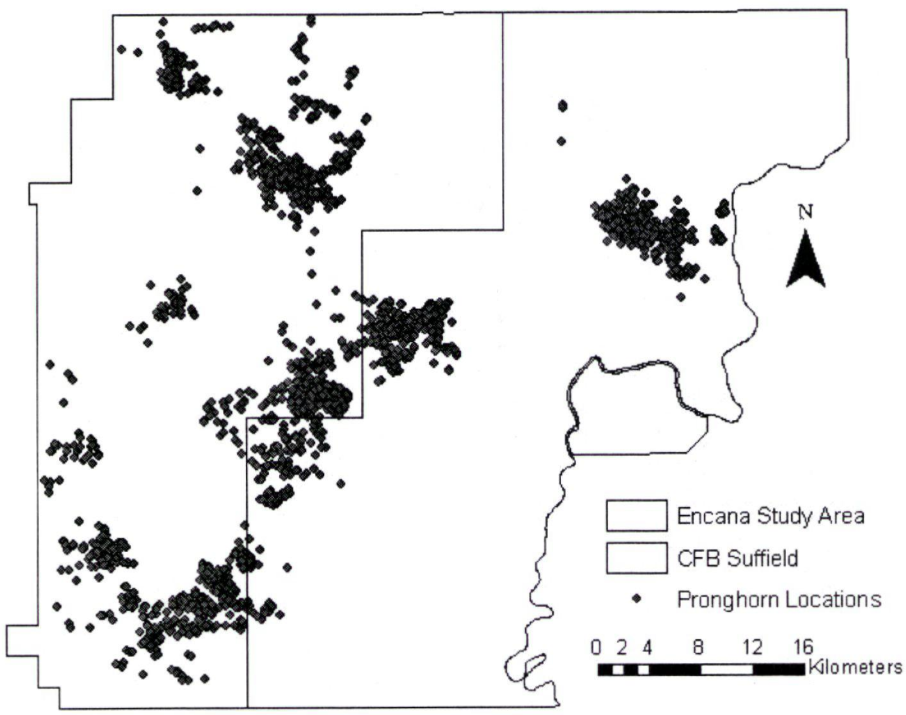


Figure 4: Summer GPS locations. Data collected from 7 collared pronghorn does.

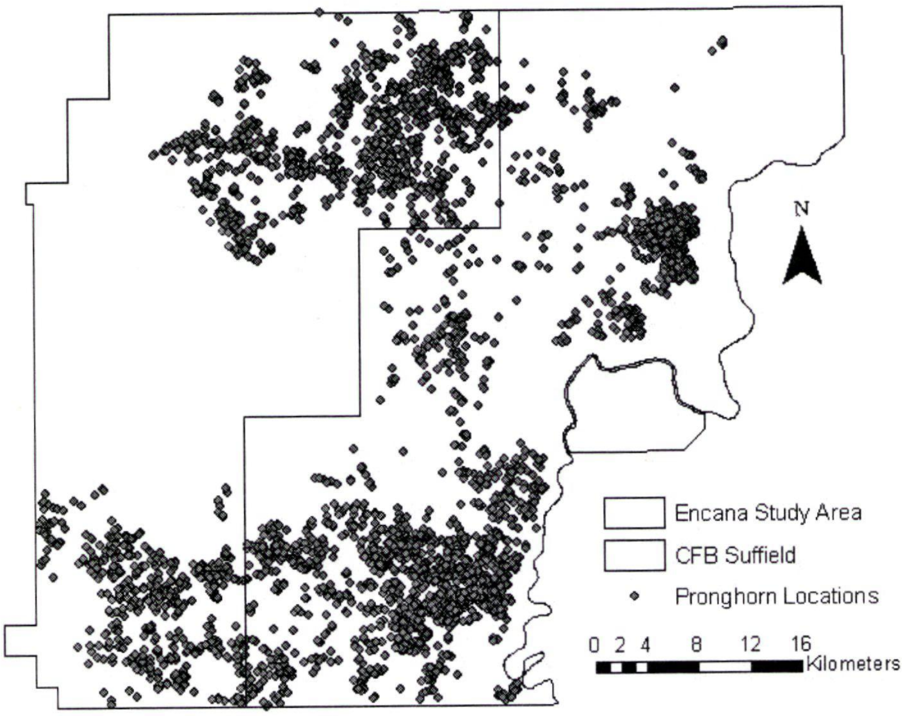


Figure 5: Winter GPS locations. Data collected from 12 collared pronghorn does.

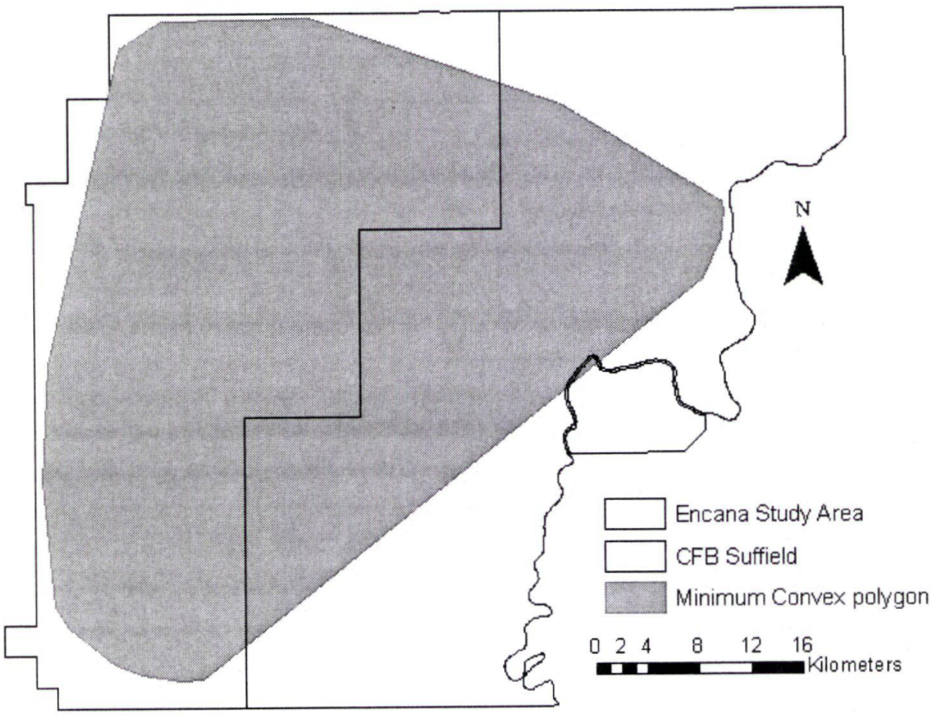


Figure 6: Minimum convex polygon for summer GPS data.

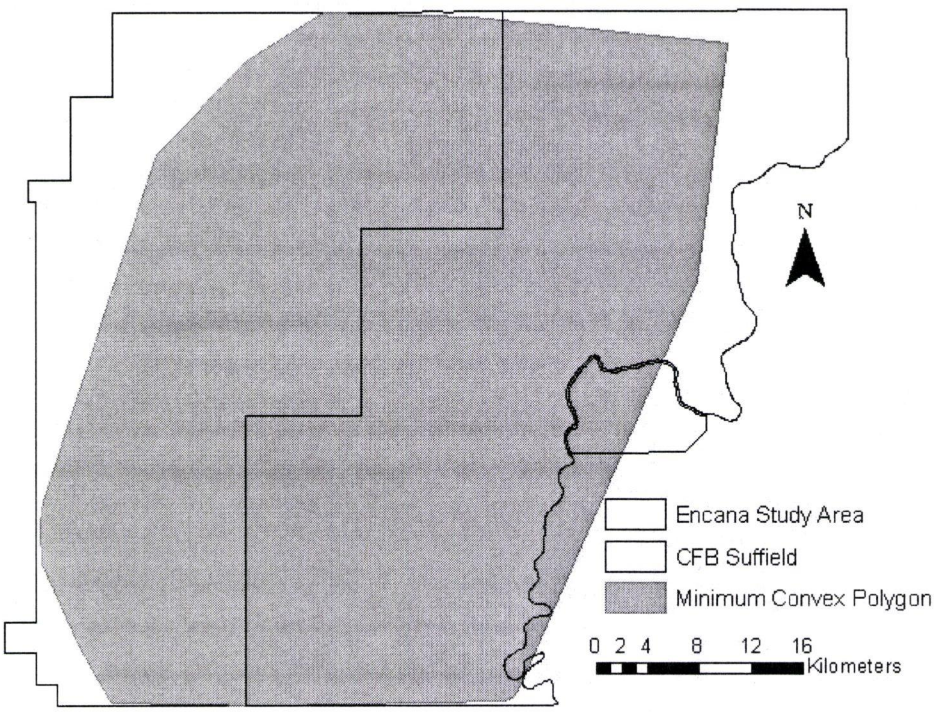


Figure 7: Minimum convex polygon for winter GPS data.

3.3 Biophysical attributes

An area of 427.99km^2 was burned in 2003 on CFB Suffield (Figure 8). This represents 24% of the EnCana study area and 16% of CFB Suffield. Five thousand cattle graze two areas (Figure 9) not used for military training from June to October annually. Grazing is administered by an independent committee of range management and wildlife professionals who advise the Base Commander on stocking rates and environmental concerns. Grazing capacity varies year to year with drought and other conditions. An average hectare of land in the Casa Berardi pasture provides 0.13 animal unit months grazing capacity. Ecological range groups were adapted from Adams et al. (2005), and aggregated into six groups: Wetlands and Riparian, Blowouts, Loamy, Choppy Sandhills, Clayey, and Overflow (Figure 10). The Loamy ERG comprises 75% of each study area (Table 2). There is twice the percentage of Choppy sandhills in the EnCana study area (14%) compared to CFB Suffield (7%). Blowouts represent 7.8% of CFB Suffield but less than 1% of the EnCana study area.

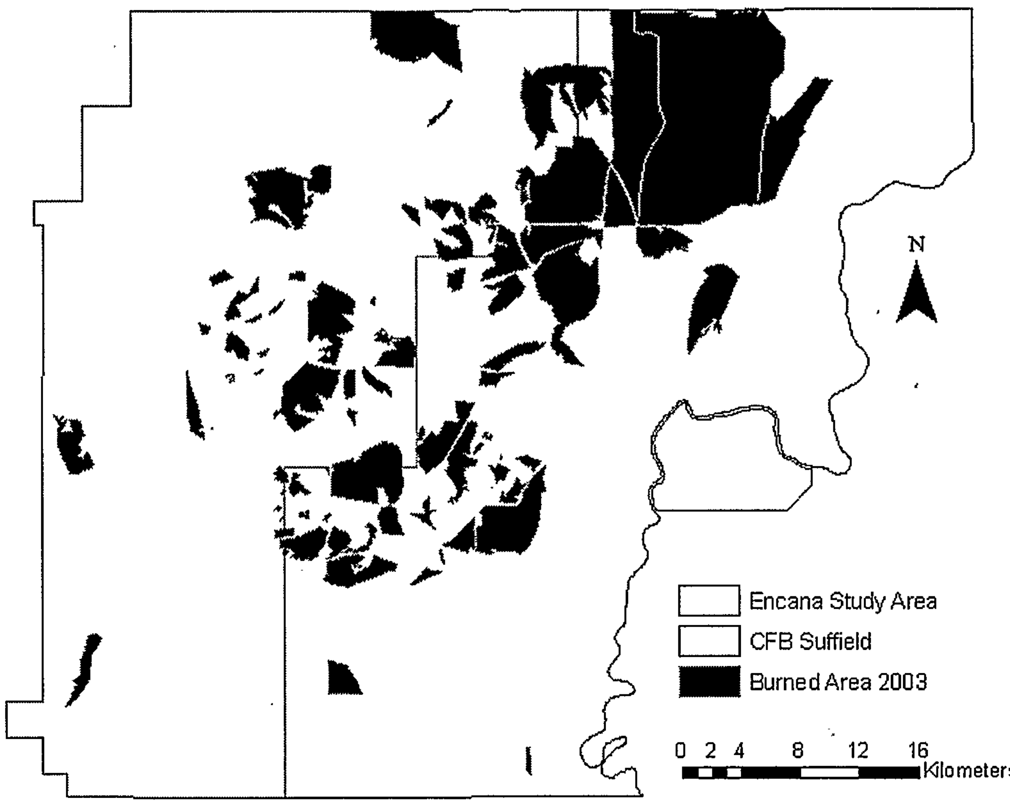


Figure 8: Area burned in 2003 on CFB Suffield. The burned area represents 24% of the EnCana study area and 16% of CFB Suffield.

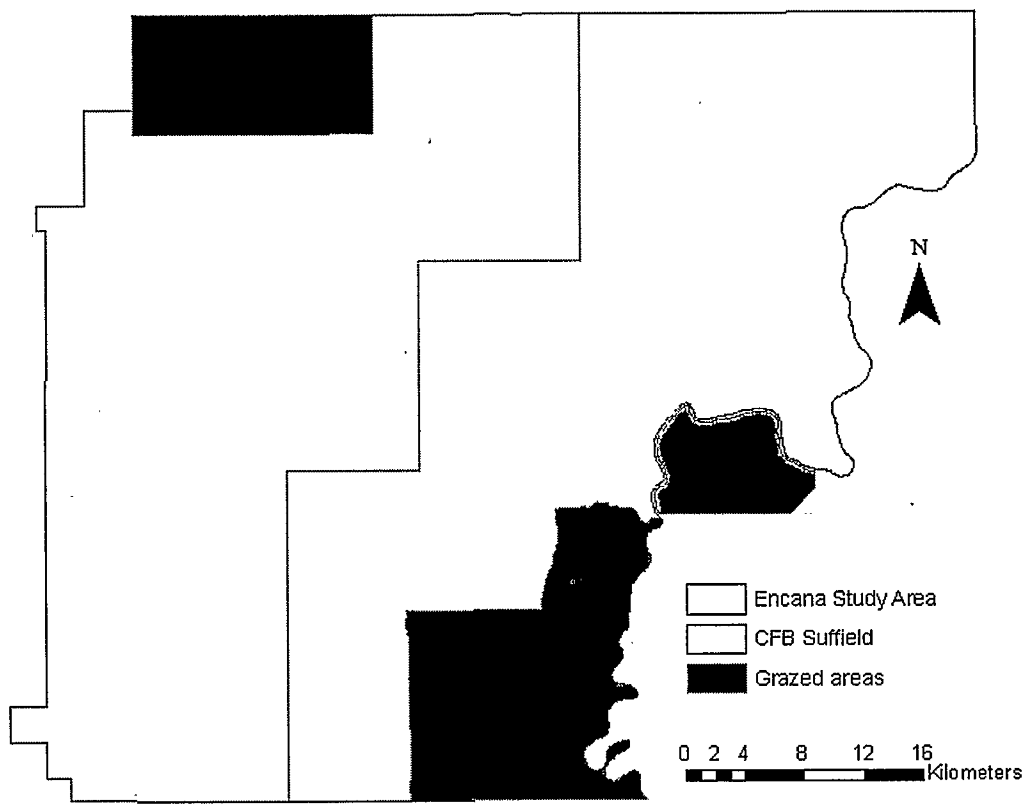


Figure 9: Prairie Farm Rehabilitation Administration (PFRA) grazing leases on CFB Suffield.

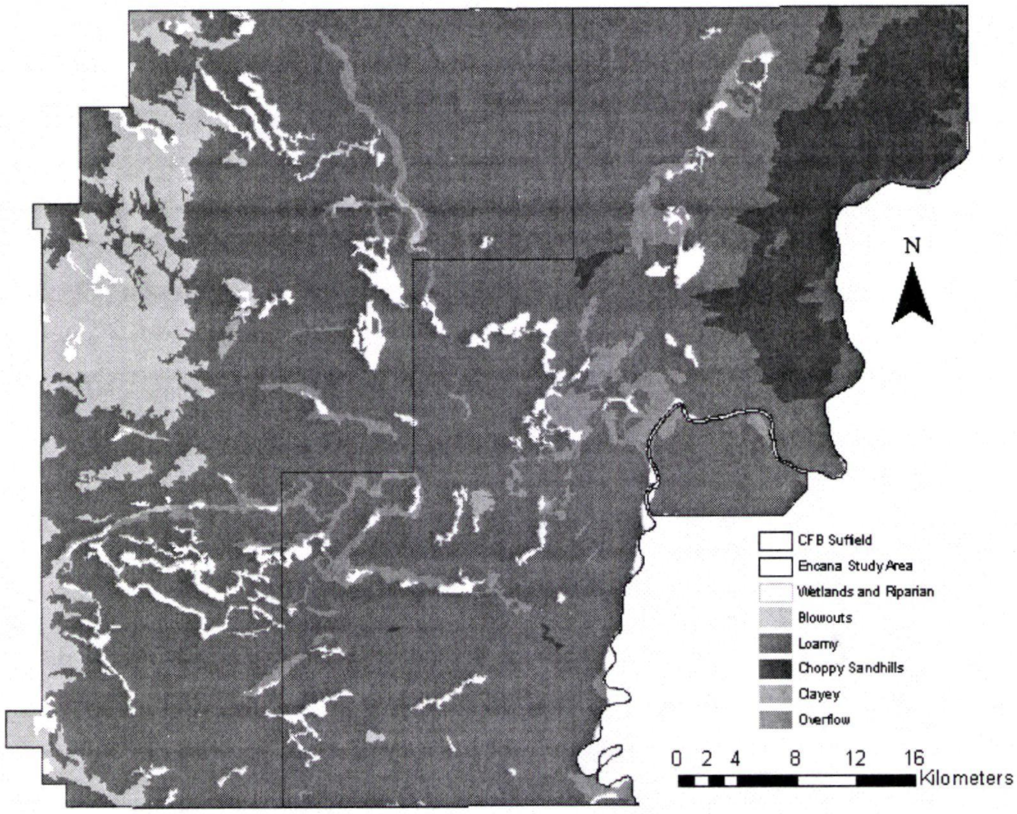


Figure 10: Ecological range groups on CFB Suffield.

Table 2: Comparison of the habitat composition of CFB Suffield and the EnCana study area.

Ecological range groups (Adams et al. 2005)	Range Plant Community (Adams et al. 2005, Adams 2007)	% of EnCana study area	% of CFB Suffield
Wetlands and Riparian	No forage relevant to pronghorn	3.8	4.6
Blowouts	DMGA15 Wheat Grass-Needle and Thread-June Grass	0.065	7.8
Loamy (an aggregation of gravel, limy, loamy, saline lowlands, sands, sandy)	DMGA3 Range Plant Community: needle-and-thread grass, June grass and blue grama grass	75.4	75.6
Choppy sandhills	DMGC5 Needle-and-thread, Northern Wheatgrass, Plains Reed grass	14.2-	7.4
Clayey	DMGA8 Western Wheat Grass-Pasture Sagewort-Prickly Pear Cactus	0.14	0.3
Overflow	DMGA1 Snowberry/Western Porcupine Grass - Needle and Thread	6.42	4.4

Military training takes place from May to October annually (EnCana 2007). Training locations are rotated spatially throughout the year, exclusive of the AEC Oil Access Area and the Suffield NWA.

3.4 Pronghorn summer distribution model based on aerial survey locations

I developed a logistic regression model for pronghorn distribution in the EIS study area based on an aerial survey carried out during August 1 to 3, 2006. The inferential value of the model with respect to anthropogenic disturbance is limited because data were not available to adequately model two of the three dominant land uses (military activities and activities associated with energy development). Eleven variables were chosen a priori of which seven were included in the top model. In ranked order of most influential to least (ranked by Wald value), the variables included in the top model included: Grazed area, the Blowouts ERG, Distance to intermittent water, Well nearest neighbor density, Area burned in 2003, NDVI, Distance to water, Overflow ERG, Loamy ERG, Wetlands and riparian ERG, Clayey ERG. The second ranked model had a ΔAIC > 2, therefore it was not considered.

Table 3: Habitat selection model for pronghorn surveyed aerially at CFB Suffield in summer 2006 (N = 6864. Nagelkerke $R^2 = 0.064$. -2LL=4754.502).

Variable	B	S.E.	Wald	Sig
Ecological Range Group	n/a	n/a	38.01475	n/a
Grazed area	-.622466	.11176688	31.01740	.000
Blowouts ERG	3.067435	.56639649	29.32984	.000
Distance to intermittent water	-.000200	.00003949	25.71233	.000
Well nearest neighbour density	-.001467	.00029324	25.02832	.000
Constant	-1.46039	.31941698	20.90351	.000
Area burned 2003	-.518251	.11666794	19.73229	.000
NDVI	2.753231	.66859785	16.95724	.000
Distance to water (minimum)	.00011987	.00003145	14.52836	.000
Overflow ERG	.88074906	.23258333	14.33994	.000
Loamy ERG	.48121142	.18880407	6.496047	0.011
Wetlands and riparian ERG	.39249562	.27779178	1.996323	0.158
Clayey ERG	-19.1241	13324.764	0.00000206	0.999

Reference = Choppy sandhills ERG.

The top three variables in the summer model based on the aerial survey data ranked as follows (Table 3): Grazed area, the Blowouts ERG, and Distance to intermittent water (note: well nearest neighbour density has roughly the same Wald value as Distance to intermittent water). Pronghorn responded negatively to grazed area and distance to water, and positively to the Blowouts ERG. Three anthropogenic variables were included in the summer model built from aerial survey data (Table 3). They were ranked as follows: Grazed area, Well nearest neighbour density, and Area burned in 2003.

3.5 Pronghorn summer distribution model based on GPS locations

I developed a summer distribution model for pronghorn for the entire area of CFB Suffield based on locations of seven pronghorn equipped with GPS collars. GPS locations for the seven collared pronghorn were not evenly distributed throughout the base (Figure 4). Eleven variables were chosen a priori of which seven were included in the top model. The inferential value of the model with respect to anthropogenic disturbance is limited because data were not available to adequately model two of the three dominant land uses (military and energy development activities). In ranked order of most influential to least (ranked by Wald value), the variables selected include: Grazed Area, Loamy ERG, Choppy sandhills ERG, Area burned 2003, Distance to major roads, Wetlands and riparian ERG, Overflow ERG, Brightness, Well nearest neighbour density, NDVI, and Clayey ERG. The second ranked model had a $\Delta AIC > 2$, therefore it was not considered.

Table 4: Summer habitat selection model for pronghorn based on GPS locations for seven individuals (N=15030). Nagelkerke $R^2 = 0.083$. -2LL = 14586.619).

Variable	*B*	S.E.	Wald	Sig.
Grazed area	-1.21809765	.08146186	223.592	.000
Ecological Range Group	n/a	n/a	187.734	.000
Loamy ERG	1.57864535	.12397476	162.145	.000
Constant	-3.87561050	.34279786	127.822	.000
Choppy sandhills ERG	1.55352289	.14836909	109.635	.000
Area burned 2003	-.65455966	.06684614	95.884	.000
Distance to major roads	-.00030641	.00003227	90.147	.000
Wetlands and Riparian ERG	1.16948214	.16093348	52.807	.000
Overflow ERG	1.11702323	.16779067	44.319	.000
Brightness	.01238857	.00195277	40.248	.000
Well nearest neighbor density	-.00082309	.00013593	36.665	.000
NDVI	1.92855981	.33475233	33.191	.000
Clayey ERG	.20262563	.74838614	.073	.787

Reference = Blowouts ERG.

The top three variables (Table 4) in the summer GPS model were (1) Grazed area; (2) Loamy ERG; and (3) Choppy sandhills ERG. Pronghorn responded negatively to grazed areas and positively to both ecological range site classes. The next closest variable was Area burned in 2003 to which pronghorn responded negatively. Four anthropogenic variables were included in the top summer model (Table 4) ranked in order of influence as follows: Grazed area, Area burned 2003, Distance to major road, and Well nearest neighbour density. Pronghorn responded negatively to all anthropogenic variables in the summer GPS location model.

3.6 Pronghorn winter distribution model based on GPS locations

I developed a distribution model for pronghorn during the winter in the entire area of CFB Suffield based on locations of twelve pronghorn equipped with GPS collars. The inferential value of the model with respect to anthropogenic disturbance is limited because data were not available to adequately model two of the three dominant land uses. Eleven variables were chosen a priori of which nine were included in the top model. The results of logistic regression included 10 of the 11 variables in the model (Table 5). In ranked order of most influential to least (ranked by Wald value), the variables selected include: Grazed area, Area burned 2003, Loamy ERG, Distance to intermittent water, Choppy sandhills ERG, Overflow ERG, Distance to water, Distance to pipelines, Terrain ruggedness index, Distance to major road, Wetlands and riparian ERG, NDVI, Brightness, and Clayey ERG.

Table 5: Winter habitat selection model for pronghorn surveyed using GPS collars at CFB Suffield (N=16408. Nagelkerke $R^2 = 0.145$. -2LL = 17491.389).

Variable	*B*	S.E.	Wald	Sig.
Ecological Range Group (Feature)	n/a	n/a	296.571	.000
Grazed area	.76801928	.04561200	283.522	.000
Area burned 2003	-1.08714269	.07519105	209.046	.000
Loamy ERG	2.18613944	.15254584	205.379	.000
Distance to intermittent water	.00018289	.00001889	93.778	.000
Choppy sandhills ERG	1.71145890	.17702070	93.473	.000
Overflow ERG	1.71455599	.19135775	80.281	.000
Distance to water (minimum)	.00013844	.00001561	78.628	.000
Constant	-2.37364369	.29555091	64.501	.000
Distance to pipelines	.00110796	.00015293	52.490	.000
Terrain ruggedness index	-.00618109	.00086258	51.348	.000
Distance to major roads	-.00018322	.00002681	46.692	.000
Wetlands and riparian ERG	1.21285132	.19581182	38.365	.000
NDVI	1.57339856	.28862900	29.716	.000
Brightness	-.00824705	.00165725	24.764	.000
Clayey ERG	-18.34867193	7046.70535005	.000	.998

Reference = Blowouts ERG.

The top three variables in the winter GPS location model identified by logistic regression were (1) Grazed area; (2) Area burned 2003; and (3) Loamy ERG. Pronghorn responded positively to grazed areas and Loamy EGR. The next closest variable was Distance to intermittent water to which pronghorn responded positively. Four anthropogenic variables were included in the model (Table 5); they ranked as follows: Grazed area, Area burned 2003, Distance to pipelines and, Distance to major road. Pronghorn responded positively to grazed areas, proximity to roads, and proximity to pipelines. They responded negatively to burnt areas.

3.7 Validation

K-fold cross validation is better suited to evaluating the predictive capacity of use-availability RSF models than typical approaches such as ROC, Hosmer-Lemeshow goodness of fit, and percent correctly classified (Fielding and Bell 1997, Hastie et al. 2001, Boyce et al. 2002, Johnson et al. 2006). A model that is proportional to the probability of use has a slope of 1, an intercept of 0 and a high R^2 value (Johnson et al. 2006). χ^2 goodness of fit was not useful in this study because I was looking at a linear relationship between observed and expected, not the true differences between observed and expected described by χ^2. The aerial survey model ($R^2 = 0.80$) performed well having a slope close to 1, an intercept close to 0, and a high R^2 value (Figure 11). Grouping of points at the bottom of Figure 11 is a result of the relatively even distribution of pronghorn across the landscape with exception of a few locations of higher pronghorn concentration. Both the summer ($R^2 = 0.65$) and winter ($R^2 = 0.94$) GPS models performed well (Figures 12 and 13). The summer GPS model had a slope close to 1, however, the intercept wasn't as close to 0 as expected, and model fit was lower than expected ($R^2 = 0.65$) suggesting some RSF bins were different than expected from a model that is approximately proportional to the probability of use. The winter GPS model performed very well having a slope close to 1, an intercept close to 0, and a high R^2 value ($R^2 = 0.94$). Both the summer and winter GPS models had clusters of 5 points on the right of the graph. These clusters represent high concentrations of location data (visible in Figures 12 and 13), and may represent when pronghorn were stationary for longer periods such as rest.

Figure 11: Relationship between expected and observed pronghorn locations in the summer model derived from aerial survey data.

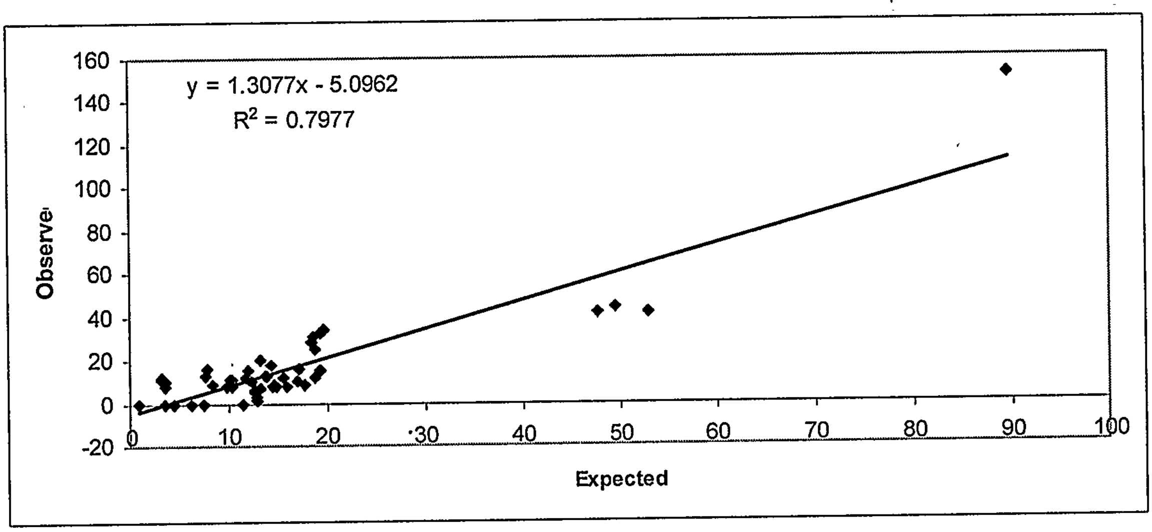


Figure 12: Relationship between expected and observed pronghorn locations in the summer model derived from GPS data.

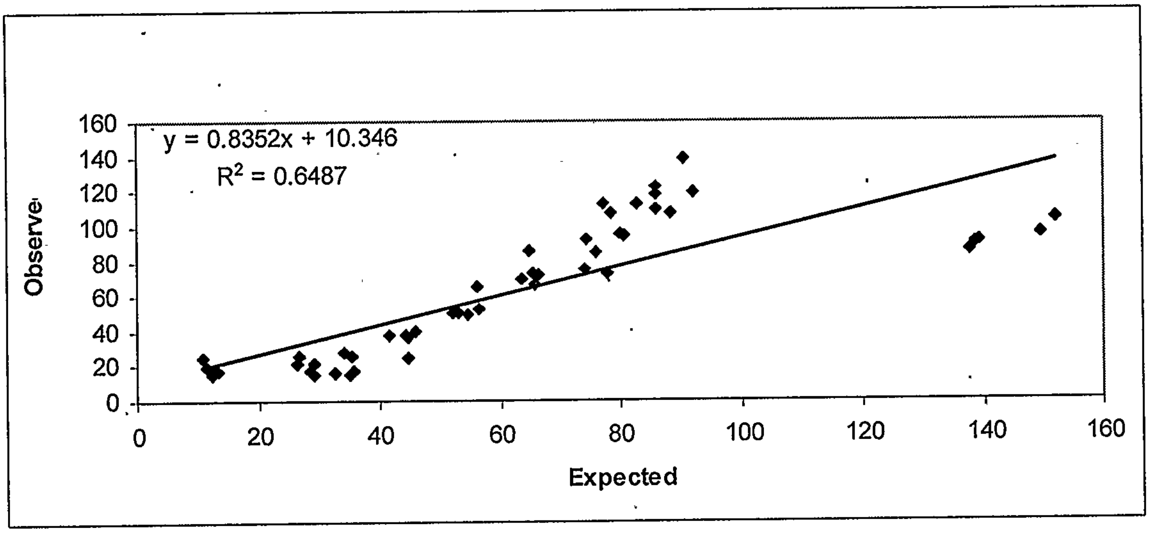
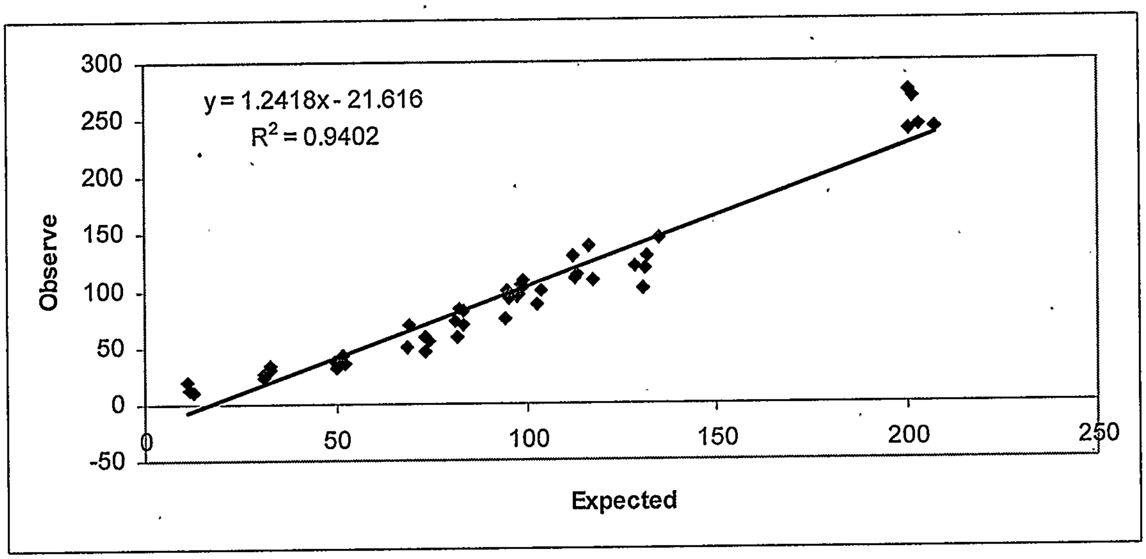


Figure 13: Relationship between expected and observed pronghorn locations in the winter model derived from GPS data.



Chapter Four: Discussion

4.1 Introduction

Animal distribution patterns are a central aspect of applied animal ecology that are useful for addressing cumulative effects assessments (Scott et al. 2002). Anthropogenic disturbance from development is changing and fragmenting existent wildlife habitat (Childress 1980, Hoskinson and Tester 1980, Cook and Irwin 1985, Andrews et al. 1986). Alberta is experiencing similar development pressures to those recorded in the US (PCF 2006), and this impact is reducing the size of natural regions and the wildlife they support. In the Grasslands Natural Region of Alberta, the primary cause of habitat loss has been conversion of grassland through cultivation (PCF 2006). Pressures on remaining native grassland include additional conversion for cultivation or tame pasture, oil and gas field development, roads and pipelines, rural acreage development and urban expansion (PCF 2006). Pronghorn density is positively related to the proportion of native grass prairie (Sheriff 2006). As such, understanding pronghorn distribution is an important part of environmental impact assessments in the Grassland Natural Region of Alberta. Inferences from this study in respect to cumulative effects management on CFB Suffield are limited by the inadequacy of the models to completely address the impacts of military activities and oil and gas development, two of the three dominant land uses on CFB Suffield.

The two-fold purpose of my study was to compare the relative merits and shortcomings of pronghorn distribution models derived from two location data types, GPS collar and aerial surveys, and to evaluate the influence of natural and selected anthropogenic features on pronghorn distribution in summer and winter.

4.2 A comparison of summer resource selection models based on aerial survey data and GPS locations

The inferential value of resource selection models is influenced by the spatial and temporal attributes of the data used to develop the model (Manly et al. 2002). The more representative a survey data set is of the life history of a species, the closer the RSF will be to approximating the resource selection of the species being modelled (Manly et al. 2002). I compared RSF models for summer locations obtained from an aerial survey (100% coverage) and from GPS locations of seven individuals. The results of my research indicated that aerial survey data and GPS data resulted in similar RSF models in terms of the independent variables included in the models, and their order and direction of influence on pronghorn distribution. The following discusses the relative merits and shortcomings of each of the survey techniques in determining density distributions.

A resource selection model can be developed from aerial survey animal location data using Design 1 described by Manly et al (2002). Used resource units are represented as animal locations obtained during the survey. Available resource units are randomly sampled for the entire study area (Manly et al. 2002). The proportion of used resources is compared to the availability of these resources to evaluate resource selection (Manly et al. 2002). Aerial surveys provide a rapid method for obtaining location data that can be used to develop distribution models (Allen and Samuelson 1987, Pojar and Guenzel 1999, Manly et al. 2002). Distribution models based on aerial survey data provide a "snapshot in time" whereby the survey is performed over one or several consecutive days dependant on the size of the study area and the number of animals being sampled. Aerial surveys are conducted routinely by government agencies for census purposes. Typically they are done as a discrete survey once a year. Rarely does a survey involve more than one pass. There are three assumptions involved when undertaking line transect surveys: (1) all animals being surveyed are detected, (2) all animals are detected and recorded at their original location prior to moving, and (3) recorded locations are accurate (Buckland et al. 2002). Pronghorn are an ideal species for aerial line transect surveys because they predominantly use open habitats, and sightability is primarily a function of distance from the aircraft (Smyser 2005). However, when compared with quadrat sampling, line transects underestimate the pronghorn population (Pojar and Guenzel 1999).

Sources of error associated with aerial surveys include undercounting bias, aircraft disturbance, circadian variation in distribution, and survey design. Undercounting is a major shortcoming of aerial surveys (Pojar and Guenzel 1999, Jachmann 2002). Undercounting results from sighting probability bias and visibility bias (Bailey and Nagy 1969, Pojar and Guenzel 1999, Jachmann 2002). Sighting probability bias exists where there is a low probability of spotting single animals, small groups, or camouflaged animals (Jachmann 2002). Visibility bias results from line-of-sight obstructions that conceal the animal from the observer (Jachmann 2002). Undercounting bias can be mitigated by limiting aerial surveys to large conspicuous grazers in open habitat such as elephant (*Loxodonta africana Africana*), buffalo (*Sincerus caffer*), zebra (*Equus burchell*), wildebeest (*Connochaetes*) and lechwe (*Kobus leche*) and by using a double count technique (Jachmann 2002). In addition, height, speed and transect strip width should be kept to a reasonable limit to increase observer probability of viewing and accurately counting an animal (Pojar et al. 1995). Helicopters should be used to obtain accurate estimates as they have greater manoeuvrability compared to fixed wing aircraft (Pojar et al. 1995). Observer experience and flight duration affects undercounting bias, where by more experienced observers and shorter transect flight times reduce undercounting bias (Pojar et al. 1995). Visibility bias acknowledges that only a portion of animals within a sampled land using will be enumerated (Caughley 1974). The main factors that affect large ungulate visibility using aerial surveys are the animal's reaction to the aircraft, dispersion, body size, and colour (Jachmann 2002). Animals that move are more likely to be observed than static animals (Jachmann 2002). Animals with high colour contrast between them and their background are more likely to be seen (Barrett and Vriend 1980, Barrett 1981), large groups are easier to spot than individuals, and large animals are easier to spot than smaller animals (Jachmann 2002). In addition, the terrain and vegetation cover (Smith and Beale 1980), and the time of day and season in which the surveys were conducted (Manly et al. 2002) affect undercounting and sighting probability bias of pronghorn during aerial surveys.

The aerial survey conducted as part of this study was designed to minimize undercounting and sighting probability bias (AFWD 1990, Jachmann 2002). Visibility bias was considered to be minimal in the open grassland area surveyed. Surveys were flown in summer when sun angle is high, animal group size small and animals contrast to a great degree with their background than in the winter. The height and speed of the survey helicopter was selected for consistency with other aerial pronghorn surveys in Alberta, based on the Alberta Pronghorn Management Plan (AFWD 1990). During the aerial survey pronghorn were rarely observed in groups too large to count accurately from the helicopter (approximately half a dozen of 887 locations).

Response of animals to a survey aircraft (noise and visual) can affect the accuracy of the recorded locations during a survey and limit the inferences that can be drawn about resource selection (Burnham and Anderson 1998). Animals may be moved from pre-disturbance locations to the recorded locations (Burnham and Anderson 1998). In addition, double counting animals is possible where aircraft disturbances force animals to move from one transect to another (Caughley 1974, Allen and Samuelson 1987). In my study every effort was made to minimize double counting pronghorn. When pronghorn were run by the surveyors, the aircraft was used to push the pronghorn away from unsurveyed transects.

Pronghorn activity levels and distribution patterns vary by time of day and season as well as between sexes (Byers 1997, Gamo 1997, Boyce et al. 2002). Gamo (1997) concluded that in summer pronghorn spent 57% of their day feeding, 28% bedded, 8% walking, and 17% standing. In winter they were observed to spend 50% of the day feeding, and 50% bedded (Gamo 1997). In summer, Gamo (1997) reported that activity levels were greatest in the morning and the late afternoon; pronghorn avoided being active during the heat of the day (Gamo 1997). Because of the circadian variability in pronghorn activity levels, the timing at which a survey is flown introduces bias that affects the outcome of a resource selection model (Manly et al. 2002). In this study, surveys were conducted in the morning and late afternoon, coinciding with periods of foraging. Therefore, I assumed the analysis of survey location reflects pronghorn distribution while they were active. Active pronghorn are responding to habitat quality configuration and disturbance factors that evoke taxic responses in the short term. Aerial survey data is not capable of representing short term responses of individuals to point source disturbance (Burnham and Anderson 1998).

Unlike sequential GPS location data for an individual animal, aerial surveys reflect the entire population of animals within a study area and represent the collective response of individual animals to habitat selection in a study area (Boyce et al. 2002, Manly et al. 2002).

The biophysical characteristics of each study area are similar (Table 1).The study areas for both the GPS and aerial data sets are dominated by a ~75% Loamy landscape. The EnCana study area has far fewer Blowouts (<1%) in comparison to CFB Suffield (~7.8%). It is noteworthy that Blowouts were highly selected by pronghorn in the aerial survey model. Although they are more abundant in the CFB Suffield study area than in the EnCana study area, they were not used by GPS collared animals in the summer. This result is possibly attributable to pronghorn avoiding Blowouts in the CFB Suffield study, or more likely to a low number of collared individuals none of which had summer range that included the Blowout area.

The disturbance footprint is greater in the portion of CFB Suffield that excludes the EnCana study area, due primarily to a greater road density, military activity and a more frequent fire regime (EnCana 2007). Grazed area was included in both summer models and pronghorn exhibited a strong negative response to grazed areas in both. Burned areas (2003) and well nearest neighbour density were also included in each model, with pronghorn exhibiting a weak negative response in each model type.

Pronghorn exhibited a weak negative response to roads in the summer and winter GPS models.

The aerial survey represented the distribution of animals evenly throughout the EnCana study area, whereas, the GPS data set exhibited clumped landscape usage due to the limited number of collared animals within the study area. The summer aerial survey resulted in 440 independent observations representing 867 pronghorn. The survey accounted for over 80% of the pronghorn estimated by ARSD on CFB Suffield based on a census two days before I surveyed the EnCana study area. Note: ASRD data were not available at the time of this analysis and consequently not used in this analysis.

Generalized linear models and GIS are useful tools for wildlife management and planning but can be complicated by issues of data availability, scale and model extrapolation (Johnson et al. 2004). Continuous data sets generated using GPS collars are time series of discrete data points for each animal that has been collared, providing a history of each animal's movement at intervals over a given time frame. The GPS data, representing diurnal and nocturnal resource selection by pronghorn for the duration of the study, provides a more complete picture of resource selection by pronghorn that allows us greater scope for interpretation of the outcomes in terms of the animal's response to habitat variables. Location data for seven GPS collared pronghorn in the summer generated 3141 location points. Design II Resource Selection Design enables analysis of resource selection for individual animals (Manly et al. 2002). Estimates calculated for individuals are used to estimate parameters for the population of animals (Manly et al. 2002). It is assumed that the collared pronghorn represent the behaviour of the entire population, however, this assumption is violated when locations are pooled across animals that differ in behaviour (Manly et al. 2002). GPS data collects location data across a broader range of spatial and temporal conditions than aerial surveys (Frair et al. 2004) enabling interpretation of short-term response to disturbance (Smith et al. 2000, Vistnes et al. 2004, Weclaw and Hudson 2004). However, the potential to detect short term responses using GPS data is constrained by recording interval. The time between the radio relocations influences what can be inferred from the data (Manly et al. 2002). In this study, location data were recorded every 4 hours. Pronghorn responses lasting four or more hours could be inferred from this study.

There are three possible sources of error associated with GPS location data: availability and cost, scale and spatial autocorrelation (Bissonnette 1999). Analysis of wildlife distribution patterns using GPS collars are often financially prohibitive for researchers (Bissonnette 1999, Manly et al. 2002). For each animal collared there is the cost of collar purchase, deployment, maintenance, and retrieval. This cost is variable but even at a minimum it is several order of magnitudes greater than the cost of a one-time aerial survey. Consequently, a small proportion of a population is sampled using GPS collars (Bissonnette 1999, Johnson et al. 2002, Johnson et al. 2004). For example, a study of woodland caribou in British Columbia collared 8 caribou generating 2,178 locations for estimating RSF models (Johnson et al. 2002). Minimum sample size in Design II resource selection analysis is not clearly defined in the literature (Bissonnette 1999, Johnson et al. 2002). Small sample sizes are generally acceptable given the administrative and financial limit on generating larger data sets using GPS technology (Bissonnette 1999). In my study, seven collared pronghorn were in the study area during the summer; twelve collared pronghorn were present in the winter. Although greater sample size would have been more informative to the study, RSFs are frequently built from a low sample size and the results are considered adequate (Manly et al. 2002).

Pronghorn locations in the aerial survey exhibited a uniform distribution across the EnCana study area. GPS data locations were grouped throughout the CFB Suffield study area. Figure 6 shows that pronghorn range (defined by a minimum convex polygon) in the summer GPS model did not cover the entire Base. Consequently, portions of the Base were not sampled as part of this study. This introduces error whereby more spatially limited biophysical variables have an even lesser chance of being sampled, as demonstrated in the case of Blowouts explained above (Frair et al. 2004). This affects the entire model, because bias in use data for one variable can influence conclusions about selection of others (Frair et al. 2004).

Spatial autocorrelation is a potential source of error in wildlife distribution analysis using GPS collars (Otis and White 1999, Boyce et al. 2002). Spatial autocorrelation occurs when the value at any one point is dependent on the values of surrounding points (Otis and White 1999). GPS data is potentially subject to spatial autocorrelation since we are observing the same individual multiple times (Boyce et al. 2002). The lack of independence inherent in the GPS data increases the chance of error since model coefficient variances are underestimated (Lennon 1999, Boyce et al. 2002). Rarefying data (Swihart and Slade 1985) or the use of variance inflators to obtain a more robust standard error (Boyce et al. 2002) have been proposed as methods to reduce the likelihood of spatial autocorrelation. Rarification of data has produced highly conservative results and has tended to omit habitat types considered to be highly selected by subject animals (Boyce et al. 2002) and as such was not used in this study. Variance inflators inflate P-values without altering model coefficients (Boyce et al. 2002), but were not used in this study because they have little effect on the model coefficients and in order to simplify the approach.

The use of aerial survey data for distribution models is appropriate for environmental assessment because it provides an economical population level density survey. However, aerial survey data does not inform resource managers in regards to the circadian variability of pronghorn distribution, short-term response to disturbance, and information in regards to year-round distribution. Aerial survey data could miss critical or important changes in the behaviour of pronghorn, because the aerial survey data only paints a part of the picture. GPS data for individual animals better reflects the variability of pronghorn behavioural patterns throughout the day and year, but is generally limited by a small sample size relative to the population. Different questions can be addressed with GPS data; specifically detection of short term distribution responses is possible with GPS data measured as changes in rates of travel, direction of travel, and linear displacement (Smith et al. 2000, Vistnes et al. 2004, Weclaw and Hudson 2004). From a management perspective, dealing with continued anthropogenic development and changing climatic cycles a GPS data set provides a more detailed and complete distribution analysis.

4.3 Pronghorn distribution patterns in summer and winter

O'Gara and Yoakum noted that winter resource selection is significantly more limited than in the summer months as good quality forage can be limited in distribution and availability (O'Gara and Yoakum, 2000). Severe winters can decimate pronghorn populations (Martinka 1967, Riddle and Oakley 1973, Barrett 1987, O'Gara and Yoakum 2004). In this study, the biophysical variables selected in the summer and winter GPS models differed, suggesting pronghorn responded seasonally to the biophysical variables in the study area. In this study, the inferential value of the models derived from GPS data with respect to biophysical variables is limited by the under-dispersion of locations among a limited number of collared individuals. The following contrasts the dominant biophysical variables selected by the summer and winter GPS models.

4.3.1 Seasonal response to ecological range groups

As mentioned previously, Barrett (1982) found that 85-90% of pronghorn in Alberta select native grassland and/or sagebrush throughout the year. Pronghorn diet is predominantly graminoids (40-60%), forbs (10-30%) and browse (5-20%). Pronghorn select for high protein food sources year-round and succulent vegetation in dry climates where water is not readily available (O'Gara and Yoakum, 2000; (Dirschl 1963). Forbs are selected preferentially in spring, summer and fall and when they are not available succulent high-protein grasses and browse (i.e.: Grasses: *Bouteloua gracili* and *Stipa comata.* Shrubs: *Artemisia frigida* and *Artemisia cana*) are substituted (Mitchell and Smoliak, 1971; (Dirschl 1963, Gainer 1991). Grasses are only observed to be heavily browsed in spring when their high-protein content is beneficial as other forage is generally of lower quality (Dirschl 1963, Sexton et al. 1981). Resource availability for pronghorn in Alberta varies with the season (Hoover, 1966; (Dirschl 1963, Mitchell and Smoliak 1971). Winter is the most limiting time of year when most forbs senesce, become less available (possibly snow covered) or low in nutrients; exceptions include pasture sage and winter fat (Hoover, 1966; (Dirschl 1963, Mitchell and Smoliak 1971). In winter in Alberta, browse constitutes the highest proportion of pronghorn diet, although its availability is critically limited (Mitchell and Smoliak, 1971).

I found; pronghorn selected most strongly for the Loamy ERG and Choppy Sandhills ERG in the summer GPS model (Table 4). In winter, pronghorn selected for the Loamy ERG (Table 5). The Loamy ERG is characterized as the DMGA3 Range Plant Community: needle-and-thread grass, June grass and blue grama grass on loamy range sites in the Dry Mixed Grass region (Adams et al. 2005). It is considered the most common grassland community type in the brown soil zone. Soils are moderately well drained to rapidly drained Orthic Brown and Solonetzic soils. Grasses are much more abundant than forbs in the DMGA3 Range Plant Community, representing 536.48 kg/ha and 24.64 kg/ha respectively (Adams et al. 2005). Plant species represented in the communities associated with the Loamy ERG include:

Forbs:

- Silver sage *(Artemisia cana)* (~0-13% canopy cover);
- Pasture Sagewort *(Artemisia frigida)* (~0-28% canopy cover);
- Scarlet Mallow *(Sphaeralcea coccinea)* (~0-23% canopy cover);

Grasses:

- Needle and thread grass (*Stipa comata)* (~4-85 canopy cover)
- June grass *(Koeleria macrantha)* (~0-44 canopy cover)
- Blue grama grass *(Boutelua gracilis)* (~0-51 canopy cover)
- Undifferentiated sedge *(Carex)* (~0-25 canopy cover)

- Western wheat grass *(Agropyron smithii)* (~0-38 canopy cover)
- Plains reed grass *(Calamagrostis montanensis)* (~0-15 canopy cover)
- Sandberg bluegrass *(Poa sandbergii)* (~0-22 canopy cover)
- Northern wheat grass *(Agropyron dasystachyum)* (~0-29 canopy cover)

The Loamy ERG provides abundant forbs for winter and summer and grasses for early summer use by pronghorn. Of importance for pronghorn in winter is the presence of sage forbs and silver sage (a shrub), a major component of pronghorn winter diet (Mitchell and Smoliak 1971, Irwin and Cook 1985). The forb community and pronghorn respond favourably to light grazing (Willms et al. 1986). Under heavy grazing pressure wheatgrass and needle-and-thread are replaced by blue grama and Sandberg bluegrass. Intensive grazing does not take place on CFB Suffield. Pronghorn responded favourably to grazed areas in the winter when the grazing leases were not being grazed by cattle.

The Choppy Sandhills ERG included in the summer GPS model is characterized by the DMGC5 Range Plant Community: needle-and-thread, northern wheatgrass, and plains reed grass (Adams et al. 2005). DMGC5 is a late-seral reference plant community on a loamy range site. Soils include Orthic Brown, Solonetzic Brown, and Brown Solods that are moderately well drained to well drained. Plant species include:

Forbs:

- Pasture sagewort *(Artemisia frigida)* (~0-14 canopy cover);
- Common dandelion *(Taraxacum officinale)* (~0-15 canopy cover);
- Common goat's beard *(Tragopogon dubius)* (~0-6 canopy cover).

Grasses:

- Needle-and-thread grass *(Stipa comata)* (~11-48 canopy cover);
- Northern wheat grass *(Agropyron dasystachyum)* (~6-47 canopy cover);
- Plains reed grass *(Calamagrostis montanensis)* (~0-29 canopy cover);
- June grass *(Koeleria macrantha)* (~11-21 canopy cover);
- Blue grama grass *(Boutelua gracilis)* (~0-16 canopy cover);
- Western wheat grass *(Agropyron smithii)* (~0-21 canopy cover);
- Thread-leaved sedge *(Carex filifolia)* (~0-14 canopy cover);
- Undifferentiated sedge *(Carex)* (~0-9 canopy cover);
- Sandberg bluegrass *(Poa sandbergii)* (~0-9 canopy cover).

The Choppy Sandhills ERG provides good summer forage with an abundance of needle-and-thread grass (Mitchell and Smoliak 1971). It does not have the same quantity or quality of winter forage like silver sage and consequently is not highly selected by pronghorn in the winter GPS model. Based on the literature I would have expected to see more pronounced variability between the summer and winter GPS models. However, several mild winters during the period of study could have meant pronghorn may not have been acutely restricted in their range between seasons. Furthermore, had more GPS collars been deployed, I would anticipate greater variability between seasonal models since a better representation of the population would be possible. In addition, I would expect to see difference in ERG usage as more collars would likely sample the landscape more completely.

4.4 The response of pronghorn to select anthropogenic land management practices (fire regime, grazing, well density and roads)

The three most influential anthropogenic land uses on CFB Suffield include: military activities, oil and gas development, and grazing. Two of the three dominant anthropogenic land uses on CFB Suffield (military activities and human activities associated with oil and gas development) were not effectively accounted for in the models developed as part of this study, thus limiting the inferences that can be made from this study for cumulative effects management. In my study, data were available for fire, grazing, well density and major roads. Trails form an integral component of oil and gas development in addition to well density, and were not available to be modelled as part of this study. Furthermore, I was not able to obtain data on military activities in CFB Suffield. Models still need to be developed to test the effects of military activities as well as oil and gas development on CFB Suffield, and to consider if pronghorn are a useful indicator of cumulative effects from these activities.

Pronghorn are listed as sensitive by ASRD owing to threats to their habitat (ASRD 2005). Anthropogenic disturbance from development is eroding and fragmenting existent pronghorn habitat (Childress 1980, Hoskinson and Tester 1980, Cook and Irwin 1985, Andrews et al. 1986, PCF 2006). Alberta is experiencing similar pressures to those recorded in the US (PCF 2006). Habitat loss results from the reduction in the area of effective habitat and/ or the reduced usage of habitat owing to disturbance (Bender et al. 1998, Fahrig 2001). Fragmentation results from a change to landscape composition and configuration and results in discontinuities in an animal's preferred habitat (Saunders et al. 1991, Andren 1994). Winter range size is impacted by human development in an area, whereby more development results in a smaller winter range (Childress 1980, Hoskinson and Tester 1980).

Light fire regime and light grazing provide disturbance necessary for the health of many grassland plant species important in the pronghorn's diet (Willms et al. 1986, Adams et al. 2004). However, in cases where the natural fire regime has been inhibited by fire suppression, less frequent more intense fires can degrade forage and damage soil. Grazing regime functions similarly, whereby light grazing increases forb productivity providing improved forage for pronghorn, however, overgrazing can damage plant productivity reducing their value as forage. The fire regime on CFB Suffield is higher than in the surrounding region where fire is suppressed. On CFB Suffield, most fires occur in the military training area as a result of live fire exercise and lightning. Most of CFB Suffield has a light fire frequency and light grazing regime, which is beneficial for forage favoured by pronghorn (EnCana 2007).

Preliminary research by the Wildlife Conservation Society suggests that pronghorn adapt to fragmentation of their home range by oil and gas wells up to a certain threshold whereby pronghorn use of the landscape declines significantly (Berger et al. 2006). Habitat parcels less than ~243 ha in size have a less than 50% probability of pronghorn occurrence, and habitat parcels less than ~40.5 ha have a 6.7% probability of pronghorn occurrence (Berger et al. 2006). Roads and trail networks associated with oil and gas wells fragment the landscape as well as providing sensory disturbance for pronghorn (Jaeger et al. 2005). Pronghorn avoid highly concentrated gas fields (Berger et al. 2006).

With the continuing trend of development in Alberta, how can managers include anthropogenic changes in the management process to meet the goals of the Pronghorn Management Plan? The following discusses pronghorn response to fire regime, grazing, well density and roads.

Fire regime

Historically, fire and grazing determined plant community structure in the northern prairies (Adams et al. 2004). Expansive herds of bison grazed the prairie and trampled the soil. The bison herds that once roamed the northern prairies have been extirpated and domesticated livestock have been introduced in their place. Grazing on CFB Suffield is limited to two leases confined to the northwest and southeast corners of the base. Today, fire frequency on CFB Suffield varies in frequency from 1-23 years (EnCana 2007). On lands surrounding the base, fire suppression is practiced exclusively.

Kindschy et al. (1978) suggest that preferred pronghorn habitat is likely maintained by intermittent fire and grazing. Intermittent fire can be beneficial for pronghorn, improving the palatability, digestibility, and nutrition of forage following regrowth (Courtney 1989). Pronghorn in Alberta have been observed moving onto burned sites within a month following fire to forage new forbs and graminoids (Stelfox and Vriend 1977, Courtney 1989). In addition, pronghorn have been observed to browse recently burnt cacti which are more palatable with the spines burnt off (O'Gara and Yoakum, 2000). Succulent vegetation such as cacti provide a valuable source of water to pronghorn in the summer months (O'Gara and Yoakum 2004). Benefits of fire have been observed for up to 3-4 years following a fire (Courtney 1989). However, where fire frequency is excessive the benefits of increased forage production can be compromised (O'Gara and Yoakum 2004). Fires are common on CFB Suffield resulting from lightning strikes, prescribed burns and live fire exercises (annually from June to October), however, fire is suppressed in the Suffield NWA. Payne and Bryant (1998) describe the following as benefits of fire for pronghorn:

- Increased forb abundance; (i.e. forage for pronghorn);
- Retarded shrub and tree invasion;
- Temporary increase of grass and shrub palatability and nutrient content;
- Increased vegetative diversity;
- Retarded plant succession;
- Altered distribution of ungulates;
- Improved forage accessibility;
- Reduced litter and removal of decadent material;
- Rejuvenated woody plants for browse production;
- Stimulated green-up of fire tolerant grasses.

In my study, pronghorn displayed a negative response to burned areas in all three models, most notably in the winter GPS model. I could not detect short-term effect of fire recorded by previous authors (Mitchell and Smoliak 1971, Courtney 1989), however, I saw a longer term response which was avoidance. I attribute this to reduction in forage availability, due in part to the timing of the data acquisition relative to the fire event.

Only fires that occurred in 2003 were included in the models because the fires of 2003 covered a meaningful percentage (16%) of CFB Suffield (Figure 8). The aerial survey was conducted in 2006 and the GPS collars include data from the summers of 2004 and 2005. The 2003 fires were larger than fires in 2004 and 2005 and as such are assumed to be greater in intensity, thus possibly damaging rangeland health. In addition, 450mm of rain fell on Suffield in the first half of 2003 and 2006 (well above average), where as roughly 225mm fell in the first half of 2004 and 2005 (Sheriff 2006). Consequently, forb abundance outside burned areas would likely have been greater in 2003 and 2006. As such, the burned areas of 2003 may have exhibited low forage availability and were avoided by pronghorn.

Grazing

Grazing and fire have similar effects on prairie ecosystems, improving the palatability, digestibility, and nutrition of forage following regrowth (Willms et al. 1986, Courtney 1989). Historically, pronghorn shared the landscape with bison, deer and elk (O'Gara and Yoakum, 2000). High intensity grazing by bison increased *Bouteloua gracilis* and forbs, and wallows disturbed the terrain leading to increased forb abundance (Schwartz and Ellis 1981, O'Gara and Yoakum 2004). Where snow accumulated, bison broke snow cover exposing vegetation for pronghorn that do not paw snow. In light of these results, bison distribution positively affected pronghorn distribution (O'Gara and Yoakum 2004). The historical compatibility of pronghorn and bison is paralleled by the non-disruptive relationship of pronghorn to cattle (O'Gara and Yoakum 2004). It is believed that little competition occurred owing to different diet niches and different seasonal and spatial use of rangelands (O'Gara and Yoakum 2000). Research by O'Gara and Yoakum (2004) suggests that pronghorn are more common on ungrazed or lightly grazed rangeland than on heavily grazed sites, since forbs preferred by pronghorn are in higher abundance in the former (Willms et al. 1986, Brady et al. 1989, Adams et al. 2004). Grazed area was the dominant variable in both of the models based on summer and winter GPS data. The response was negative in the summer GPS model and positive in the winter GPS model. I found that pronghorn exhibited selection against grazed areas in summer and selected for grazed areas in winter. In other areas, pronghorn do not avoid the presence of cattle (O'Gara and Yoakum 2004), so that is not an explanation of pronghorn avoidance of grazed areas in the summer. Possibly, pronghorn reduce their use of grazed areas in the summer owing to the presence of people using horses to tend cattle. However, this is highly speculative and I was unable to find any reference in the literature describing such an effect. In addition, pronghorn are a concentrate feeder and could be responding to greater forage diversity and quality on grazed areas in the winter when non-grazed areas have lesser quality forage.

Elk, mule deer, and white-tailed deer were seen in significant numbers and favoured the NWA over the military training area. The effects of grazing on pronghorn by other ungulates on Suffield were not studied.

Well Density

Well density in Suffield and the Suffield NWA varies between 4 and 8 wells per section. Density is lowest in the northern part of the study area and highest in the southern part, with the exception of the AEC oil access area where well density is high.

Most wells in the Suffield military training area are buried, with the exception of the AEC oil access area and the NWA where wells are generally above ground surface level, thereby providing little direct sensory disturbance for pronghorn.

Natural gas exploration, development, and production results in direct and indirect habitat loss to roads, pipeline, wellpad construction, site degradation, invasive species creep, and loss of rare plant species and communities (Jaeger et al. 2005, Gavin 2006). Mule deer (*Odocoileus hemionus)* were less likely to frequent areas close to well pads (Sawyer et al. 2006). Over several years of study in Wyoming, acclimatisation to well pads did not occur and mule deer sightings were determined to be lower up to 3.7km from well pads, suggesting indirect habitat loss affected mule deer to a greater degree than direct habitat loss (Sawyer et al. 2006).

In my study, pronghorn distribution was negatively related to well density in the summer aerial survey model and the summer GPS model, but not the winter GPS model. In the case of both summer models, well density was ranked of less importance in the model than grazed area or ERGs. Trails constitute a significant component of the footprint of oil and gas development on a landscape but data for this feature was unavailable for my analyses. The well nearest neighbour density variable could only be used to evaluate pronghorn responses to the well locations themselves and not the footprint of access trails. The absence of data on trail footprints as a variable in my study represents a significant limitation on inferences that can be drawn about the contribution of linear features to cumulative effects on this landscape. As mentioned previously, wells and pipes on CFB Suffield are predominantly buried, and as such the visible impact of oil and gas is defined by a low density road and trail network. The negative response of pronghorn to well density could be a function of habitat loss or alteration to native plant cover (e.g. invasive agronomic plant species) associated with roads and well pads, or the human activities (traffic) associated with well maintenance. The weakness of the response could be a result of the ability of pronghorn to habituate to human presence where not hunted or harassed (Berger et al. 2006), as on CFB Suffield where hunting is prohibited. Further analysis would allow us to better understand the impact of well density on pronghorn.

It is my opinion that since most of the wells on CFB Suffield are buried (with the exception of the AEC oil access area), that they would provide only minor sensory disturbance for pronghorn. However, the weak negative response of pronghorn to nearest neighbour well density in both summer models suggests the wells have indirect impacts on pronghorn. These indirect impacts may include fragmentation of the landscape and net habitat loss to well pads, pipelines, roads, and invasive species. Fragmentation and net habitat loss were not explored in this analysis, and should be considered in future studies. Studies by Joel Berger and the Wildlife Conservation Society in the Upper Green River Basin, Wyoming are exploring the relationship between habitat fragmentation by oil and gas development and pronghorn occurrence (Berger et al. 2006). Their preliminary results suggest fragmentation of previously undisturbed lands are resulting in reduced usage and abandonment by pronghorn, particularly in parcels of land less than ~243 ha in size (Berger et al. 2006).

Berger's work (2006) alludes to the concepts of *thresholds of change* or *tipping points*, beyond which pronghorn populations could be threatened. In an ecological context, these terms refer to modifications to an ecosystem to a point or threshold beyond which the past response of the system no longer predicts the future, as a new organization of ecological structure and process initiates a different self-maintaining regime (Holling 1973). Thresholds are reached once ecosystem resilience has been exceeded (Cairns 2004), and exist at different temporal and spatial scales (Beisner et al. 2003, Washington-Allen and Salo 2007). In Alberta, where pronghorn survival is limited by winter severity, added stress caused by development in their habitat that eliminates or fragments habitat and severs movement corridors, could push them over the edge. There exists the potential for large-scale mortality if pronghorn migration is impeded. Mitigation of tipping points should focus on locating tipping points and managing development to avoid shifting ecosystems into undesirable states (Washington-Allen and Salo 2007).

Roads

The effect of roads on pronghorn habitat selection can be classified as direct impacts (visual and audible disturbance) and indirect impacts (net habitat loss, fragmentation, invasive species creep) (Jaeger et al. 2005). The summer aerial and GPS models and the winter GPS model identified a weak negative response by pronghorn to the major roads on CFB Suffield. As part of EnCana's Suffield EIS (2007), researchers conducting ground surveys of pronghorn noted 28% ran from vehicles (EnCana 2007), suggesting pronghorn on the Base exhibit a propensity for flight in the presence of vehicular traffic (direct impact). Net habitat loss and/or invasive species creep are possible indirect impacts of roads that could be factoring into the observed negative response. It should be noted that trails were not included in this study, although they represent a significantly greater linear disturbance on CFB Suffield than the major roads modelled in this study. To better understand the impacts of roads and trails on pronghorn further analysis is required using more detailed data once it becomes available.

4.5 Utilization distributions and resource selection functions

Resource selection models derived from GPS data are most commonly based on a comparison of used vs. unused or used vs. available resource units, the latter being the case in this study. However, this procedure does not account for the variability in the intensity of use of habitat units in the data. In response to this shortcoming, using utilization distributions (UD) has been proposed as a way of quantifying resource use along a continuum in RSF analysis (Millspaugh et al. 2006). Utilization distributions are used to estimate the intensity or probability of use of an animal in its home range (Millspaugh et al. 2006). Whereas non-UD relies on the correct classification of habitat at the exact locations analyzed, UD avoids this problem by using a smoothed function of all telemetry locations (Millspaugh et al. 2006). Furthermore, separate UDs can be calculated for each animal, making each animal a primary sampling unit (Millspaugh et al. 2006). In other words, instead of relying on individual sampling points as would be derived from aerial surveys, the pattern of animals space use is utilized to define the study area. If used in this study, the use of UD would re-evaluate the study area used in the GPS models using a kernel based estimate of space use. This would likely reduce error in my study resulting from a pre-determined study area that was not entirely used by pronghorn even though the landscape was available. Using UD also facilitates the following:

- Traditional home range calculation derived from estimation of the area of any probability of use;
- The joint probability of use by 2 or more animals;
- The probability of use within a specified area;
- The intensity of use at specific coordinates.

The precision of resource selection functions are a function of the sample size (independent samples) used in the analysis (Millspaugh et al. 2006). Larger sample sizes (50+) are required to represent a population and reduce error (Millspaugh et al. 2006). If used in this study, a kernel home range could have been calculated for seven pronghorn in summer and twelve in winter. Analysis of an individual's resource selection is possible within their seasonal home range, but not at a population level (Millspaugh et al. 2006). Future study design should consider the use of UD as an improvement on traditional resource selection modelling procedures. The current study being conducted by the ACA, Alberta Sustainable Resource Development and the University of Calgary is an excellent opportunity to evaluate this further as more data is produced in subsequent years of sampling.

4.6 Conclusions

In conclusion, aerial survey and GPS data can be used to create habitat selection models. Aerial survey data is collected infrequently, typically annually or seasonally. This data is not useful for evaluating short term responses to disturbances, but is useful perhaps for evaluating longer term distribution responses to habitat loss, alteration and fragmentation occurring over longer periods of time. GPS data can be used for evaluating short and long term distribution responses to disturbances, in addition to evaluating longer term distribution responses to habitat loss, alteration, and fragmentation. The major variables influencing summer distribution patterns represented in models based on aerial data and GPS data were similar, though models were limited in their inferential value because data describing two of the three dominant land uses was not available for inclusion in the study. The top three variables in the summer model based on the aerial survey data were Grazed area, the Blowouts ERG, and Distance to intermittent water. Pronghorn responded negatively to Grazed area and Distance to intermittent water, and positively to the Blowouts ERG. The top three variables in the summer GPS model were Grazed area, the Loamy ERG, and the Choppy sandhills ERG. Pronghorn responded negatively to grazed areas and positively to both ecological range site classes. The top three variables in the winter GPS location model were Grazed area, Area burned 2003 and Loamy ERG. Pronghorn responded positively to grazed areas and Loamy ERG and negatively to Burned areas in 2003. The most notable difference between the summer and winter GPS models was the high rank of Burned Areas 2003 in the winter model. The most important recommendations that result from the study are as follows. If aerial survey data are used to produce density distribution models, repeated seasonally appropriate surveys should be adopted to address errors discussed. If GPS collar data are used in developing distribution models, then more collared animals need to be used to represent the even distribution of pronghorn noted in the aerial survey. These recommendations are discussed in detail in chapter 5.

Chapter Five: Conclusions and Recommendations

The purpose of my research was to compare pronghorn resource selection models built from aerial survey and GPS survey techniques and to determine the effects of select anthropogenic disturbances on seasonal resource selection by pronghorn on CFB Suffield. I built three models representing pronghorn resource selection. One model was based on a summer aerial survey of pronghorn on the eastern portion of CFB Suffield, and this was contrasted with a second summer resource selection model built from GPS survey data of the entire area of CFB Suffield. A third model built from the GPS survey data represented pronghorn winter habitat selection on the entire area of CFB Suffield. The inferential value of the models built from GPS data was limited by the small number of collared individuals. A comparison was conducted between the summer and winter GPS models to consider the seasonal differences in habitat requirements of pronghorn. In addition, I discussed pronghorn responses to select anthropogenic variables, however, the inferential value of the models with respect to anthropogenic disturbance was limited because data were inadequate to model the full extent of two of the three dominant land uses.

Aerial survey data provides information about habitat selection of pronghorn within a short period of time. In my study, the aerial survey produced independent observations that accounted for over 50% of the pronghorn in the ASRD 2006 pronghorn census of CFB Suffield. As such, the aerial survey data set was considered to represent the true distribution of the pronghorn population in the EnCana study area at the time of the aerial survey. Although fewer pronghorn were included in the GPS survey, the data reflects the resource selection by pronghorn throughout the day and the season, producing a model more accurately portraying resource selection by pronghorn. The result of my research suggests that aerial survey data and GPS data produce similar RSF models; however, if my GPS models were repeated with greater number of collared individuals we might expect more differences between the models.

Habitat requirements for pronghorn vary seasonally as a result of forage availability and climatic factors. This study corroborated prior research, as pronghorn responded to biophysical and anthropogenic features on the landscape differently in the summer and winter GPS models. Consequently, these models provide a basis for developing better tools, and a standardised approach to data analysis and representation, to anticipate the effects of landscape change on pronghorn in Southern Alberta.

Current trends towards increased human activity and disturbance in Alberta, coupled with the implications of climate change, highlight the importance of better understanding and quantifying the impacts of anthropogenic disturbance on pronghorn and the grassland biome. Towards this goal, we need to better understand the limits of change beyond which pronghorn are negatively affected in order that appropriate environmental management decisions can be made. These decisions need to not only react to change, but be able to anticipate change as well. In light of these concerns and the results of my study I recommend the following:

5.1 Recommendation 1: When using aerial survey data to build density distribution models, repeat surveys to generate trend data and to reflect important seasonal variations in pronghorn distribution

Multiple aerial surveys conducted the same time every year produces trend data that managers can use to assess population trends and landscape utilization trends for pronghorn. Comparison of the variables selected in the density distribution models over two or more sampling periods enables assessment of change on the landscape that is not possible with a one-time aerial survey.

Significant seasonal variation in climate may necessitate multi-season analysis to adequately address year-round impacts of anthropogenic activities on pronghorn. Pronghorn distribution varies seasonally, with winter distribution being the most limited due to forage availability. Cumulative effects assessments that consider only one season can misrepresent pronghorn distributions and affect resource management/ planning decisions because they do not account for the possible effects of a project or management plan in other seasons. Consequently, seasonal distribution patterns should be addressed by cumulative effect studies.

Specifically with respect to pronghorn, summer and winter distribution patterns should be understood. In addition, fawning should also be considered. Repeating surveys annually, or with some short term periodicity (e.g. 1, 2 or 5 years) would provide a basis to monitor change and trends in pronghorn distribution and resource selection.

5.2 Recommendation 2: When using GPS data to build density distribution models use more collars to achieve better representation of the even spatial pronghorn distribution observed on CFB Suffield in the aerial surveys

There is a need to significantly refine data sets for use in models such as those developed in this study, particularly in view of anthropogenic and climate change. The GPS survey design should be repeated with more collars to increase our level of confidence that the inferences made about the population from the collared individuals are correct. A measure of the number of collars to be used would be a number that better reflects (compares) pronghorn distribution to the more even distribution found in the aerial data. Based on the results of this study, I would suggest using at least twice the number of collars I used in each season to better represent the population of pronghorn on CFB Suffield.

5.3 Recommendation 3: Improve the models by including a more complete set of variables

Models are limited by the quality of data from which they are built. Two of the three major land uses on CFB Suffield were not effectively accounted for in this study. Military activities and the full extent of oil and gas development could not be modelled in this study because data were not available. The following additions to the analyses are expected to increase confidence in, and the inferential value of the density distribution models reported herein:

- *Road and trail density:* At the time of this study, not all roads and trails had been digitally mapped for CFB Suffield or were not made available for this study. The extensive network of roads and trails throughout CFB Suffield represents a greater linear disturbance than the major roads modelled in this study. These roads and trails are used by the military as well as the oil and gas industry and contribute directly and indirectly to habitat loss through habitat fragmentation, traffic disturbance, and introduction of exotic species (Berger et al. 2006). All roads and trails should be mapped and a road density index (length/km^2) created and analyzed to quantify the potential effect on pronghorn in CFB Suffield.
- *Military training response:* future research should consider the response of pronghorn to military training activities to determine whether pronghorn exhibit spatial or temporal avoidance or selection for areas associated with military activity. Although fire was included in the models, some of which results from military activities, it was not known which fires were caused naturally and which resulted from training exercises.
- *Vegetation:* this study used ecological range groups (ERGs) as a surrogate for vegetation. However, ERGs are a soil-based model for site potential and not a true measure of vegetation on the landscape. In the near future, the Grassland Vegetation Inventory (GVI) for Alberta will be complete, providing the most up-to-date spatial vegetation inventory available for the Province. This inventory should be considered in future analysis.

5.4 Recommendation 4: Evaluate the use of utilization distributions to improve environmental assessment and management decisions

The use of utilization distributions (UD), as proposed by Millspaugh et al.(2006), would improve on several limitations of traditional RSF techniques, since the animal is used as the primary sampling unit, use is considered in a continuous and probabilistic manner, and the model area is defined based on the animal's space use. I recommend a study using the data for CFB Suffield to: a) generate UD analysis of RSF for pronghorn in CFB Suffield, and b) to determine if the results from the UD analysis are more accurate or provide outcomes which complement the analysis herein.

References

Adams, B. 2007. Personal communication. Calgary.

Adams, B., D. Carlson, T. Milner, B. Hood, B. Cairns, and P. Herzog. 2004. Beneficial grazing management practices for sage grouse (*Centrocercus urophasianus*) and ecology of silver sagebrush (*Artemisia cana*) in south-eastern Alberta. Public Lands and Forests Division, Alberta Sustainable Resource Development.

Adams, B. W., L. Poulin-Klein, D. Moisey, and R. L. McNeil. 2005. Rangeland plant communities and range health assessment guidelines for the Dry Mixedgrass Natural Subregion of Alberta. Rangeland Management Branch. Public Lands Division. Alberta Sustainable Resource Development.

Alberta Fish and Wildlife Division (AFWD). 1990. Management plan for pronghorn antelope in Alberta, Wildlife management planning series number 3. Forests, Lands and Wildlife, Fish and Wildlife Division, Edmonton, Alberta.

Alberta Sustainable Resource Development (ASRD). 2005. The 2005 general status of Alberta wild species. Alberta Sustainable Resource Development. http://www.srd.gov.ab.ca/fishwildlife/wildspecies.

Allen, A., J. Cook, and M. Armbruster. 1984. Habitat suitability index models: pronghorn. US Fish and Wildlife Service.

Allen, A., and J. Samuelson. 1987. Precision and bias of a summer aerial transect census of pronghorn antelope. Prairie Naturalist 19:19-24.

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71:355-366.

Andrews, S., G. Dickens, and R. Miller. 1986. Urbanization and pronghorn antelope. Wildlife conservation and new residential developments. K. Stenberg and W. Shaw, editors. p. 172-174. WR 213.

Autenrieth, R. 1978. Guidelines for the management of pronghorn antelope. Pages 473-526 *in* Proceedings of the Eighth Biennial Pronghorn Antelope Workshop.

Bailey, J., and J. Nagy. 1969. Recent advances in wildlife nutrition. Colorado State University.

Barrett, M., and H. Vriend. 1980. Management implications of the seasonal distribution of pronghorns and land use practices in Alberta. Proceedings of the Biennial Pronghorn Antelope Workshop. 9:196-214.

Barrett, M. W. 1981. Environmental characteristics and functional significance of pronghorn fawn bedding sites in Alberta. Journal of Wildlife Management 45:120-131.

_____. _____. 1982. Ranges, habitat, and mortality of pronghorns at the northern limit of their range. PhD thesis. University of Alberta, Edmonton

_____. 1987. History and management of the pronghorn in Alberta *in* Proceedings of the workshop in endangered species in the prairie provinces.

Beisner, B., D. Haydon, K. Cuddington. 2003. Alternative stable states in ecology. Frontiers in Ecology and the Environment 1: 376-382.

Bender, D., T. Contreras, and L. Fahrig. 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology 79:517-533.

Berger, J., K. Berger, and J. Bechmann. 2006. Wildlife and energy development: pronghorn of the Upper Green River Basin – Year 1 Summary. Wildlife Conservation Society.

Bissonnette, J. 1999. Small sample size problems in wildlife ecology: a contingent analytical approach. Wildlife Biology 5:65-71.

Boyce, M., P. Vernier, S. Nielsen, and F. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281-300.

Brady, W., M. Stromberg, E. Aldon, C. Bonham, and S. Henry. 1989. Response of a semi-desert grassland to 16 years of rest from grazing. Journal of Range Management 42:284-288.

Bruns, E. 1977. Winter behaviour of pronghorn in relation to habitat. Journal of Wildlife Management 41:560-571.

Buckland, S., D. Anderson, K. Burnham, J. Laake, D. Borchers, and L. Thomas. 2002. Introduction to distance sampling. Oxford University Press, New York.

Burnham, K., and D. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer, New York.

Byers, J. 1997. American pronghorn: social adaptations and the ghosts of predators past. University of Chicago Press, Chicago, Illinois.

Cairns, J. 2004. Ecological tipping points: a major challenge for experimental sciences. Asian Journal of Experimental Sciences 18: 1-16.

Canadian Environmental Assessment Research Council (CEARC). 1988. The assessment of cumulative effects: a research prospectus. Ottawa.

Caughley, G. 1974. Bias in aerial survey. Journal of Wildlife Management 38:921-933.

Childress, D. 1980. Impacts of rural subdivisions on an antelope population. Western Association of Fish and Wildlife Agencies. Proceedings 60: 512-516. WR 181.

Commission for Environmental Cooperation (CEC). 2003. North American agenda for action: 2003-2005. A three-year program plan for the Commission for Environmental Cooperation of North America.

Cook, J., and L. Irwin. 1985. Validation and modification of a habitat suitability model for pronghorns. Wildlife Society Bulletin 13:440-448.

Courtney, R. 1989. Pronghorn use of recently burned mixed prairie in Alberta, Canada. Journal of Wildlife Management. 53:302-305.

DeLaune, M. G. 2003. XTools ArcView extension. Oregon Department of Forestry.

Dillon Consulting Limited (DCL). 1998. CFB Suffield natural resources inventory - final report. Dillon Consulting Limited, prepared for the Department of National Defence.

Dirschl, H. J. 1963. Food habits of the pronghorn in Saskatchewan. Journal of Wildlife Management 27:81-93.

Downing, D., and W. Pettapiece. 2006. Natural Regions and Subregions of Alberta. Government of Alberta. Report T/852.

Eastman, J. R. 1999. IDRISI guide to GIS and image processing. Volume 2. Clark Labs, Clark University, Worcester, MA.

EnCana. 2007. Suffield environmental impact statement. EnCana Corporation.

Environment Canada. 2006. History and status of CFB Suffield. http://www.mb.ec.gc.ca/nature/whp/nwa/suffield/dd02s01.en.html

Fahrig, L. 2001. How much habitat is enough? Biological Conservation 100:65-74.

Fielding, A., and J. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24:38-49.

Frair, J., S. Nielsen, E. Merrill, S. Lele, M. Boyce, R. Munro, G. Stenhouse, and H. Beyer. 2004. Removing GPS collar bias in habitat selection studies. Journal of Applied Ecology 41:201-212.

Gainer, B. 1991. Changing patterns of pronghorn occupation in the Hanna Area. Alberta Naturalist 21:103-105.

Gamo, R. 1997. Big game habitat use and distribution on reclaimed mining lands. University of Wyoming.

Gates, C., D. Eslinger, P. Jones, M. Grue, D. Bender, K. Sheriff, T. Seagel, M. Suitor, P. Knaga, and K. Morton. 2006. CFB Suffield progress report for 2004-2005: temporal and spatial variation in pronghorn antelope distribution, movements, and population dynamics in relation to environmental gradients (unpublished).

Gavin, S. 2006. The effects of roads on pronghorn antelope (*Antilocapra americana*) behaviour and habitat use. M.Sc., The University of Calgary.

Gudmundson, L. 1985. Revised survey format for antelope management areas in the southern region (1984-1985). Alberta Energy and Natural Resources.

Hanski, I. 1999. Metapopulation ecology. Oxford University Press.

Hastie, T., T. Tibshirani, and J. Friedman. 2001. The elements of statistical learning: data mining, inference, and prediction. Springer, New York.

Holling, C. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4:1-23.

Hoover, R. 1966. Antelope food habits and range relationships in Colorado. Pages 75-85 *in* Proceedings of Antelope States Workshop 2.75-85.

Hoskinson, R. L., and J. R. Tester. 1980. Migration behaviour of pronghorn in south-eastern Idaho. Journal of Wildlife Management 44:132-144.

Hosmer, D., and S. Lemeshow. 1989. Applied logistic regression. John Wiley and Sons, Inc.

Hoth, J. 2001. Introduction: A plight for grasslands *in* Grassland species of common conservation concern: report on the first trinational workshop. Commission for Environmental Cooperation, Program for the Conservation of Biological Diversity, Montreal, Quebec. Pages 6-7.

Howard, J. 1995. *Antilocapra americana.* In: Fire effects information system. U. Department of Agriculture, editor. Forest Service.

Irwin, L., and J. Cook. 1985. Determining appropriate variables for a habitat suitability model for pronghorns. Wildlife Society Bulletin 13:434-440.

Jachmann, H. 2002. Comparison of aerial counts with ground counts for large African herbivores. Journal of Applied Ecology 12(2): 411-420. Aug. 1975. WR 159: 23 39:841–852.

Jaeger, J., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behaviour. Ecological Modelling 185:329-348.

Johnson, B., F. Lindzey, and R. Guenzel. 1991. Use of aerial line transect surveys to estimate pronghorn populations in Wyoming. Wildlife Society Bulletin 19:315-321.

Johnson, C., S. Nielsen, E. Merrill, T. McDonald, and M. Boyce. 2006. Resource selection functions based on use-availability data: theoretical motivation and evaluation methods. Journal of Wildlife Management 70:347-357.

Johnson, C., K. Parker, D. Heard, and M. Gillingham. 2002. A multiscale behavioural approach to understanding the movements of woodland caribou. Ecological Applications 12:1840–1860.

Johnson, C., D. Seip, and M. Boyce. 2004. A quantitative approach to conservation planning: using resource selection functions to map the distribution of mountain caribou at multiple spatial scales. Journal of Applied Ecology 41:238-251.

Johnson, D. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Kaseloo, P., and K. Tyson. 2004. Synthesis of noise effects on wildlife populations. U. D. Transportation, editor. Virginia State University.

Kindschy, R., G. Sundstrom, and J. Yoakum. 1978. Range/wildlife interrelationships–pronghorn antelope. Pages 216-269 *in* Proceedings of pronghorn antelope workshop.

Krausman, P., and L. Harris. 2002. Military jet activity and Sonoran pronghorn. Zeitschrift für Jagdwissenschaft. 48:140-147.

Krausman, P., L. Harris, S. Haas, K. Koenen, P. Devers, D. Bunting, and M. Barb. 2005. Sonoran pronghorn habitat use on landscapes disturbed by military activities. Wildlife Society Bulletin 33:16-23.

Laliberte, A., and W. Ripple. 2004. Range contractions of North American carnivores and ungulates. Bioscience 54:123.

Landwise. 2006. Soil landscape modelling methodology. Landwise Inc.

Lennon, J. 1999. Resource selection functions: taking space seriously. Trends Ecology and Evolution 14:399-400.

Loeser, M., S. Mezulis, T. Sisk, and T. Theimer. 2005. Vegetation cover and forb responses to cattle exclusion: implications for pronghorn. Rangeland Ecology and Management 58:234-238.

Manly, B. F. 2002. Estimating a resource selection function with line transect sampling. Journal of Applied Mathematics and Decision Sciences 6:213-228.

Manly, B. F., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. 2 edition. Kluwer Academic Publishers, Boston.

Martinka, C. J. 1967. Mortality of northern Montana pronghorns in a severe winter. Journal of Wildlife Management 31:159-164.

Millspaugh, J. J., R. M. Nielson, L. McDonald, J. M. Marzluff, R. A. Gitzen, C. D. Rittenhouse, M. W. Hubbard, and S. L. Sheriff. 2006. Analysis of resource selection using utilization distributions. Journal of Wildlife Management 70:384-395.

Mitchell, G., and S. Smoliak. 1971. Pronghorn antelope range characteristics and food habits in Alberta. Journal of Wildlife Management 35:142-147.

Mladenoff, D. J., T. A. Sickley, R. G. Haight, and A. P. Wydeven. 1995. A regional landscape analysis and prediction of favourable wolf habitat in the northern Great Lakes region. Conservation Biology 9:279-294.

Mladenoff, D. J., T. A. Sickley, and A. P. Wydeven. 1999. Predicting gray wolf landscape colonization: logistic regression models vs. new field data. Ecological Applications 9:37-44.

Nagelkerke, N. 1991. A note on a general definition of the coefficient of determination. Biometrika 78:691-692.

O'Gara, B., and J. Yoakum. 2004. Pronghorn ecology and management. The University Press of Colorado.

Otis, D., and G. White. 1999. Autocorrelation of location estimates and the analysis of radiotracking data. Journal of Wildlife Management 63:1039-1044.

Pojar, T., D. Bowden, and R. Gill. 1995. Aerial counting experiments to estimate pronghorn density and herd structure. The Journal of Wildlife Management 59:117-128.

Pojar, T., and R. Guenzel. 1999. Comparison of fixed-wing line transect and helicopter quadrat pronghorn surveys *in* Proceedings of Pronghorn Antelope Workshop 18: pages 64-68.

Prairie Conservation Forum (PCF). 2000. Native prairie baseline vegetation inventory. Prairie Conservation Forum.

_____. 2006. Alberta prairie conservation action plan: 2006-2010. Prairie Conservation Forum.

Pulliam, H. 1988. Sources, sinks and population regulation. American Naturalist 132:652-661.

Reider, A., J. Linnell, and R. Langvatn. 1996. Short term behavioural and physiological response of moose (*Alces alces*) to military disturbance in Norway. Biological Conservation 77:169-176.

Richardson, E., I. Stirling, and D. Hik. 2005. Polar bear (*Ursus maritimus*) maternity denning habitat in western Hudson Bay: a bottom-up approach to resource selection functions. Canadian Journal of Zoology 83:860-870.

Riddle, P., and C. Oakley. 1973. The impact of a severe winter and fences on antelope mortality in south-central Wyoming. Western Association of State Game and Fish Commissioners. Proceedings 53: 174-188.

Rodgers, A. R., A. P. Carr, L. Smith, and J. G. Kie. 2005. HRT: home range tools for ArcGIS. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research.

Saunders, D., R. Hobbs, and C. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5:18-32.

Sawyer, H., and F. Lindzey. 2003. Assessing impacts of oil and gas development on Mule deer *in* Proceedings of 69th North American Wildlife and Natural Resources Conference.

Sawyer, H., R. Nielson, F. Lindzey, and L. McDonald. 2006. Winter habitat selection of mule deer before and during development of a natural gas field. Journal of Wildlife Management 70:396-403.

Schwartz, C., and J. Ellis. 1981. Feeding ecology and niche separation in some native and domestic ungulates on the short grass prairie. Journal of Applied Ecology 18:343-353.

Scott, J., P. Heglund, M. Morrisson, J. Haufler, M. Raphael, W. Wall, and F. Samson. 2002. Predicting species occurrences: issues of accuracy and scale. Island Press, USA.

Sexton, M., J. Choate, and R. Nicholson. 1981. Diet of pronghorn in western Kansas. Journal of Range Management 34:489-493.

Sheriff, K. 2006. Modeling temporal and spatial variation in pronghorn antelope population dynamics in southern Alberta in relation to environmental gradients. Master's degree project. University of Calgary, Faculty of Environmental Design.

Smith, A., and D. Beale. 1980. Pronghorn antelope in Utah: some research and observations.

Smith, K., E. Ficht, D. Hobson, T. Sorensen, and D. Hervieux. 2000. Winter distribution of woodland caribou in relation to clear-cut logging in west-central Alberta. Canadian Journal of Zoology 78:1433-1440.

Smyser, T. 2005. Response of pronghorn (*Antilocapra americana*) populations to habitat conditions with modification to survey methods. University of Idaho.

Stelfox, J., and H. Vriend. 1977. Prairie fires and pronghorn use of cactus. Canadian Field-Naturalist 91:282-285.

Stephenson, T., M. Vaughan, and D. Andersen. 1996. Mule deer movements in response to military activity in southeast Colorado. Journal of Wildlife Management 60:777-787.

Swihart, R., and N. Slade. 1985. Influence of sampling interval on estimates of home-range size. Journal of Wildlife Management 49:1019-1025.

Telesco, D., and F. Van Manen. 2006. Do black bears respond to military weapons training? Journal of Wildlife Management 70:222-230.

Vistnes, I., C. Nelleman, P. Jordhoy, and O. Strand. 2004. Effects of infrastructure on migration and range use of wild reindeer. Journal of Wildlife Management 68:101-108.

Washington_Allen, R. and L.Salo. 2007. Catastrophic thresholds: perspectives, definitions, and applications. Bulletin of the Ecological Society of America 88: 219-225.

Weclaw, P., and R. Hudson. 2004. Simulation of conservation management of woodland caribou. Ecological Modelling 177:75-94.

Willms, W., S. Smoliak, and A. Bailey. 1986. Herbage production following litter removal on Alberta native grasslands. Journal of Range Management 39:536-540.

Wood, A. 1989. Comparative distribution and habitat use by antelope and mule deer. Journal of Mammalogy 70:335-340.

Worton, B. J. 1987. A review of models of home range for animal movement. Ecological Modelling 38:277-298.

Zink, T., M. Allen, B. Heindl-Tenhunen, and E. Allen. 1995. The effect of a disturbance corridor on an ecological reserve. Restoration ecology 3:304-310.