University of Alberta

Woodland caribou (Rangifer tarandus caribou) home range and habitat-use relationships to industrial activity in northeastern Alberta

by

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Dedication

Мамові і Татові.

Я ще мандрую по далеких стежках,
але знаю,
так як зорі і срібнолиций місяць,
Ваша любов сторожить мене крізь темноту.

З любов'ю,

Ваш син,

Боян

Abstract

The petroleum sector is implicated in the decline of woodland caribou (*Rangifer tarandus caribou*) populations in Alberta. Though caribou may avoid industrial activities, it is unclear what habitat they select during avoidance, or if they display avoidance at the level of their home range. Using well locations as an index, I examined if different levels of industrial activity in the West Athabasca Caribou Range influenced the size and location of home ranges on a seasonal (GPS data, 1998-1999) or annual basis (VHF data, 1992-2000), and influenced habitat selection on a seasonal basis (resource selection function analysis). Home range size, and the proportion of annual or seasonal home range overlap did not significantly differ between caribou subject to high or low industrial activity. The proportion of peatland within a home range was a significant predictor of home range size, and caribou exposed to high activity continued to select preferred habitats.

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Table of contents

List of Tables

List of Figures

Figure **page**

Chapter 1. General introduction and thesis overview

1.1. Introduction

Alberta's Boreal Forest is subject to multiple overlapping landuse practices, with forestry, agriculture, and the petroleum sector operating in a largely additive fashion during their continued expansion (Stelfox 2001, Schneider 2002). Of these, the petroleum sector fragments the boreal landscape via a network of linear features such as roads, pipelines, and seismic lines, which in turn are linked to compressor stations and various types of wells (Schneider 2001, Stelfox 2001, Cumming and Cartledge 2004). As industrial operations rival forestry in the direct habitat loss they cause (Schneider 2002), biologists are concerned over the impacts industry may have on biota (MacFarlane 1999, James 1999, Dyer 1999, Oberg 2001, Schneider 2002), as expansion of the industrial footprint may influence sustainable timber harvest, human access, fire frequency, and the decline of bird and animal species (Schneider 2002, Cumming and Cartledge 2004).

The woodland caribou (*Rangifer tarandus caribou*) faces decreasing populations in many of its historic ranges in Alberta (McLoughlin *et al.* 2003), with an indication that petroleum exploration and related infrastructure (seismic lines, roads, well sites and pipelines) may be causing the decline (Fuller and Keith 1981, Edmonds 1988, 1991, Boreal Caribou Research Program 2000, Dzus 2001, McLoughlin *et al.* 2003). Though the Government of Alberta supports the need for industrial expansion, it concedes that "As part of the caribou protection and maintenance effort, management plans are being prepared to facilitate industrial development on caribou range and provide that the integrity and supply of habitat is maintained to permit its use by caribou" (Alberta Energy 1991, 1994). Currently, companies active in caribou ranges are required to submit Caribou Protection Plans designed to allow for the management of the effects of industrial disturbance on caribou, and address concerns over their continued survival. Despite such initiatives, functional habitat loss, predation pressure, and energetic costs associated with the avoidance of industrial features and associated activities are still considered factors in the decline of caribou (Fuller and Keith 1981, Edmonds 1988, 1991, Grey 1999, BCRP 2000, Dzus 2001, McLoughlin *et al.* 2003). Also, existing land-use guidelines are viewed as largely ineffectual for long term caribou conservation (Dzus 2001), and woodland caribou are still listed as threatened under the provincial Wildlife Act (Alberta Environmental Protection 1998), and remain classified as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2003).

1.2. Woodland caribou habitat selection and avoidance of industrial activity

Caribou habitat selection is thought to be hierarchical, with predation pressure influencing selection at a coarse scale, and fine scale choice based on optimal forage (Bergerud *et al.* 1990). Woodland caribou are thought to utilize separation, or an "isolation strategy" against predators, using peatland-dominated complexes as refuges and avoiding upland habitats commonly used by wolves and other ungulates (Bergerud 1988, Bergerud *et al.* 1990, Bradshaw *et al.* 1995, Stuart-Smith *et al.* 1997, Rettie and Messier 2001, Schneider *et al.* 2000). Peatlands and bogs also contain lichens, the primary source of forage in winter (Darby and Pruitt 1984), and the ability of caribou to feed on lichens, a forage not utilized by other ungulates, allows caribou to exist in habitats separate from other ungulate species. The isolation from other ungulates, and an additional "spacing out" between individual caribou commonly found at low densities in their preferred habitat, may allow caribou relative safety from predation (Fuller and Keith 1981, Edmonds 1988, Stuart–Smith *et al.* 1997, Dzus 2001).

Alberta's woodland caribou populations are at risk of becoming endangered if limiting factors are not addressed (Alberta Environmental Protection 1998, Boreal Caribou Committee 2001). Bradshaw *et al.* (1997) found that caribou exposed to simulated petroleum exploration increased their movement rates, and were observed crossing habitat boundaries more often than caribou not exposed to the same treatment, potentially resulting in increased energy expenditures (Bradshaw *et al.* 1998). Caribou may avoid industrial features and human activity (Dyer *et al.* 2001, Oberg 2001), with functional habitat loss resulting in potentially 28-70% of historic caribou ranges being viewed as unusable (Dzus 2001). Roads may also act as barriers to movement, intensifying the functional habitat loss by preventing caribou from crossing into different peatland patches (Dyer *et al.* 2002). Other linear features, such as seismic lines, may also provide predators easier access to prey (James and Stuart-Smith 2000, Wolfe *et al.* 2000), and may negate the effectiveness of the spatial segregation strategy, for as predators access habitats used as refugia by caribou, the possibility of predation increases (Seip 1992).

1.3. Research needs

Though caribou tend to avoid industrial development (Dyer *et al.* 2001), it is not clear if caribou move into sub-optimal habitats while doing so, or if caribou also display avoidance at the level of their home range. Anderson (1999) found that caribou select treed-peatland stands extensively within their home ranges over all other habitat classes. However, because caribou can change habitat types while moving away from disturbance (Bradshaw *et al.* 1997), caribou may enter habitats believed to contain greater risk of predation and lower quality forage. Such movement could result in direct mortality from predators (Jalkotzy *et al.* 1998, James 1999, Dzus 2001) or from energetic costs due to the inability to maintain adequate forage intake in winter (Bradshaw *et al.* 1998). In terms of home range size, caribou in areas of high industrial activity could expand their home ranges in order to compensate for lost or low quality forage, as food availability can be negatively correlated with home range size (see McLoughlin and Ferguson 2000 for review). Also, pressure to maintain predator avoidance at the home range scale (Bergerud *et al.* 1990) may result in caribou expanding their home ranges to limit interaction with predators utilizing the industrial footprint. Alternatively, caribou may avoid industrial development by compressing their home ranges (Smith *et al.* 2000), resulting in caribou existing in smaller, more predictable areas, providing predators with greater probability of encountering caribou (James and Stuart-Smith 2000, Dyer *et al.* 2001). Caribou may also move the location of their home range away from areas of activity (Vercauteren and Hyngstrom 1998, Smith *et al.* 2000), vacating areas where industrial features and activities, increased risk of predation, or habitat loss (direct or functional) exceed some level of tolerance. However, movement away from the area of disturbance may also increase predation risk and lead to problems finding suitable forage, as movement into a novel habitat may result in less familiarity with an area (Stamps 1995, Nicholson *et al.* 1997, Kitchen *et al.* 2000).

1.4. Thesis Objectives

The Boreal Caribou Research Program (operating under the Boreal Caribou Committee) is part of a collaborative effort between industry, government agencies and academia, with a mandate to conduct research relating caribou ecology and industrial activities for use in the development of industrial land-use guidelines applied towards caribou conservation.[1] The Boreal Caribou Research Program (2000) states, that: "It is essential to understand what factors, such as predator use or human activity, are causing the response by caribou so that appropriate recovery strategies, alternate practices and mitigations can be designed." Thresholds of tolerable activity and habitat loss need to be set for caribou ranges, as caribou conservation will involve continued interaction between human interests and caribou on a common land base (McLoughlin *et al.* 2003). An examination of caribou home range size and location, and habitat selection in relation to industrial activity is required to address how caribou respond to industrial activities at larger scales than previously studied (Dyer *et al.* 2001), and indicate if functional habitat loss is compounded by selection of habitats with higher predation risk and less winter forage.

[1] Refer to BCRP website: http://deer.rr.ualberta.ca/caribou/bcrp.htm

My objectives were to examine whether industrial activity in northeastern Alberta is associated with a change in the size and location of woodland caribou annual or seasonal home ranges (second order selection, Johnson 1980), and influences patterns of habitat selection within caribou home ranges on a seasonal basis (third order selection, Johnson 1980).

1.5. Thesis overview

This thesis is divided into four chapters. Here in Chapter 1, I have briefly examined woodland caribou conservation concerns in terms of industrial activity. I then highlighted prior research examining caribou habitat selection, and the response of caribou to industrial activity. I also provide a general overview of the thesis structure.

In Chapter 2, I examine if caribou respond to industrial activity at larger scales than previously considered. I examine if industrial activity influences the size and overlap of both annual and seasonal home ranges for woodland caribou. I use long-term caribou location data to compare changes in annual home range size and overlap, and a shorter-term data set with more locations to examine the size and overlap of seasonal home ranges for caribou in areas of low to high industrial activity.

In Chapter 3, I examine habitat selection using resource selection function analysis (RSFs, Manley *et al.* 2002), and compare habitat selection of caribou in areas of low to high industrial activity on a seasonal basis. I determine if caribou in areas of high industrial activity are selecting habitats considered to be sub-optimal or carrying a greater risk of predation in winter, calving, summer and rut.

In Chapter 4, I provide general summary on caribou response to industrial activity at the annual and seasonal home range scale, and in terms of changes in habitat selection. I then outline future research and management considerations for continued caribou conservation.

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Chapter 2. Change in woodland caribou home range use in relation to industrial activity.

2.1. Introduction

A home range is classically defined as an area within a larger geographical range where an animal dwells while feeding, locating mates and caring for its young (Burt 1943, Johnson 1980, Powell 2000). Home range characteristics such as composition and location may be examined in terms of animal behaviour (e.g. migration) (Nicholson *et al.* 1997), the habitats they contain (Stuart Smith *et al.* 1997, Kie *et al.* 2002, Johnson *et al.* 2002, Tufto *et al.* 1996), and changes in habitat caused by disturbance (Pearson *et al.* 1995). Fire and flooding modify habitats, and animals may show considerable adaptability at the home range level by staying in disturbed areas and utilizing remaining habitat (Pearson *et al.* 1995, Kunst *et al.* 2001, Vernes and Pope 2001). Expansion of the human footprint also alters landscapes, and anthropogenic factors may induce changes in home range size or shifts in home range location (Van Dyke and Klein 1996, Cole *et al.* 1997, Foster *et al.* 1997, Vercauteren and Hygnstrom 1998, Smith *et al.* 2000). These changes in home range in response to potential hazards may affect the selection of high quality habitats, which in turn can affect the conservation of a species at risk of declining (Carter *et al.* 1999, Whitfield *et al.* 2001, Dickson and Beier 2002, Schmid *et al.* 2003).

In Alberta, disturbance from petroleum exploration and related infrastructure may be contributing to the decline of woodland caribou (*Rangifer tarandus caribou*) in many of their ranges via functional habitat loss, predation pressure, and/or energetic costs associated with avoidance (Fuller and Keith 1981, Edmonds 1988, 1991, Grey 1999, BCRP 2000, Dzus 2001, McLoughlin *et al.* 2003). Caribou tend to avoid anthropogenic features such as wells, roads and seismic lines within their home range, presumably to avoid the risk of predation or the noise and activities associated with the features (Dyer *et al.* 2001, Oberg 2001). Assuming an avoidance distance of 250m for anthropogenic disturbance (Dyer *et al.* 2001), estimates of the area potentially affected within caribou ranges lies between 28-70% (Dzus 2001). If caribou also display avoidance at the home range level, what was considered viable habitat within a larger population range would change considerably. Woodland caribou are currently designated as threatened (COSEWIC 2003), and appropriate definition of viable habitat is important for conservation efforts.

2.1.1. Woodland caribou home range characteristics

Woodland caribou in Alberta, on average, have home ranges that are larger than other populations in Canada (Bradshaw *et al.* 1995, Stuart–Smith *et al.* 1997). Woodland caribou inhabiting the boreal forests of northern Alberta (boreal ecotype) also show no consistent trends toward selecting distinct seasonal ranges (i.e. they are non-migratory), typically showing considerable overlap between summer and winter ranges, and moving extensively throughout the year (Stuart-Smith *et al.* 1997). This differs from caribou found in the foothills (considered a mountain ecotype), which exhibit seasonal shifts in elevation (Dzus 2001). Caribou typically have large home ranges over the winter and rut periods, with smaller home ranges in summer and calving (Fuller and Keith 1981, Stuart-

Smith *et al.* 1997, Rettie and Messier 2001). These trends may be attributed to greater movements associated with finding sufficient forage in winter and mates in rut, while females with calves remain in smaller areas separate from each other to avoid predation pressure during calving and summer (Rettie and Messier 2001).

Woodland caribou habitat selection is thought to be hierarchical, with predation pressure influencing selection at a home range scale, and forage influencing habitat selection within a home range (Bergerud *et al.* 1990). In northern Alberta, it is believed that caribou use peatland-dominated complexes as refuges against predation (Stuart-Smith *et al.* 1997, Dzus 2001) as use of these habitats is thought to provide isolation from predators such as wolves, and alternative prey species such as moose (Bergerud 1988, Bergerud *et al.* 1990, James 1999, Rettie and Messier 2001). However, linear corridors created by industrial activities may provide predators with the possibility of access to the peatland areas previously used as refugia by caribou (James and Stuart-Smith 2000, A.D.M. Latham, 2004, University of Alberta, Pers. comm.).

2.1.2. Potential response of caribou to industrial activity at the home range

Woodland caribou avoidance of industrial infrastructure and associated activities within a home range could also be expressed at larger spatial scales (Dyer *et al.* 2001). Caribou may respond to increased industrial activity by changing the size of their home range, or by changing the location of their home range. Caribou in areas of high industrial activity could expand their home ranges in order to compensate for areas lost as functional habitat due to avoidance, for food availability can be negatively correlated with home range size (see McLoughlin and Ferguson 2000 for review). Also, pressure to maintain predator avoidance at the home range scale (Bergerud *et al.* 1990) may result in caribou expanding home ranges in order to limit interaction with predators utilizing the industrial footprint. Alternatively, caribou may avoid the disturbance imposed by industrial development by compressing their home ranges, as has been observed in caribou exposed to clear–cut logging in west–central Alberta (Smith *et al.* 2000). This response may result in the "spacing out" strategy caribou utilize to avoid predation becoming compromised (Smith *et al.* 2000, Dyer *et al.* 2001), as existing in smaller more predictable areas may provide predators with greater probability of finding caribou (James and Stuart-Smith 2000, Dyer *et al.* 2001).

Caribou may also express home range responses on seasonal basis, as industrial activity are most pronounced during the winter months when frozen peatlands allow for seismic exploration and well drilling, and the amount of vehicular traffic is highest (600-800 vehicles/day) (Dyer *et al.* 2001). Caribou deplete fat reserves over the winter, and caribou facing industrial activities in winter could incur increased energetic costs via avoidance (Bradshaw *et al.* 1998), which in turn may have consequences for adult survival and calving success (Adams *et al.* 1995). Caribou may also move the location of their seasonal home ranges away from areas of activity (Vercauteren and Hyngstrom 1998, Smith *et al.* 2000) vacating areas due to industrial activities, risk of predation, or habitat deletion being beyond some level of tolerance. Movement away from the area of disturbance, however, may still increase predation risk and lead to problems foraging as movement into a novel habitat can result in less familiarity with an area (Stamps 1995, Nicholson *et al.* 1997, Kitchen *et al.* 2000).

2.1.3. Objectives

My objective was to determine if high levels of industrial activity cause caribou, on a seasonal and annual basis, to have significantly larger or significantly smaller home ranges compared to caribou exposed to lower levels of industrial activity, and to determine if caribou avoid areas of high industrial activity at the level of their home range. I quantified home range size and overlap for caribou exposed to high levels of industrial activity, and examined how these differed from caribou in areas of lower industrial activity.

2.2. Methods

2.2.1. Study Area

Located in northeastern Alberta in the West Athabasca Caribou Range (WSAR), the study area (center at 56^0N, 113^0W) spans approximately 6000 km^2 of a combination of boreal mixedwood and peatland vegetation, and is dominated by a large peatland complex (Figure 2-1). The elevation range is between 500m and 700m above sea level, with higher elevations dominated by *Polpulus tremuloides*, *Picea glauca*, and *Pinus banksiana*. Lower elevations are vegetated primarily by *Picea mariana* and *Larix* *laricina*, which form bog and fen peatland complexes. The study area sits atop the southwest corner of the Athabasca oil-sands deposits (Crandall and Prime 1998), and contains a number of industrial features including: all-weather roads, seismic lines, pipelines, well sites, tank farms, and field camps. These features and associated activities are concentrated in a central region of the study area, where "heavy oil" extraction is common (see Figure 2-1 for comment). A marked increase in industrial activity began in, and continued past 1995 (Figure 2-2), when a large number of wells were drilled, and associated infrastructure (such as all-weather roads) was built.

2.2.2. Caribou data

All caribou location data were obtained from the Boreal Caribou Research Program (BCRP) for caribou within the WSAR. Long-term (1992-2000) VHF location data were collected as part of a larger research program primarily designed to address caribou population trends (McLoughlin *et al.* 2003). Short-term GPS location data (1998-2000) were initially used to address woodland caribou avoidance of industrial features within the home range (Dyer *et al.* 2001).

2.2.2.1. Annual home range data

Caribou were equipped with very high frequency (VHF) radio collars (Lotek Engineering Systems, Newmarket, Ontario) and were located monthly and bi-monthly using a fixed-wing aircraft, with locations recorded using GPS receivers. I generated 174 annual home ranges using 100% minimum convex polygon (MCP) estimates for 45 caribou tracked between 1992-2000 (see Table 2-1). Annual home ranges were calculated using locations from March 1-February 28, following the delineation of a "caribou year" used by Dyer *et al.* (2001). Home ranges were calculated using 17-24 locations per animal, with the number of annual MCPs generated per individual caribou ranging between 1 to 8, with a mean of 3.9.

2.2.2.2. Seasonal home range data

Thirty-six caribou were fitted with GPS collars (Lotek Engineering Systems, Newmarket, Ontario) in the WSAR between 1998-2000, with locations taken approximately every two hours (see Dyer *et al.* 2001 for more detail). I classified data into five seasons for woodland caribou (Bergurud 1975, Dyer *et al.* 2001): LW - late winter (22 February - 30 April), C - calving (1 May – 30 June), S - summer (1 July – 15 September), R - rut (16 September – 15 November), and EW - early winter (16 November – 21 February of following year). This delineation provided ten seasons over two newly defined "caribou years" (1998-1999). I generated seasonal 100% MCPs for all caribou which had locations which spanned the entire time period of a given season. This delineation generated a total of 154 seasonal home ranges for the 36 individuals. However, not all individuals had sufficient locations spanning each of the five seasons, nor did individuals have locations in all seasons between years. This was primarily due to change of individuals between years, mortality, and collar failure (see Dyer *et al.* 2001).

Individual caribou had between 130-1535 locations per season, with a total of 116,361 locations for all caribou combined over 1998/1999.

2.2.3. Industry data

Alberta Energy and Utilities board (AEUB) well data (1966-2000), provided by Alberta-Pacific Industries Inc. was used as an index of overall industrial activity, as wells are closely associated with linear features (see Cumming and Carteledge 2004). However, because wells of varying types have different activities associated with their operation (Schneider 2001), I used crude-bitumen, or "heavy oil" wells to delineate the area of highest industrial activity (Figure 2-1). Though anthropogenic features were found throughout the study area, heavy oil wells were found concentrated exclusively in the center of the study area. Heavy oil exploration and extraction was found in association with large numbers of other conventional wells, and typically involves large drilling operations, all weather road access, a large amount of vehicular traffic (600-800 vehicles per day during the winter months, Dyer *et al.* 2001), and can be considered to represent the greatest amount industrial disturbance present in the study area (A. Cicoria, Lormel Consultants, Pers comm., E. Pooley, Char Rose Exploration Enterprises Ltd., Pers. comm.). The change in industrial activity over time was tracked using the date-of-drilling for wells listed in the database.

To track changes in home range size and overlap, I placed a 95% kernel estimate around all cumulative heavy oil wells to delineate the central area of interest where the most change in activity would occur. I used the proportion of overlap that caribou home ranges had with this central area to define the relative amount of industrial activity that a caribou would be exposed to, creating three categories of exposure. Caribou home ranges with less than 1% overlap with the central area were placed in a category of "low" industrial activity and were assumed to have the lowest relative amount of industrial activity present in the study area for all years of study. Caribou home ranges with 1-20% overlap were placed in a "medium" category, and were assumed to be exposed to an intermediate level of disturbance. Caribou home ranges with greater than 20% overlap were considered to be in an area of "high" industrial activity, as they would be exposed to the majority of industrial expansion in 1995 and beyond (see Table 2-1 for sample sizes). To illustrate, before 1995, caribou in the high area of activity had an average 13.49±6.36 (mean ± standard error) heavy oil wells within their home range, a number which increased to 83.61±15.00 in years after 1995. The number of wells (both heavy oil and conventional wells combined) present in the same home ranges shows the increase in overall industrial activity more dramatically, as the pre-1995 average was 88.75±13.91 wells, and from 1995-onwards the average was 213.78±29.86 wells. By comparison, the average number of all wells in the home ranges of caribou in the area of low activity was 30.42 ±7.63 before 1995 and 42.46±4.31 from 1995 onwards, indicating that industrial activity categories delineated were subject to substantially different levels of activity. All caribou polygons were created in ArcView 3.1 (ESRI 1998) using the Animal Movement extension (Hooge and Eichenlaub 1997) and all data were projected to NAD 27 Zone 12.

2.2.4. Habitat Data

The Peatland Inventory of Alberta (PIA) (Vitt *et al.* 1998) was used to classify the study area into "peatland" and "non-peatland" habitat classes. The PIA is based on jjpolygons composed of vegetation types identified from aerial photography, where a hierarchical classification system reflecting the percentage composition of wetland types is used to delineate each polygon in the inventory. The PIA had been re-classified into "peatland" if polygons contained greater than or equal to 50% fen or bog, and "non-peatland" if they were dominated by species typically found in well drained habitats (Bradshaw *et al.* 1995, Anderson 1999, Dunford 2003). Peatland was assumed to remain constant as the amount of peatland lost due to fire was minimal in the study area over the last 10 years (Dunford 2003). Proportion of peatland contained within the annual and seasonal home ranges was calculated using the patch analyst extension (Rempel *et al.* 1999) for ArcView 3.1.

2.2.5. Statistical analysis

To examine change in annual and seasonal home range size, and to examine annual and seasonal home range overlap over time, I employed a cross sectional time series multiple regression (Stata Corporation 2001). To address concerns of pseudoreplication, home ranges were clustered by individual caribou in order to adjust the test statistics. In all instances, home range size was log transformed, and proportion of peatland was arcsine square-root transformed to increase normality.

2.2.5.1. Caribou annual and seasonal home range size

For the annual home range data (1992-2000), I regressed the annual home range size of caribou against: level of industrial activity, year, interaction between year and location, and the proportion of peatland within a home range. For the seasonal home range data (1998-1999), I regressed the seasonal home range size of caribou against: level of industrial activity, the season, interaction between season and activity and the proportion of peatland within a seasonal home range.

2.2.5.2. Caribou home range overlap

I examined annual home range overlap by measuring the proportion of a previous years home range that was included in the following years home range. This annual overlap was compared between categories of industrial activity over time. For the seasonal home range data, I examined the proportion of overlap for the same season between 1998 and 1999, and examined the overlap of successive seasons within the same year. As home range size should be considered when examining overlap (Rettie and Messier 2001), the size of the home range of the second year was included in the model. Proportion of overlap was arcsine square-root transformed for normality (see Table 2-2 for sample sizes).

I also compared the frequency with which caribou remained in the same area of activity or moved to a different an area of different activity on an annual basis after 1995.

Caribou in areas of low activity were considered to display natural differences in overlap, with caribou in areas of high activity potentially showing differences related to industrial activity. Caribou in areas of low activity could choose to remain in the same area, move into an area of medium activity, or move into an area of high activity via shifts in overlap. Conversely, caribou in areas of high activity could move into areas of medium activity, or into areas of low activity. Chi-square frequency analyses compared the change in location between caribou in the high area of activity (observed) to caribou in the low area of activity (expected). A probability of 0.05 was used to determine significance for statistical tests throughout. Mean values are reported with 1 standard error.

2.3. Results:

2.3.1. VHF annual home range data

2.3.1.1. Home range size

Over the duration of the study, caribou in areas of high activity had larger mean home ranges (483±36 km^2) than caribou in the area of low (334±36 km^2) or medium activity (344±81 km^2) (Figure 2-3, Table 2-1 for sample size). Mean annual home range size for caribou in the low area of industrial activity ranged between 159±0km^2 (1992), and 530±1km^2 (1993), and no consistent pattern in home range size was displayed over duration of the study. Caribou in the medium area of activity displayed a large mean annual home range size in 1992 (926±414 km^2), but then maintained a home range size between 164±37 km^2 and 441±141 km^2 from 1993 onwards, also showing no consistent pattern in home range size over time. Caribou in the high area of industrial activity ranged between 325±50 km^2 (1996) and 612±188 km^2 (1993), showing no consistent pattern from 1992 to 2000. In addition, though caribou in the high area of industrial activity displayed a decrease in mean home range size in 1996, there was no overall shift in the size of home range in years after 1995 when industrial activity increased (Figure 2-3).

The overall model examining annual home range size based on area of industrial activity, year, the interaction between area of industrial activity and year, and the proportion of peatland in the home range was significant (Wald $\chi^2 = 49.16$, $P < 0.01$, overall $r^2 = 0.17$). However, there was no significant difference in woodland caribou annual home range size in the different areas of industrial activity (Wald $\chi^2 = 2.52$, $P = 0.28$). Both year and the interaction term between industrial activity and year were not significant (Wald $\chi^2 = 10.29$, $P = 0.25$; Wald $\chi^2 = 15.59$, $P = 0.34$ respectively), indicating that home range size was relatively constant year to year for caribou, with no overall significant difference between caribou in different areas of activity in each year. There was no significant change in home range size occurring after increases in human activity as was predicted. Proportion of peatland emerged as a significant predictor of home range size (Wald $\chi^2 = 5.50$, $P = 0.02$) with caribou in the area of highest activity showing the lowest proportion of peatland. The overall proportion of peatland in home ranges was 0.64±0.02 for caribou in the area of high industrial activity, 0.78±0.06 for caribou in the area of medium industrial activity, and 0.85±0.05 for caribou in the area of low industrial activity.

2.3.1.2. Annual home range overlap:

Over the duration of the study, caribou in the low area of industrial activity had a mean proportion of annual home range overlap between consecutive years of 0.61 ±0.03, ranging between 0.50±0.06 (1997-1998) and 0.77±0.08 (1998-1999), displaying no consistent pattern over time (Figure 2-4, see Table 2-2 for sample size). Caribou in the area of medium industrial activity had a mean proportion of overlap of 0.57±0.05 for the duration of the study, with the lowest proportion of overlap between 1995-1996 (0.26±0.12), and the greatest overlap between 1998-1999 (0.67±0.13). In the high area of industrial activity the mean proportion of overlap of consecutive annual ranges over the study period was 0.63±0.04, with a low of 0.47±0.07 (1992-1993), and the highest proportion of overlap between 1995-1996 (0.94±0.03). As with caribou in the other classes of activity there was no consistent pattern in annual home range overlap for caribou in the high industrial activity over the course of the study. There was no indication that caribou in the area of high industrial activity displayed less home range overlap, or abandoned the area of high activity in years after 1995, and no obvious differences in home range overlap between areas of industrial activity (Figure 2-4).

The overall model explaining annual home range overlap was significant (Wald χ^2 = 48.85, $P < 0.01$, overall $r^2 = 0.31$), though year and industrial activity were not significant predictors (Wald $\chi^2 = 7.29$, $P = 0.40$, Wald $\chi^2 = 1.89$, $P = 0.38$ respectively). The interaction between year and area of industrial activity did emerge as significant (Wald $\chi^2 = 25.35$, $P = 0.03$), with caribou in the high area of industrial activity showing significantly greater overlap between 1995-1996 only, caribou in the area of medium industrial activity showing significantly less overlap between 1995-1996, and caribou in the low area of industrial activity showing significantly less overlap between 1997-1998. Home range size also emerged as a significant predictor of home range overlap (Wald $\chi^2 = 11.66$, $P < 0.01$).

Chi-square analysis indicated that caribou in areas of high industrial activity did not shift their home ranges into areas of less activity with any more frequency than did caribou in areas with low industrial activity move into areas of high activity ($\chi^2 = 0.87$, $P > 0.05$, df=2) (Table 2-3).

2.3.2. GPS seasonal home range data

2.3.2.1. Seasonal home range size

Overall, caribou in the high area of industrial activity displayed a relatively similar home range size in all seasons, with the largest average seasonal home ranges in early winter (256±38 km^2), and smallest average home ranges in calving (130±36km^2) (Figure 2-5). Caribou in the areas of medium industrial activity had the largest seasonal home ranges in late winter (335±51 km^2), rut (282±41 km^2), and early winter (228±25

km^2), with smaller home ranges in summer (117±21 km^2) and the smallest home ranges in calving (55±37 km^2). Caribou in the low area of industrial activity had seasonal home ranges of a similar size to caribou in areas of high activity in both winter seasons (low industrial activity: late winter 181±54 km^2, early winter 245±64 km^2; high industrial activity: late winter 195±36 km^2, early winter 256±38 km^2, respectively), though they displayed smaller seasonal home ranges than caribou in the area of high industrial activity in summer and calving (low industrial activity:summer 118±29 km^2, calving 61±13 km^2; high industrial activity: summer 181±53 km^2, calving 129±36 km^2, respectively).

The overall model examining seasonal home range size was significant (Wald χ^2 = 80.81, $P < 0.01$, overall $r^2 = 0.34$), with season emerging as a significant predictor of home range size (Wald χ^2 =31.10, $P < 0.01$). Caribou in all areas of industrial activity had smaller home ranges during calving (coefficient =-0.4, SE± 0.09, P <0.01), while rut and early winter had larger home ranges (coefficient =0.21±0.08, P <0.01; coefficient =0.21±0.08, P <0.01 respectively). However, industrial activity and the interaction between activity and season were not significant (Wald χ^2 = 3.13, P = 0.21; Wald χ^2 =3.65 P = 0.88 respectively), indicating that home range size did not differ significantly within each season between each level of activity. Proportion of peatland was significant (Wald χ^2 = 5.97, P = 0.01), with larger seasonal home ranges having a lower proportion of peatland overall. The average proportion of peatland in all seasonal home ranges was 0.62 (± 0.19) for caribou in the area of high industrial activity, 0.85 (±0.20) for caribou in the area of medium industrial activity, and 0.67 (±0.18) for caribou in the area of low industrial activity.

2.3.2.2. Overlap between seasonal home ranges consecutive years

Across all seasons, caribou in the high area of industrial activity displayed a similar proportion of home range overlap between seasons from year to year (ranging from 0.33±0.33 to 0.56±0.05, with the greatest variation in seasonal home range overlap in summer (Figure 2-6). Caribou in areas of low industrial activity displayed overlap similar to caribou in the area of high activity in both calving (low activity: 0.36±0.06; high activity 0.38±0.17, respectively) and summer (low activity: 0.35±0.13; high activity 0.33±0.33, respectively). Caribou in the medium area of industrial activity showed higher proportion of overlap in late winter (0.82±0.11) and early winter (0.77±0.11), as did caribou in the area of high industrial activity (late winter 0.54±0.12, early winter 0.56±0.05, respectively). The overall model examining seasonal overlap year to year was not significant (Wald $\chi^2 = 10.59$, $P = 0.72$), with neither activity, season, size of home range, nor the interaction between activity and season being significant predictors of the proportion of overlap.

2.3.2.3. Overlap between consecutive seasons in the same year

Within each comparison of the proportion of overlap of home ranges in consecutive seasons, caribou in the different areas of industrial activity displayed a similar proportion of overlap (range 0.22±0.06 to 0.70±0.12), with caribou in the area of medium activity displaying the lowest proportion of overlap overall between summer and rut (0.22±0.06)(Figure 2-7). Caribou in all areas of industrial activity similarly displayed the highest degree of overlap between consecutive seasons between late winter and calving, with similar proportion of mean overlap among groups (low activity: 0.70±0.12, medium activity: 0.65±0.10, and high activity: 0.58±0.06, respectively). The overall model was significant (Wald $\chi^2 = 50.11$, $P < 0.01$), however neither treatment, season, nor the interaction term between season and treatment were significant. Only home range size emerged as a significant predictor of overlap ($\chi2 = 27.00$, $P < 0.01$).

2.4. Discussion:

2.4.1. Effect of industry on home range size

Woodland caribou do not appear to change the size of their annual home range significantly with an increase in industrial activity. Caribou home ranges overlapping the central area where high industrial activity occurred were large before the industrial activity increased in 1995 and afterwards, indicating a factor other than activity may determine caribou annual home range size. Home ranges need to be large enough to contain required resources, yet be small enough to allow for familiarity with an area and to avoid unnecessary expenditure of energy while traversing the area (Powell 2000). For caribou, maintenance of a large home range may provide sufficient peatland habitat for forage, and allow for continued predator avoidance at a broad scale. Home range size is inversely related to food availability (Tufto *et al.* 1996, McLoughlin *et al.* 2003), and Dunford (2003) hypothesized that the large home ranges of caribou in one of the more northern ranges in Alberta was due to underlying peatland patterns, which may also be the case in the WSAR. Additionally, in a landscape with fragmented peatland, Stuart-Smith *et al.* (1997) expected that caribou would show larger home ranges and movement rates, likely compensating for low forage availability. However, they found that movements were more constrained by peatland area, suggesting that avoidance of non-peatland habitat may be a powerful pressure, or that caribou can in fact fulfill their needs in smaller habitat patches (Stuart-Smith *et al.* 1997). Stuart-Smith *et al.*'s (1997) definition of a fragmented landscape included large peatland fragments at a large spatial scale. In the WSAR, the lower proportion of peatland in annual home ranges in the area of high industrial activity suggests that caribou may not be as restricted in a landscape with relatively smaller fragments, as the proportion of peatland in these home ranges was often composed of smaller peatland fragments.

Caribou can forage across a wide range of environmental conditions (Johnson *et al.* 2001), and can also show habituation to human activities (Wolfe *et al.* 2000). It is conceivable that a change in home range size in relation to industrial activity was also not observed, because on a large spatial scale caribou have already selected areas with sufficient resources, resources which to date have not been deleted sufficiently by industrial activity or functional habitat avoidance to cause changes. Woodland caribou responding to wildfire disturbance also did not significantly change home range size, even after a substantial proportion of their range had been burnt (Dunford 2003).

As woodland caribou often use large areas in winter (Fuller and Keith 1981, Stuart-Smith *et al.* 1997, Rettie and Messier 2001), the tendency towards larger home ranges in winter cannot be solely attributed to the high level of industrial activity also present during those seasons. However, as caribou in the area of highest industrial activity displayed trends toward similar sized home ranges across seasons, and as the proportion of peatland emerged as a significant predictor of seasonal home range size (as in the annual home ranges), there remains the indication that habitat requirements may primarily determine home range size. However, caribou with larger home ranges in rut may also be moving over greater distances to increase encounter rates between caribou during the breeding season (Rettie and Messier 2001). The trend towards smaller seasonal home ranges in calving and summer also follows expected trends, as females with calves are thought to moves less to avoid predators (Rettie and Messier 2001), and summer is a time of widespread high quality forage availability, with caribou presumably needing to move less to obtain sufficient forage (Edmonds 1988). However, though trends were seen in seasonal home range size, no significant difference was found between caribou in the different areas of industrial activity.

The size of calving home ranges for caribou in the area of highest industrial activity on average were larger than those documented for caribou in other areas (albeit non-significantly), suggesting that the calving range is large to simply ensure a high enough proportion of peatland to be able to ensure enough forage and shelter to successfully produce a calf. However, if caribou in areas of high industrial activity lost calves to predation and moved over larger areas because they did not need to remain with a calf, then areas with greater access, though not abandoned by caribou on an annual or season basis, may potentially provide considerable risk for calves and females. The implication then would be that access, and not functional habitat loss is of main concern. Unfortunately information on calving success and time/location of calf mortalities was not available.

2.4.2. Effect of industry on home range overlap

Caribou did not vacate the area exposed to high industrial activity, and showed variation in annual and seasonal home range overlap similar to caribou in areas with lower levels of activity. By not abandoning areas of high industrial activity, caribou may be able to maintain a connection to their preferred habitat, and functional habitat loss may not be as of great of importance at the home range scale as previously thought (Bradshaw *et al.* 1997, Dyer *et al.* 2001). It is conceivable that industrial activity, though deleting habitat, may not eliminate sufficient amounts directly (or large contiguous amounts, as forestry may, Smith *et al.* 2000) to cause caribou to move their home range into an area of lower industrial activity. In all likelihood, caribou are responding to a series of changing needs and pressures (Johnson *et al.* 2001), and are meeting forage requirements even in areas with a low proportion of peatland (Dunford 2003).

In general, caribou in the WSAR appear to remain in similar areas year to year, possibly reducing the amount of predation risk attributed to moving into new areas (Stamps 1995, Nicholson *et al.* 1997, Kitchen *et al.* 2000, Schaefer *et al.* 2000). Overlap of home ranges between consecutive seasons also indicates that caribou do not have distinct seasonal ranges, providing support to a previous study (Stuart-Smith *et al.* 1997). The wider distribution in the winter seasons by caribou over the landscape (Fuller and Keith 1981, Stuart-Smith *et al.* 1997, Rettie and Messier 2001), presumably allows caribou to meet forage requirements (Dunford 2003), and may potentially define an area where a caribou lives on an annual basis, allowing for overlap of other seasonal home ranges seen in this study.

Home range estimates, at their best, should be able to have some form of predictable ability in delineating where an animal can be found (Powell 2000). However, the sometimes subjective choice of a home range estimate may influence results, and it is important to consider the limitations and advantages of estimators (Seaman and Powell 1996, Ostro *et al.* 1999, Powell 2000). The MCP estimate is sensitive to sample size (Powell 2000), and though sample size did not emerge as a significant predictor of home range size, low sample sizes and differences in sample size may have influenced my estimation of the extent of the study area over which caribou may have been found.

2.4.3. Management considerations

Caribou do not appear to alter their annual home range location or size in relation to an expanding industrial footprint, indicating that caribou may tolerate disturbances at the level of their home range. Dunford (2003) examined the dominant agent of disturbance in the boreal forest, fire (Johnson 1992), and found that caribou do not alter their home range size or location after fire, even though some home ranges had up to 40% of their area burned. It was thought that as site fidelity reduces predation risk, caribou would remain in the disturbed areas, still being able to find sufficient habitat. Animals are adaptable, and there are instances when habituation or movement from preferred habitats (such as bedding or forage) is not observed (Richens and Lavinge 1978, McLellan and Shackleton 1989, Yost and Wright 2000, Gibeau *et al.* 2002). The lack of selection for different habitats may be due to strong selection for the preferred habitats, *or* because there are no alternative areas which animals can move to (Gill *et al.* 2001).

Examination of the amount of effective habitat in Alberta's regional caribou ranges indicated that caribou ranges with a greater industrial footprint have declining populations (BCC 2003), supporting the claim that industrial activity affects survival. However, though caribou populations have been declining in the majority of these ranges, the WSAR currently appears to have a population that is relatively stable (McLoughlin *et al.* 2003). The possibility that predators (wolves, coyotes and bears) are using utilizing linear corridors to enter core peatlands more frequently than thought cannot be discounted, and is currently being examined (A.D.M. Latham, 2004, Pers. comm.). Interestingly, some of the caribou in the WSAR VHF dataset collared for the longest period (6 years) did maintain annual home ranges in the area of high industrial activity in the mid to late 1990's, indicating the possibility of survival in an area rife with industrial features. However, survival and fecundity of caribou in the different areas of industrial activity has not been examined, and I believe that this link to population dynamics is vital and should be made. Though caribou may not leave an area of high industrial activity, their survival and reproductive success may still suffer, potentially limiting the recovery of this threatened species.

2.4.4. Conclusions

Woodland caribou do not change the size of their annual home range significantly with an increase in industrial activity. Though caribou in areas of highest industrial activity had large annual home ranges in general, they displayed this tendency before an increase in industrial activity occurred in 1995 and onwards. Range fidelity varied for caribou in all areas, but there was no abandonment of areas of highest industrial activity. On a seasonal basis, caribou in the area of high industrial activity did not significantly differ from caribou in areas of low or medium activity in terms of home range size in each season, nor was there a difference in overlap in seasons between years, or consecutive seasons within years. Caribou in all areas of industrial activity had significantly larger home ranges in rut and early winter, indicating that increased industrial activity during the winter seasons may not be determining home range size, and that resource availability may influence movements at these times. The proportion of peatland was a significant predictor of annual and seasonal home range sizes overall, with the largest home ranges having the lowest proportion of peatland. This implies that habitat, and not industrial activity may be the main determinant of caribou distribution at the level of the home range in the West Athabasca Caribou Range.

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Table 2-1. Number of individual caribou in each class of industrial activity for each year of study. High, medium, and low activity describe what relative amounts of activity caribou in the study area were subject to, with caribou placed in each category based on their annual home range overlap with a central area of the greatest amount of industrial activity in the study area.

	Year								
Activity	1992	1993	1994	1995	1996	1997	1998	1999	2000
Low	1	2	4	10	13	15	12	11	10
Medium	2	2	1	3	10	6	4	4	2
High	2	7	7	5	8	8	8	8	9

Table 2-2. Number of annual caribou home ranges in each class of industrial activity for each year of study used in overlap analysis.

Activity	1992	1993	1994	1995	1996	1997	1998	1999
Low	1	3	4	7	13	13	9	10
Medium	1	1	2	3	9	4	4	2
High	2	5	4	3	8	7	8	8

Table 2-3. Percentage of annual caribou home ranges which remain in the same area of industrial activity, move to areas of increased activity, or move to areas of less activity though a change in proportion of overlap for years after 1995. Number of occurrences in parentheses.

	Industry class		
State change	Low	Medium	High
Highest activity	0 (0)	0.0	n/a
More activity	3.85 (2)	24.00 (6)	n/a
No change	96.15 (50)	60.00 (15)	91.18 (31)
Lower activity	n/a	16.00 (4)	8.82 (3)
Lowest activity	n/a	0.0	0.0

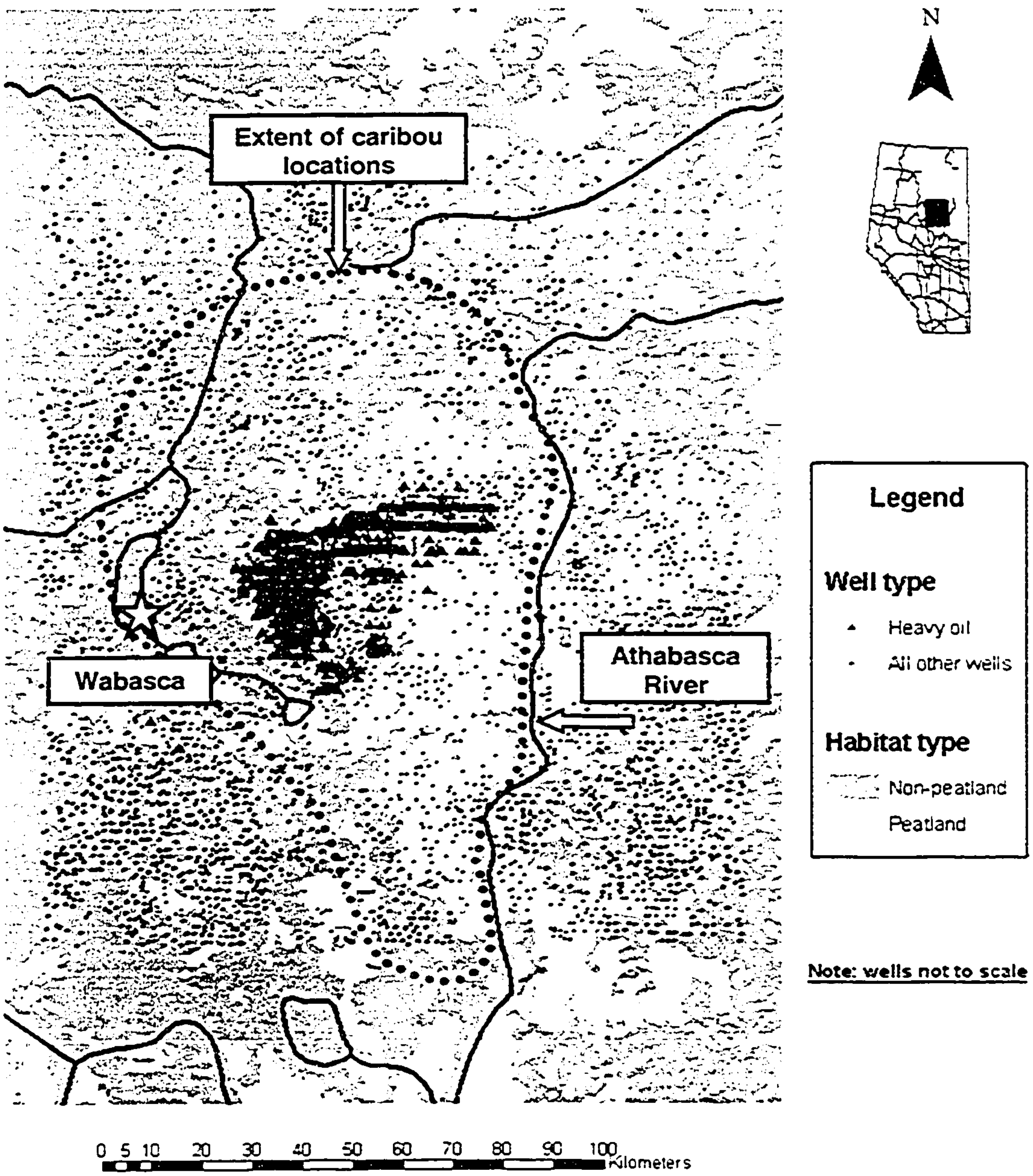

Figure 2-1. Study area with caribou locations from the West Athabasca Caribou Range (WSAR) found within the dashed polygon. Peatland / non-peatland habitat at a coarse scale (Peatland Inventory of Alberta) is indicated, and locations of all wells in the Alberta Energy and Utilities Board dataset to 2000 are shown, with emphasis on the central area of high industrial activity with heavy oil wells highlighted.

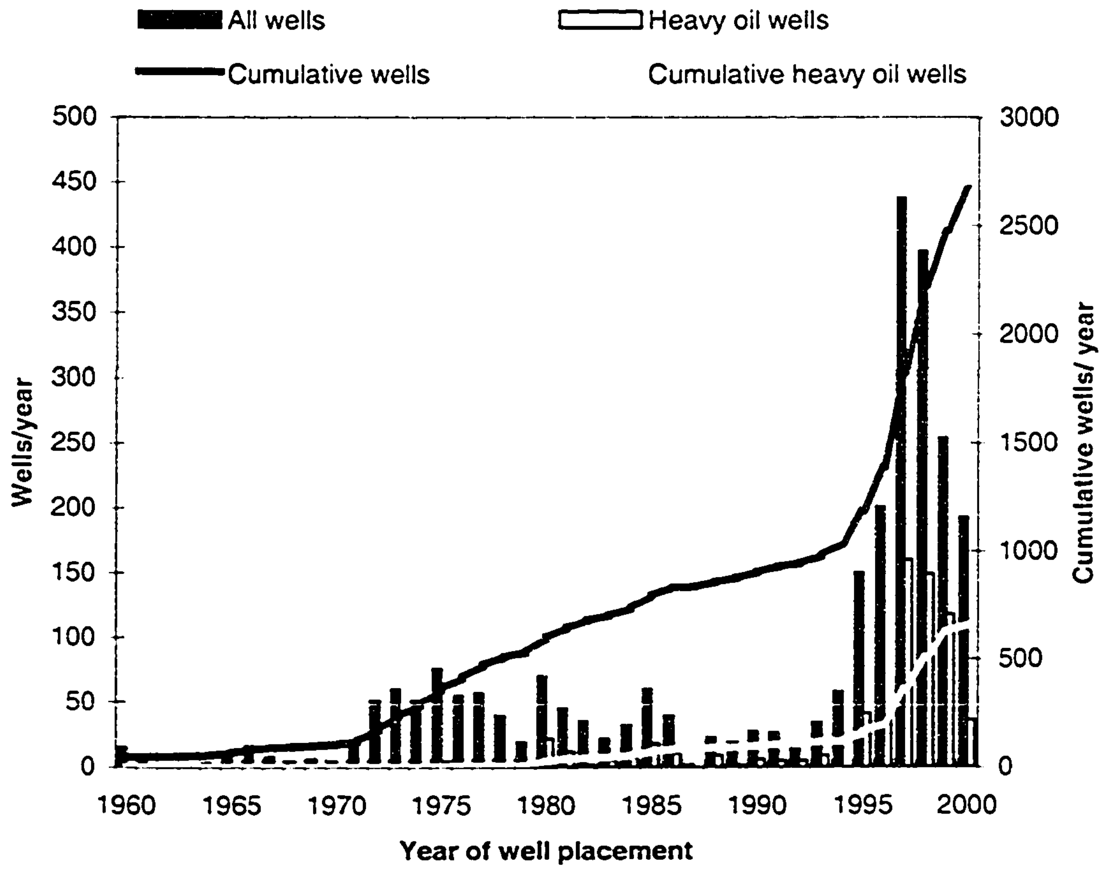

Figure 2-2. The total number of wells drilled by year, and the cumulative number of wells (1960-2000) in the study area. Values are given for both wells of all types (gas, oil, and heavy oil) and heavy oil wells only. Note increase in number of wells placed in 1995 and onwards.

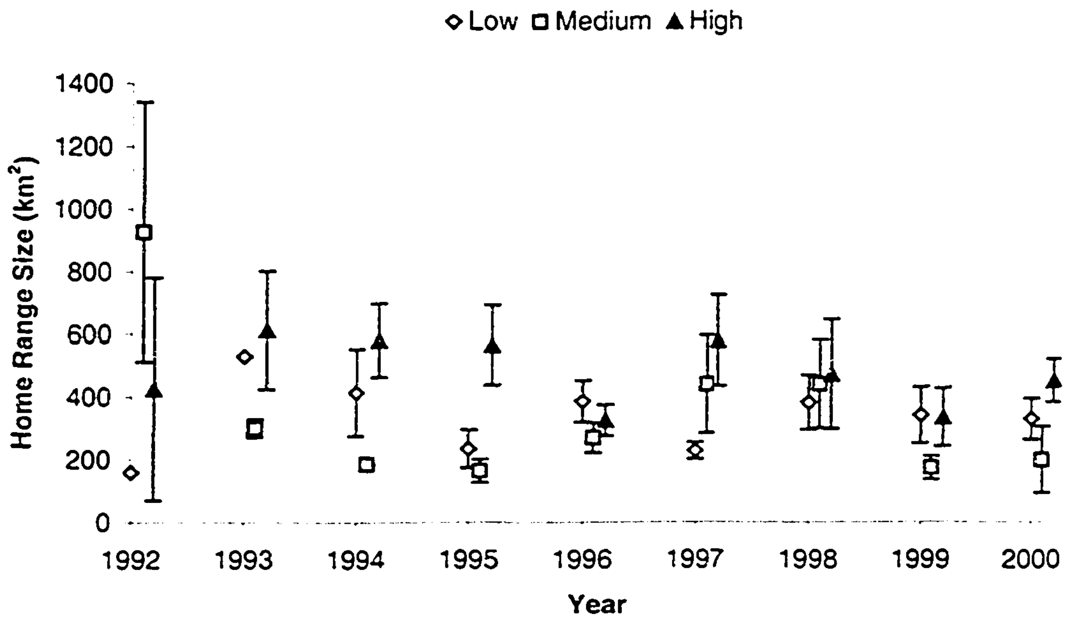

Figure 2-3. Mean annual home range size for caribou in areas of high, medium, and low areas of industrial activity from 1992 to 2000. Mean home range sizes are shown in square kilometers with one standard error.

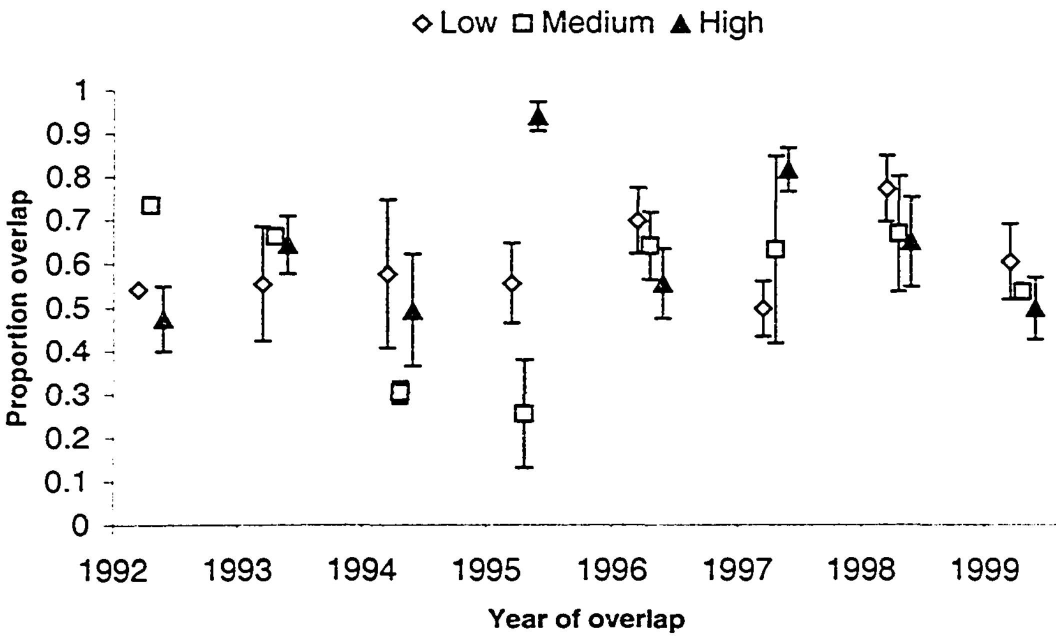

Figure 2-4. Proportion of overlap between consecutive annual home ranges for caribou in areas of high, medium, and low industrial activity from 1992 to 2000. The x-axis indicates the first year of overlap, such that 1992 indicates the overlap between a caribou home range in 1993 with the previous year 1992. Mean proportion is shown with one standard error.

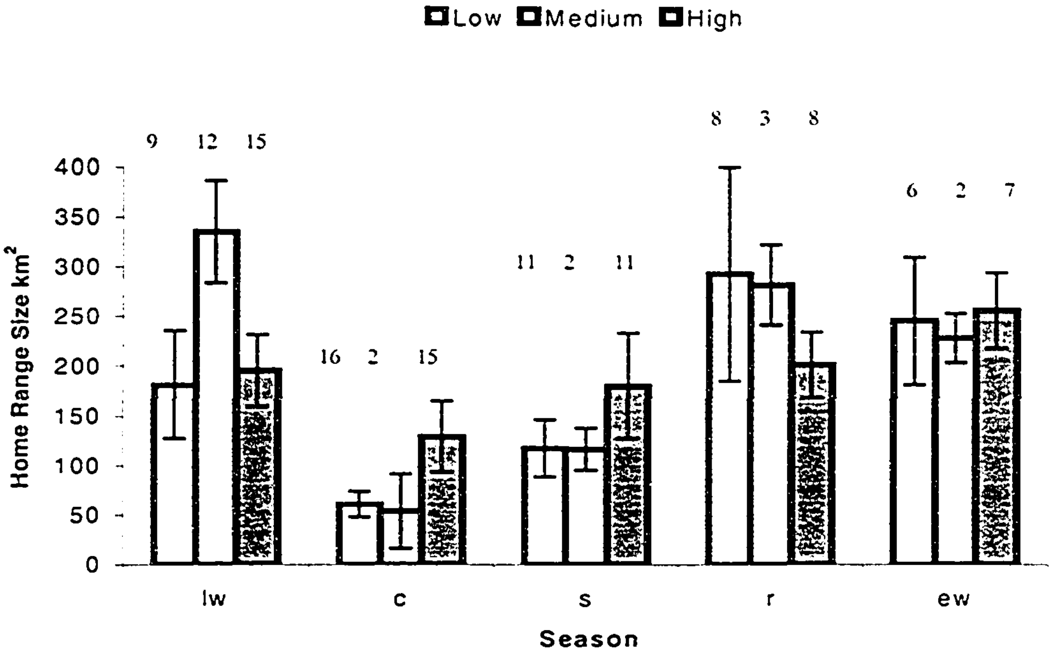

Figure 2-5. Seasonal home range size in areas of high, medium, and low areas of industrial activity during late winter, calving, summer, rut, and early winter in 1998-1999. Mean home range sizes are in square kilometers with one standard error. Numbers of individual caribou used to generate seasonal home ranges are indicated above bars.

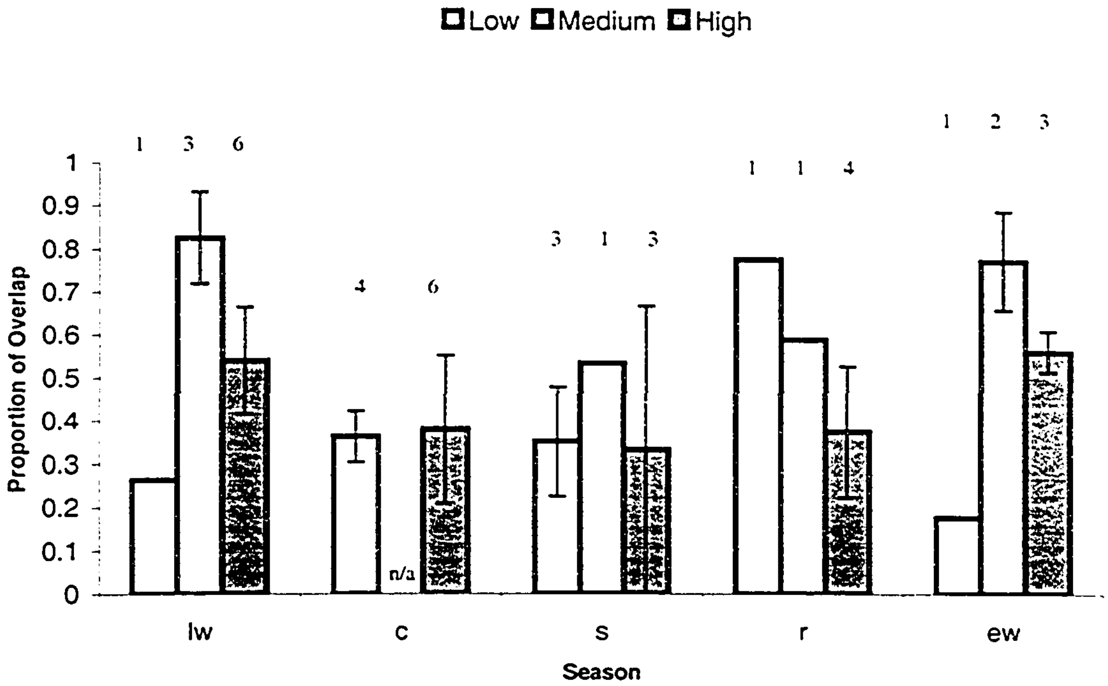

Figure 2-6. Proportion of overlap between seasonal home ranges from 1998 to 1999 for late winter, calving, summer, rut and early winter home ranges in areas of high, low and medium industrial activity. Mean proportion of overlap is shown with one standard error. Insufficient data were available for caribou in the medium area of industrial activity to compare overlap in calving from 1998-1999. Numbers of individual caribou used to generate seasonal home ranges are indicated above bars.

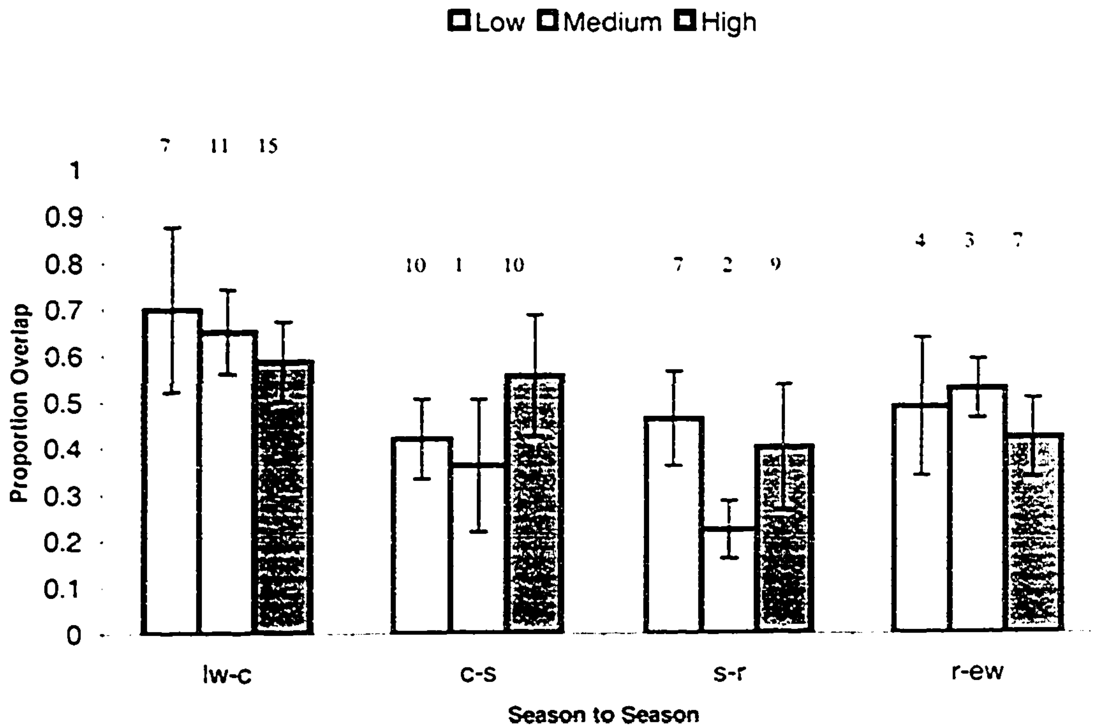

Figure 2-7. Proportion of seasonal home range overlap for consecutive seasons in 1998 and 1999 in areas of high, medium, and low industrial activity. Mean proportion of seasonal home range overlap is shown with one standard error. Number of individual caribou used to generate seasonal home ranges are indicated above bars.

Chapter 3. Seasonal habitat use by woodland caribou in relation to industrial activity.

3.1. Introduction:

Effective wildlife management relies on the knowledge of habitats that an animal uses (Garshelis 2000), and the study of habitat selection is central to understanding a species' ecology (Johnson 1980, Chamberlain *et al.* 2002). As fitness is linked to habitat quality (Garshelis 2000), evaluation of habitat selection is key when maintaining threatened or endangered populations (Merril *et al.* 1999, McComb *et al.* 2002, Janis and Clark 2002, Sakuragi *et al.* 2003, Schadt *et al.* 2002). Conservation biology studies frequently examine the effects of human encroachment on habitat, as habitat disturbance, fragmentation and deletion resulting from human activities have all been implicated in wildlife mortality, decreased reproductive success, and population declines (Cole *et al.* 1997, Phillips and Alldredge 2000, Gill *et al.* 2001, Gibeau *et al.* 2002, Schmiegelow and Mönkkönen 2002).

Woodland caribou (*Rangifer tarandus caribou*) in Alberta are currently classified as threatened (COSEWIC 2003) with declining populations in many of their ranges (Boreal Caribou Research Program 2000, McLoughlin *et al.* 2003). Petroleum exploration and related infrastructure may facilitate this decline via functional habitat loss, predation pressure, hunting and/or poaching, or the energetic costs associated with avoidance (Fuller and Keith 1981, Edmonds 1988, 1991, Gray 1999, BCRP 2000, Dzus 2001, McLoughlin *et al.* 2003). Alberta's woodland caribou populations may continue to decline and risk becoming endangered if limiting factors are not addressed (Dzus 2001, Weclaw 2001).

3.1.1. Caribou habitat selection and industrial activity

Woodland caribou (of the boreal ecotype) in Alberta select lowland habitats dominated by treed fens and bogs while avoiding dry upland habitats (Bradshaw *et al.* 1995, Stuart-Smith *et al.* 1997, Schneider *et al.* 2000). Caribou may also choose to remain at a distance from non-peatland habitats, as they select core peatland areas presumably to avoid predation in and along the edge of non-peatland habitats (James and Stuart-Smith 2000, McLoughlin *et al.* unpub.). Within their home range, caribou select treed-peatland stands over habitats such as non-peatland, open fens, and wet non-peatland areas, as treed stands contain the greatest amount of lichens (Anderson 1999). The ability of caribou to feed on lichens, a forage not utilized by other ungulates, allows them to exist in habitats separate from other ungulate prey. This spatial separation from alternative prey, and an additional isolation between individual caribou is though to provide reduced predation pressure within their preferred habitat (Bergerud 1988, Bergerud *et al.* 1990, Stuart-Smith *et al.* 1997, Rettie and Messier 2000, Dzus 2001).

Woodland caribou inhabiting the boreal forests of northern Alberta (considered a boreal ecotype) show no consistent trends toward selecting distinct seasonal ranges (i.e. they are non-migratory), in contrast to the mountain caribou ecotype inhabiting the foothills of Alberta (Dzus 2001). Caribou physical condition is largely based on their summer diet, while winter factors such as temperature and snow depth can affect survival (Klein 1982, Dzus 2001). Caribou typically have large home ranges during the winter and rut periods, with movements over larger areas associated with finding sufficient forage and mates, while smaller home ranges in summer and calving may be linked to cow - calf pairs remaining in areas separate from each other to avoid predation pressure (Fuller and Keith 1981, Stuart-Smith *et al.* 1997, Rettie and Messier 2001). Metabolic demands are high in early lactation and high-quality forage is of importance at this time (Nellemann and Cameron 1998), as female body mass and condition can affect early calf survival (Cameron *et al.* 1993). In addition, fall may be a critical period for energy acquisition, as there are energetic costs associated with the rut (Romlinger *et al.* 2000).

Though woodland caribou have been shown to avoid industrial features and human activity (Dyer *et al.* 2001), it is not known what habitat caribou use while displaying avoidance behaviour. Currently, industrial activities are allowed in caribou ranges as long as "the integrity of the habitat is maintained to support use by caribou" (Alberta Department of Energy 1991). If caribou are subject to functional habitat loss via displacement (Dyer *et al.* 2001), and move into habitats considered to be sub-optimal while displaying avoidance (Bradshaw *et al.* 1997) then availability of quality forage may be compromised and caribou health affected, with decreased reproductive success a result (Cameron *et al.* 1993, Nellemann and Cameron 1990, Vistnes and Nellenmann 2001). If caribou still avoid, but are found in close proximity to non-peatland habitats, there may also be increased risk of predation (James and Stuart-Smith 2000, McLoughlin *et al.* unpub.). My examination of what habitat caribou are selecting in relation to industrial activity may give insight into how caribou expose themselves to lower quality habitat and increased predation risk, as predators may use industrial features and non-peatland habitat (Jalkotzy *et al.* 1997, James 1999, Dzus 2001).

3.1.2. Objectives

My objective was to compare the habitat selection of woodland caribou within the seasonal home range (third order selection, Johnson 1980) between areas of high to low industrial activity in each of five seasons (late winter, calving, summer, rut, and early winter). In all seasons, I expected that caribou would show strong affinity for treed bog and fen areas, show less selection of open peatlands and wet non-peat/water areas, and show strong avoidance of non-peatland habitat (Anderson 1999). However, because caribou have been shown to change habitat types while moving away from disturbance (Bradshaw *et al.* 1997), there was the potential that caribou with seasonal home ranges in the area of highest industrial activity would show patterns of habitat selection/avoidance different than caribou in areas with low industrial activity. I expected that caribou in areas of high industrial activity would move into areas of less suitable habitat (such as non-peatland) while displaying avoidance behaviour, with this change being most evident in the winter seasons when the majority of avoidance of industrial activity occurs (Dyer *et al.* 2001).

3.2. Methods:

3.2.1. Study Area

Located in northeastern Alberta in the West Athabasca Caribou Range (WSAR), the study area spans approximately 6000 km^2 of a combination of boreal mixedwood and peatland vegetation, and is dominated by a large peatland complex (center at 56^0N, 113^0W). Elevation ranges between 500m and 700m above sea level, with higher elevations dominated by *Polpulus tremuloides*, *Picea glauca*, and *Pinus banksiana*. Lower elevations are vegetated primarily by *Picea mariana* and *Larix laricina*, which form bog and fen peatland complexes. The study area sits atop the southwest corner of the Athabasca oil-sands deposits (Crandall and Prime 1998), and contains a number of industrial features including: all-weather roads, seismic lines, pipelines, well sites, tank farms and field camps. These features and associated activities are concentrated in a central region of the study area, where heavy oil exploration and extraction is common. (see Chapter 2, Figure 2-1).

3.2.2. Habitat Data

The Alberta Vegetation Inventory (AVI) consists of polygons based on 1:20,000 base maps, and was developed to meet the information needs of forest managers (Nesby 1997). I re-classified the AVI into 6 habitat classes using the Alberta Wetland Inventory (AWI) definitions (Halsey and Vitt 1997) incorporated into the (AVI). This allowed for delineation of peatland polygons based on vegetation attributes such as tree species composition, ecological moisture regime, and crown closure. Polygons were placed in the following classes: non-peatland, one of four peatland classes (treed bog, treed fen, open bog, open fen), and water/non-peatland wet vegetation (Figure 3-1, see Table 3-1 for detailed definition of habitat classes). A measure of the distance to all non-peatland habitat was also included, and was ranked 1-6 for ease of interpretation (with 1 being furthest from non-peatland and 6 being closest to), and was treated as a continuous variable in analyses (see Table 3-2 for comment). All AVI re-classifications and calculations were completed using ArcMap 8.1 (ESRI 1998a), and were projected to NAD 27 Zone 12.

3.2.3. Caribou data

Thirty-six caribou were fitted with GPS collars (Lotek Engineering Systems, Newmarket, Ontario) in the WSAR between 1998-2000, with locations taken approximately every two hours (see Dyer *et al.* 2001 for more detail). I classified data into five seasons for woodland caribou (Bergurud 1975, Dyer *et al.* 2001): LW - late winter (22 February - 30 April), C - calving (1 May – 30 June), S - summer (1 July – 15 September), R - rut (16 September – 15 November), and EW - early winter (16 November – 21 February of the following year). This delineation provided ten seasons over two "caribou years" (1998-1999). However, not all individuals had sufficient locations spanning each of the five seasons, nor did individuals have locations in all seasons between years. This was primarily due to change of individuals between years, mortality, and collar failure (see Dyer *et al.* 2001). Individual caribou had between 130-1535 locations per season, with a total of 116,361 locations for all individual caribou combined over 1998/1999.

3.2.4. Industry data

AEUB (Alberta Energy and Utilities Board) well data (1966-2000), provided by Alberta-Pacific Industries Inc. was used as an index of overall industrial activity, as wells are closely associated with linear features (also Cumming and Carteledge 2004). However, because wells of varying types have different activities associated with their operation (Schneider 2001), crude-bitumen, or "heavy oil" wells were used to delineate the area of highest industrial activity (see Figure 2-1, Chapter 2). Though anthropogenic features were found throughout the study area, heavy oil wells were found concentrated exclusively in the center of the study area. Heavy oil exploration and extraction was found in association with large numbers of other conventional wells, and typically involves large drilling operations, all weather road access, a large amount of vehicular traffic, and can be considered to display the greatest amount industrial disturbance present in the study area (A. Cicoria, Lormel Consultants, Pers. comm., E. Pooley, Char Rose Exploration Enterprises Ltd, Pers. comm.).

I placed a 95% kernel estimate around all cumulative heavy oil activity to delineate the central area of interest where the highest level of industrial activity was located. I used the proportion of overlap caribou home ranges had with this central area to define the relative amount of industrial activity that a caribou would be exposed to, creating three categories of exposure. Caribou seasonal home ranges with less than 1% overlap with the central area were placed in a category of "low" industrial activity and were assumed to have the lowest relative amount of industrial activity present in the study area for all years of study. Caribou seasonal home ranges with 1-20% overlap were placed in a "medium" category, and assumed to be exposed to an intermediate level of disturbance. Caribou seasonal home ranges with greater than 20% overlap were considered to be in an area of "high" industrial activity.

3.2.5. Statistics

I used a third-order (Johnson 1980) seasonal selection use/availability study design, where actual caribou GPS locations provided an estimate of seasonal resource use, which was then compared to available habitat found at randomly placed locations using logistic regression (Manley *et al.* 2002, Nielsen *et al.* 2002). I defined available habitat by generating 10 random locations per square kilometer within polygons produced by using all available locations taken over the duration of the study for each individual caribou. This delineation restricted random locations to an area used by caribou at some point during the study period, and provided a reasonable sampling of habitat types (S. Nielsen Pers. comm). I created all caribou polygons in ArcView 3.1 (ESRI 1998b) using the Animal Movement extension (Hooge and Eichenlaub 1997) and imported them into ArcMap 8.1. All random point generation and calculation of intersection of caribou locations with the habitat layers were completed in ArcMap 8.1

(ESRI 1998a) using the Hawth's Tools extension (Bayer 2004). All data were projected to NAD 27 Zone 12.

I pooled caribou locations within each industry class (high, medium, and low), and ran separate models for each of the three classes within each season. To address concerns of pseudoreplication (Otis and White 1999, Nielsen *et al.* 2002) and unequal sample sizes, I used a robust clustering technique (with individual caribou as the clusters or unit of replication) similar to a conditional fixed-effects logistic regression (Pendergast *et al.* 1996).

Resource Selection Function (RSF) models for each industry class within each season using the seven habitat variables followed the structure (Boyce *et al.* 2002).

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots \beta_7 x_7)$$

where $w(x)$ is the resource selection function, x_i is a predictor variable, and β_i is the selection coefficient. The β_i's can be considered equivalent to selection ratios, and can be used to determine if a habitat type is selected or avoided. If $\beta_i > 0$, then caribou can be considered to be using a habitat more then would be expected in relation to its availability. A $\beta_i < 0$ indicates less use of a habitat type than expected relative to availability. I compared 95% confidence intervals between β_i's of industry classes to determine if caribou in areas of industrial activity differed in their degree of avoidance or selection of a habitat type within a given season.

I assessed the performance of models for each industry class in each season using a k-fold cross validation technique (Boyce *et al.* 2002). Five k-fold groups were used, where 80% of data were used for model training and 20% of data were retained for model testing in each of the five groups. I examined model performance using the pattern of predicted RSF scores (presence only testing data) against categories of RSF score. A Spearman-rank correlation was calculated for each model, with a strong positive correlation indicating a model with good predictive performance (Boyce *et al.* 2002). All logistic regressions, estimation of coefficients for the habitat variables, and the k-fold model validations were achieved using Stata (2001).

Prior to analyses, I examined a correlation matrix between all habitat variables. All correlations were less than 0.7, and I determined that colinearity was not of concern (Sokal and Rohlf 2000). I pooled all seasonal data between years as preliminary RSF analyses showed similar trends between years for caribou in the areas of industrial activity in each season (see Table 3-3 for pooled sample sizes).

3.3. Results

Caribou in the high area of industrial activity significantly avoided non-peatland habitat in all seasons (range of mean β =–1.77 to –3.47), displaying the greatest amount of avoidance in calving (mean β =–3.47) (Figure 3-2). Caribou in the area of medium industrial activity also showed significant avoidance of non-peatland habitat in all seasons (range of mean β =–1.89 to -6.06), with most avoidance occurring in calving (mean β =–6.06) and rut (mean β =–5.03). In contrast, caribou in the area of low industrial activity displayed statistical avoidance of non-peatland habitat in calving (mean β =–4.00), summer (mean β =–2.54), and rut (mean β =–3.36), but not in early and late winter. Caribou in the medium area of activity also displayed a significantly greater amount of avoidance of non-peatland than caribou in the area of high industrial activity.

In addition to avoiding non-peatland habitat, the majority of caribou locations were found greater than 250m away from the edge of non-peatland habitat, with caribou in the area of low industrial activity having approximately 35-40% of their locations found less than 250m away from non-peatland habitat in both winter seasons (Table 3-4). Caribou in the area of highest activity avoided areas closer to non-peatland in all seasons (range of mean β=–0.52 to –0.88), with caribou in the area of medium activity showing significant avoidance of areas closer to non-peatland habitat in every season (range of mean β =–0.95 to –2.66) except for summer (Figure 3-3). However, caribou in the area of low activity showed no significant selection of areas away from non-peatland in early winter and late winter, but were found significantly further away in calving (mean β =–1.44), summer (mean β =–0.79) and late winter (mean β =–0.82).

Caribou in all areas of industrial activity showed significant selection for open bog in all seasons (Figure 3-4), with caribou in the area of high industrial activity (range of mean β= 1.47 to 2.36) showing strongest selection in calving (mean β= 2.36), as did caribou in the area of low activity (mean β= 2.09). Caribou in the medium area of industrial activity showed strongest significant selection in rut (mean β= 2.34). However, for caribou in the low area of activity the strength of selection in late winter (mean β= 0.94) and early winter (mean β= 1.15) was significantly lower than caribou in areas of medium and high activity in late winter, and caribou in the medium area of activity in early winter.

Caribou in the area of high industrial activity significantly avoided open fen habitat in calving (mean β=–0.52), summer (mean β=–0.56) and rut (mean β= –0.96) with no significant avoidance in late and early winter (Figure 3-5). In contrast, caribou in the area of medium industrial activity selected open fen habitat in calving (mean β=1.09), showing an opposite trend from caribou in the high area of activity. Caribou in the medium area of activity also significantly selected open fen habitat in early winter (mean β=0.20), while caribou in the area of low industrial activity showed no significant avoidance or selection of open fen habitat in any season.

There was significant selection of treed bog by caribou in the area of high industrial activity in all seasons (range of mean β= 0.39 to 0.99), and by caribou in areas of medium industrial activity (range of mean β= 0.68 to 1.54) (Figure 3-6). However, caribou in the area of low industrial activity only showed significant selection for treed bog in calving (mean β= 0.78) and rut (mean β= 0.56). Caribou in both the areas of low and high industrial activity displayed weaker selection for treed bog than caribou in the area of medium industrial activity in calving, and caribou in the high area of industrial activity displayed weaker selection for treed bog than caribou in the medium area of activity in rut.

Selection of treed fen by caribou in the area of high industrial activity was significant in all seasons (range of mean β= 0.34 to 0.67), except for summer (Figure 3-7). Caribou in the area of medium activity displayed significant selection in late winter (mean β=0.45), summer (mean β=0.77) and rut (mean β=1.18). Caribou in the area of low activity significantly selected for treed fen in all seasons (range of mean β= 0.70 to 0.99), except for late winter. Caribou in the high and low areas of industrial activity both showed significant selection in early winter which differed from caribou in the area of low activity who showed no significant selection.

Caribou in the area of highest industrial activity only showed significant avoidance of water/non-peatland wet vegetation in summer (mean β=–0.58), while caribou in the area of medium activity displayed both significant avoidance in summer (mean β=–1.32) and significant selection in calving (mean β=0.90). Caribou in the area of low industrial activity also showed significant avoidance in summer (mean β=–0.74), calving (mean β=–0.49) and early winter (mean β=–0.69).

Spearman-rank correlations between RSF bins and area adjusted frequencies for the models tested ranged from 0.39 to 0.82 in each season, indicating variation in the predictive capability of the models for each industry class in different seasons (Table 3-5). Average Spearman-rank correlations taken across all seasons for each class of activity indicated the model for caribou in the area of high industrial activity had the best overall mean predictive ability (mean rho = 0.68), followed by caribou in the area of low industrial activity (mean rho = 0.61), and caribou medium area of industrial activity (mean rho = 0.59).

3.4. Discussion

Caribou showed strong selection for treed bog and fen habitats, and a strong avoidance of non-peatland habitat in all seasons, following previous trends in habitat selection (Bradshaw *et al.* 1995, Stuart-Smith *et al.* 1997, Anderson 1999, Schneider *et al.* 2000). In addition, caribou in the area of highest industrial activity did not exhibit selection of habitats considered less suitable during winter seasons when industrial disturbance were highest. These data provide no convincing evidence that caribou choosing to remain in areas of high industrial disturbance move into lesser quality habitats as a result of their previously documented avoidance of features and associated activities (Dyer *et al.* 2001).

3.4.1. Avoidance of non-peatland habitat

In early and late winter, caribou in the area of high activity showed avoidance of non-peatland habitat while caribou in the area of low activity showed no avoidance, a trend opposite to the one I expected. As caribou in the areas of highest activity are subject to disturbances which are considered ubiquitous across habitats (Dyer *et al.* 2001), one can speculate that faced with the choice of moving into an area of sub-optimal non-peatland habitat with high industrial activity from an area of high-quality peatland habitat with high industrial activity, caribou opt to remain in their preferred habitats. This may be related to caribou maintaining a sufficient intake of lichens in winter in peatland habitat (Darby and Pruitt 1984, Edmonds and Bloomfield 1984, Bradshaw *et al.* 1995, Johnson *et al.* 2001), while avoiding potential predation in non-peatland habitats (Dzus 2001, McLoughlin *et al.* unpub.), or avoiding industrial activities of a certain type or certain density in conjunction with habitat. Caribou have been observed in aspen stands (M. Fremmerlid, 2004, Slave Air, Pers. comm.), and Jackpine/spruce stands (A.D.M. Latham, 2004, University of Alberta, Pers. comm.) in the WSAR, possibly exploiting novel forage or finding bedding sites. Also, proximity to non-peatland edges may provide increased exposure to predation risk (McLoughlin *et al.* unpub.), though adult caribou mortalities have been found to be highest not in the winter, but in the summer months (McLoughlin *et al.* 2003). One can speculate that while using components of non-peatland habitat, the time in non-peatland in areas of high industrial activity exposes caribou to increased predation risk, especially if predators are moving on linear features, and if they are in search of alternative prey species associated with anthropogenic disturbances (e.g. deer) (M. Fremmerlid, 2004 Slave Air, Pers. comm.).

Caribou in the area of highest industrial activity may be constrained by the size and configuration of the peatland patches they have selected. Annual home ranges in the area of the highest activity were larger, and possessed a lower proportion of peatland than annual home ranges further away from activity (see Chapter 2). This implies that the amount of peatland available for caribou in the area of highest activity is less than in surrounding areas. As fat reserves are depleted over the winter (Ademczewski *et al.* 1987, Gerhart *et al.* 1996), caribou may be forced to move over large areas to obtain sufficient lichen biomass, and may preferentially choose to stay in lichen dominated habitats, avoiding non-peatland patches which are lacking lichen cover, or are large or in close proximity to one another to provides a perceived risk of predation.

Caribou with calves are frequently sedentary for a period of time during calving, and select areas providing both predator avoidance and nutrition (Bergerud and Page 1987, Bergerud *et al.* 1990, Barten *et al.* 2001). Consistent avoidance of non-peatland, and selection of peatland areas including: treed fen, and both treed and open bog in calving by caribou in all areas of industrial activity may indicate that caribou continue to minimize their risk of predation, and potentially disregard nearby industrial activity as a consequence. Though specific calving areas are not recognized for caribou in the WASR (Stuart–Smith *et al.* 1997), there may be areas of preferred habitat which caribou select while giving birth (M. Fremmerlid, 2004 Slave Air, Pers. comm.). Future analysis of fine-scale habitat characteristics such as forage biomass and cover (Barten *et al.* 2001) could clarify if pregnant caribou select areas in peatland habitat with specific attributes.

Incorporation of measurements of non-peatland at fine, and increasingly larger spatial scales is warranted when examining caribou habitat selection (Johnson *et al.* 2001), and there have been repeated calls for multi-scale studies when addressing topics in landscape ecology (Bissonnette 1997, Turner *et al.* 2001, Kie *et al.* 2002). Though this study did incorporate examination of annual (Chapter 2), seasonal (Chapter 2) and within season (this Chapter) habitat selection, the configuration of peatland habitat was not examined. It is conceivable that an examination of caribou avoidance of non-peatland habitat without incorporation of its spatial arrangement and proportion at different scales resulted in an incomplete view of how caribou utilize their landscape in relation to industrial activity. Habitat configuration, rather than habitat alone may decree where caribou are in relation to predators and other ungulate species that use industrial features. A current study investigating the effect of landscape configuration and fragmentation on the distribution of predators and alternative prey in the WSAR proposes to examine use of anthropogenic features in relation to non-peatland and riparian habitats viewed at different scales (A.D.M. Latham, 2004, University of Alberta, Pers. comm.).

3.4.2. Avoidance of areas associated with open water

Avoidance of water/wet non-peatland vegetation in summer is not surprising as wolves are thought to use waterways as travel corridors (Seip 1992, Stuart Smith *et al.* 1997), and caribou have shown avoidance of riparian areas (Oberg 2001, A.D.M. Latham, 2004, University of Alberta, Pers. comm.). As the water/non-peatland wet vegetation class possessed both open water and wet vegetation (i.e. riparian areas), there may have been differences in the avoidance of these two sub-classes in the areas of different activity. There are many small lakes throughout the study area, but it is in the area of contiguous peatland and lowest industrial activity where riparian areas are more common. Also, the open fen habitat class contained sedge meadows which typically contain no trees and are also closely associated with open water and waterways (Halsey and Vitt 1997). This habitat class may also be selected by moose (A.D.M. Latham, 2004, University of Alberta, Pers. comm.), making it an area used by wolves and thus avoided by caribou.

3.4.3. Habitat selection and validity of models used

The order of habitat preference by woodland caribou quantified by Anderson (1999) was not completely supported by my study, as I found open bog was selected with greater strength than both treed bog classes, rather than treed peatland being selected over all other habitat classes as Anderson (1999) found. However, the overall selection of peatland habitat with treed cover, and avoidance of non-peatland habitat was similar in both studies. The differences in order of selection observed are likely due to differences in habitat classes used. The AVI used in my study listed <30% as the lowest denomination of forest coverage, where Anderson's (1999) delineation of "open" considered areas with < 6% tree cover to be "open", a difference which makes direct comparison of this class difficult. An "open bog" class was not used by Anderson (1999) as <6% treed bog was a very rare class, and was not considered as a separate category. However, a lower limit of 30%, still describes areas with limited tree coverage, and as other peatland coverage schemes use 25-30% to distinguish habitat classes (National Wetlands Working Group 1988, 1997), I believe 30% does not erroneously describe an "open" habitat. Further, the open fen class also contained sedge meadows which contain no trees, and provide little cover and lichen forage, whereas an open bog still may.

The purpose of this study was not to construct the most parsimonious model to predict habitat selection by woodland caribou (Boyce *et al.* 2002, Nielsen *et al.* 2002) but rather, using recognized habitat classes, compare habitat selection between areas of differing industrial activity. With removal of classes such as open fen and water/non-peatland wet vegetation, which had infrequent statistical avoidance or selection, it is conceivable that the predictive ability of models would have been greater. Also, Garshelis (2000) argues that though Manly *et al.*'s (1993) technique is believed not to have its measures of preference change with changes in density of a resource, availability of a resource and its interspersion and juxtaposition may in fact have an influence. That is, a relatively common habitat, though heavily used, may be viewed as being selected less based primarily on the overall abundance. For example, caribou locations fell in treed bog habitat over 30% of the time versus 5-10% in open bog habitat, even though the RSF analysis indicated that open bog was more highly selected than treed bog. Though definition of habitat may affect habitat selection outcomes (Garshelis 2000), I believe focus should remain on the finding that that avoidance of non-peatland and selection for treed-peatland habitats is maintained by caribou in the area of high industrial activity, especially during the winter seasons.

3.4.4. Management considerations

A number of studies have examined the effect of human activity on caribou (see Dyer *et al.* 1999 for extensive review), with many behavioural responses of caribou considered to be negative. Caribou may move away from point sources of disturbance.

show increased energy expenditures, delay or fail to cross linear structures, move away from areas of intense development, and face direct mortality though vehicle collisions (see Wolfe *et al.* 2000 for additional review). However, caribou can also show habituation to industrial features, the activities associated with them, and may show a high degree of resilience to habitat loss and disturbance (see Wolfe *et al.* 2000 for review). It is possible that caribou in areas of high industrial activity have selected areas at a home range scale and within the home range with enough quality habitat to remain in areas viewed as lacking a large proportion of functional habitat. As caribou may not abandon areas post-natural disturbance (Dunford 2003), perhaps once caribou have selected peatland complexes to reside in they may be reluctant to leave, possibly due to strong avoidance of large areas of non-peatland habitat (Stuart-Smith *et al.* 1997), and the predation risks that moving to a novel landscape may incur (Stamps 1995, Nicholson *et al.* 1997, Kitchen *et al.* 2000, Schaefer *et al.* 2000).

If caribou remain within preferred peatland habitats in areas of high industrial activity then displacement into undesirable habitats may not be as great of a concern for management initiatives, as caribou exposed to simulated industrial exploration did not significantly alter the proportion of time they spent feeding (Bradshaw *et al.* 1997). Though functional habitat loss has been shown in modeling exercises to be of paramount importance (Weclaw 2001), I would suggest that predator access may be of more concern for future caribou conservation. One can speculate that caribou remaining in habitats traditionally believed to provide spatial segregation from alternative prey and predators may in fact be in areas currently lacking that function due to anthropogenic access. As the area of high industrial activity is also located in a landscape composed of more highly fragmented non-peatland habitat, caribou avoiding industrial features and activities may remain in smaller peatland patches, potentially increasing their local densities (Nellemenn and Cameron 1998) moreso than caribou in the large contiguous peatland complex would. This presents a situation where an increased encounter rate with predators may occur, even though behaviourally, caribou are maintaining their anti-predator strategy.

Future analyses should examine the movements of caribou between peatland patches in a matrix of non-peatland patches of different sizes and local densities. Movements of caribou have been modeled to describe behaviours, but a link to underlying habitat or industrial activities has not been made (Franke *et al.* 2004). I further suggest that examining movements in relation to the location of industrial features could indicate what decisions are made during the approach towards industrial features, and as to what habitat selected during their movements while displaying avoidance. These behaviours could be of critical importance when dealing with the barrier effects which roads may create (Dyer *et al.* 2002), and when deciding where to most effectively employ mitigative measures such as pipeline and road crossings (Suncor Energy Inc. 2004).

3.5. Conclusions

Based on resource selection function analysis, woodland caribou in the West Athabasca Caribou Range exposed to high levels of industrial activity do not select non-peatland habitat, nor did they use preferred peatland habitat less than caribou in the area of low industrial activity, notably during the winter seasons when industrial activity is highest. Though this study has provided insight into the selection and/or avoidance of habitats in the WSAR, a link to the survival and reproduction of the caribou in the different areas of disturbance would demonstrate if caribou remaining in areas of high activity within preferred habitats show lower calving success, or calf or adult survival. I believe this link to the demography of caribou will provide an indication of where caribou are subject to increased risk, and if the combination of access and habitat, rather than access alone is of greatest importance in conserving this threatened species.

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Table 3-1. Definition of habitat classes used in resource selection function model classified via the Alberta Wetland Inventory standards applied to the Alberta Vegetation Inventory.

Variable	*Definition*	**Abbreviation**
Non-peatland	Vegetated land with an ecological moisture regime listed as dry or mesic, a crown closure class of >30%, dominant tree species *Populus tremuloides, Populus balsamifera, Picea glauca, Pinus banksiana*, and anthropogenic land. This class is considered to regularly avoided by woodland caribou (Bradshaw *et al.* 1995, Stuart-Smith *et al.* 1997, Schneider *et al.* 2000, Dyer *et al.* 2001).	NP
Treed Bog	Vegetated land with an ecological moisture regime listed as wet, a crown closure class of >30%, trees limited to *Picea mariana*	TB
Treed Fen	Vegetated land with an ecological moisture regime listed as wet, a crown closure class of >30%, trees limited to some combination of *Picea mariana, Larix laricina, Betula sp.* and *Salix sp.*	TF
Open Bog	Vegetated land with an ecological moisture regime listed as wet, a crown closure class of <30%, trees limited to *Picea mariana* and/or presence of bryophyte cover.	OB
Open Fen	Vegetated land with an ecological moisture regime listed as wet, a crown closure class of <30%, trees limited to some combination of *Picea mariana, Larix laricina, Betula sp. Salix sp.* and/or presence of grammenoid cover.	OF
Water/Non-peatland wet vegetation	Naturally non-vegetated land classified as lakes, rivers of flooded beaver ponds, and vegetated land with an ecological moisture regime listed as wet, and with presence of undifferentiated shrubs and/or herbaceous forbes.	W/NPWV
Distance to non-peatland	Measure of distance to all (NP and W/NPWV) non-peatland polygons; categorized as a continuous distance measure ranging from 1-6 (see Table 3-2 for detail).	DIST

Table 3-2. Definition of distance of caribou locations to non-peatland rank. Distance measures used were similar to definition of distance buffers around industrial features used by Dyer *et al.* (2001).

Measure	Proximity to non-peatland polygon
1	Over 1000m away from perimeter of non-peatland polygon
2	Between 500-1000m of perimeter of non-peatland polygon
3	Between 250-500m of perimeter of non-peatland polygon
4	Between 100-250m of perimeter of non-peatland polygon
5	Within 100m of perimeter of non-peatland polygon
6	Within perimeter of non-peatland polygon

Table 3-3. Number of seasonal home range polygons in each industry class for each season during 1998/1999. Number of individual caribou used to generate seasonal home ranges in parenthesis.

	Industry class		
Season	Low	Medium	High
Late Winter	10 (9)	13 (12)	19 (15)
Calving	20 (16)	2 (2)	19 (15)
Summer	13 (11)	3 (2)	13 (11)
Rut	9 (8)	4 (3)	11 (8)
Early Winter	7 (6)	4 (2)	10 (7)

Table 3-4. Percentage of caribou locations in each class of industrial activity in each season found greater than 250m away from non-peatland habitat.

	Industry class		
Season	Low	Medium	High
Late Winter	60.94	76.98	67.55
Calving	90.19	98.15	80.40
Summer	77.47	82.75	70.58
Rut	77.24	93.93	74.65
Early Winter	65.56	83.31	70.38
Mean	74.28	87.62	72.71

Table 3-5. K-fold cross validated Spearman-rank correlations (rho) between RSF bin ranks and area-adjusted frequencies for the average test sets.

	Industry class		
Season	Low	Medium	High
Late Winter	0.59	0.64	0.64
Calving	0.57	0.67	0.79
Summer	0.56	0.39	0.50
Rut	0.82	0.67	0.72
Early Winter	0.52	0.59	0.76
Mean	0.61	0.59	0.68

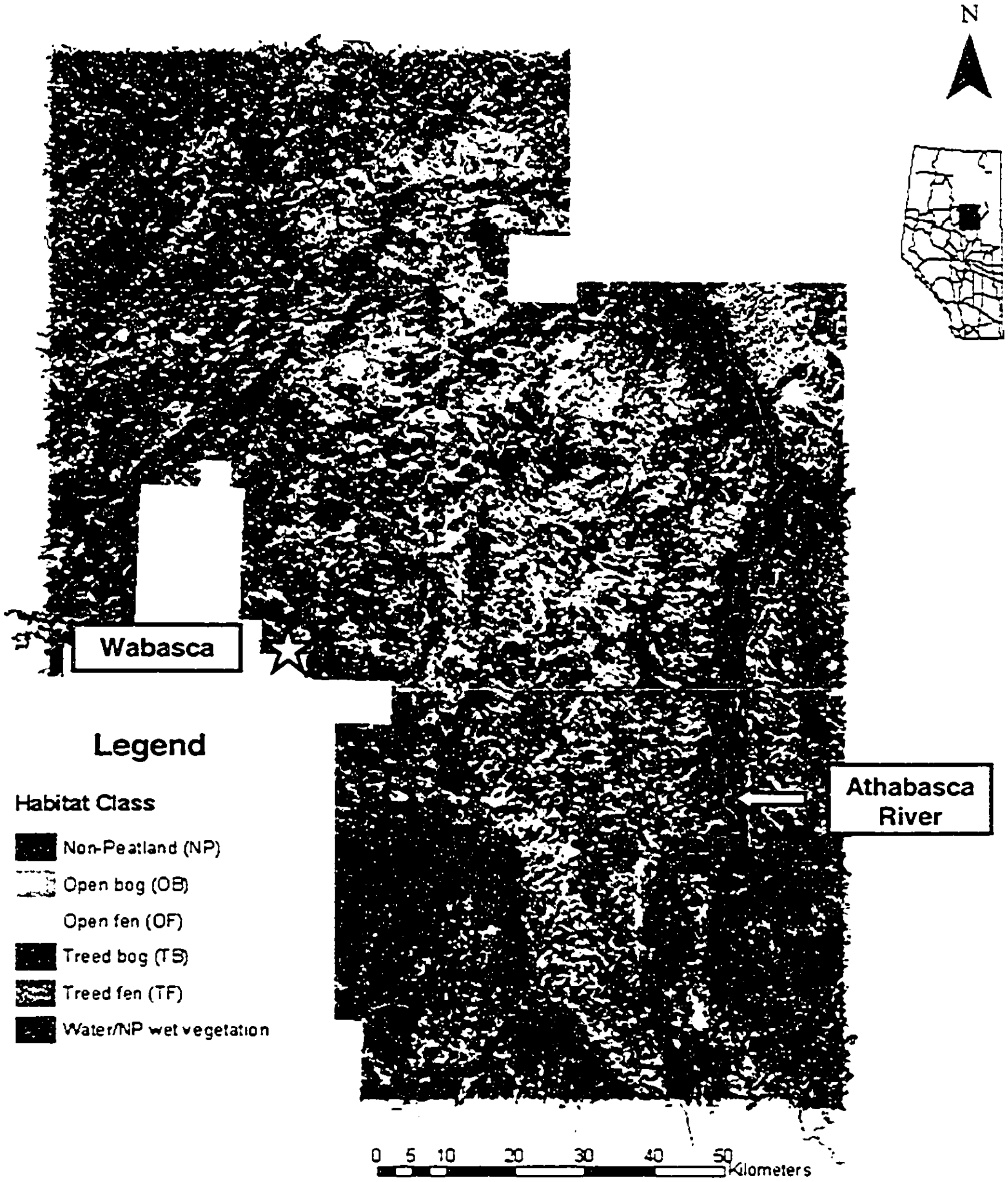

Figure 3-1. Study area located in the West Athabasca Caribou Range (WSAR) showing six habitat classes used in resource selection function analysis. Habitat classes are based on Alberta Vegetation Inventory (AVI) polygons re-classified according to Alberta Wetland Inventory (AWI) definitions.

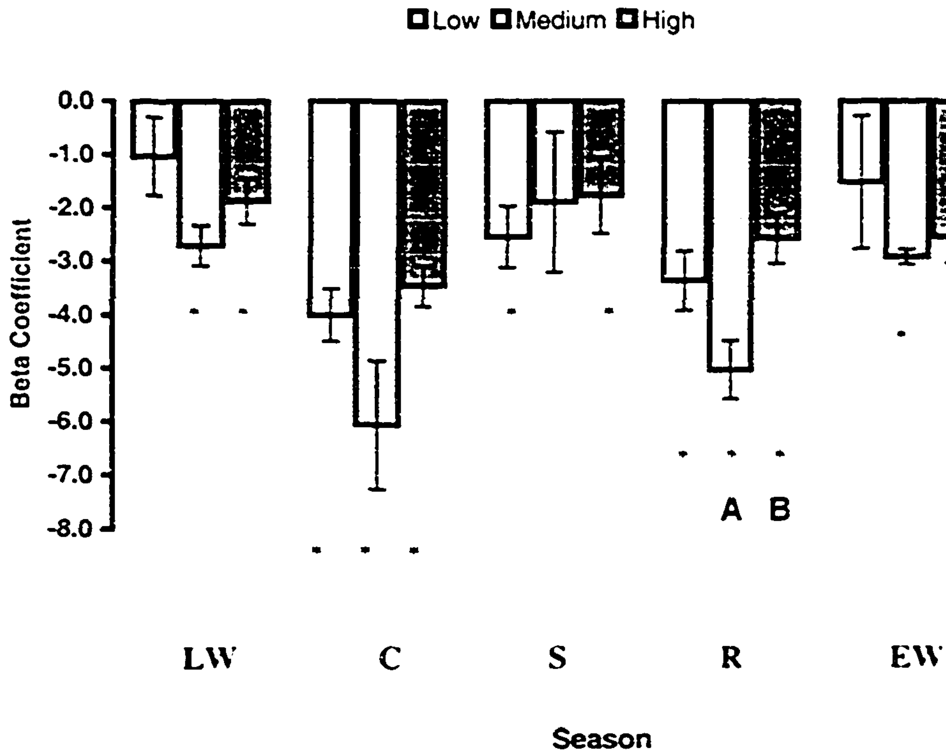

Figure 3-2. Pattern of selection of non-peatland habitat by woodland caribou within the West Side Athabasca Region (WSAR) in areas of varying industrial activity (Low, Medium, and High) during five seasons (Late Winter, Calving, Summer, Rut, and Early Winter) between 1998-1999. Beta coefficients below zero indicate proportionally less use of habitat than availability (implying avoidance). Error bars represent one standard error, and asterisks show significant differences between used and available habitat. Different letters indicate significant differences between industry classes within a season based on no overlap of 95% confidence intervals. Refer to Table 3-3 for sample size in each area of industrial activity in each season.

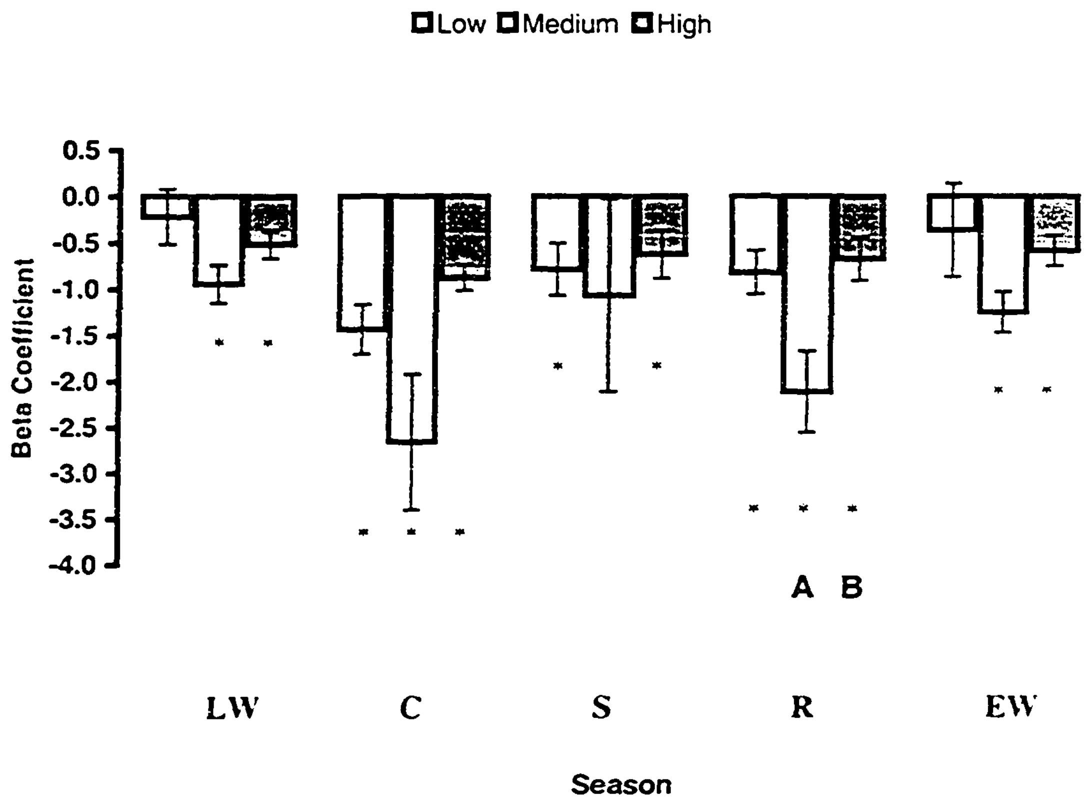

Figure 3-3. Pattern of selection for proximity (distance) to non-peatland areas by woodland caribou within the West Side Athabasca Region (WSAR) in areas of varying industrial activity (Low, Medium, and High) during five seasons (Late Winter, Calving, Summer, Rut, and Early Winter) between 1998-1999. Beta coefficients below zero indicate proportionally less use of habitat than availability (implying avoidance). Error bars represent one standard error, and asterisks show significant differences between used and available habitat. Different letters indicate significant differences between industry classes within a season based on no overlap of 95% confidence intervals. Refer to Table 3-3 for sample size in each area of industrial activity in each season.

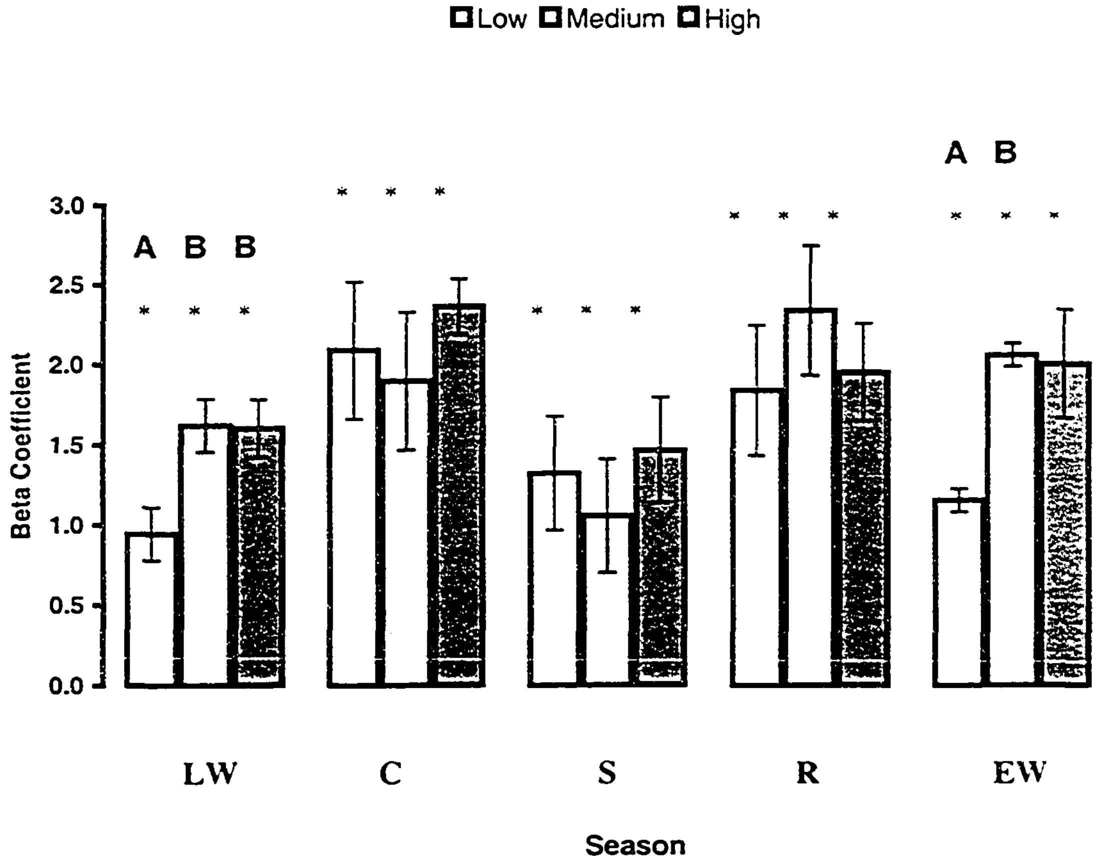

Figure 3-4. Pattern of selection of open bog habitat by woodland caribou within the West Side Athabasca Region (WSAR) in areas of varying industrial activity (Low, Medium and High) during five seasons (Late Winter, Calving, Summer, Rut, and Early Winter) between 1998-1999. Beta coefficients above zero indicate more use of habitat than availability (implying selection). Error bars represent one standard error, and asterisks show significant differences between used and available habitat. Different letters indicate significant differences between industry classes within a season based on no overlap of 95% confidence intervals. Refer to Table 3-3 for sample size in each area of industrial activity in each season.

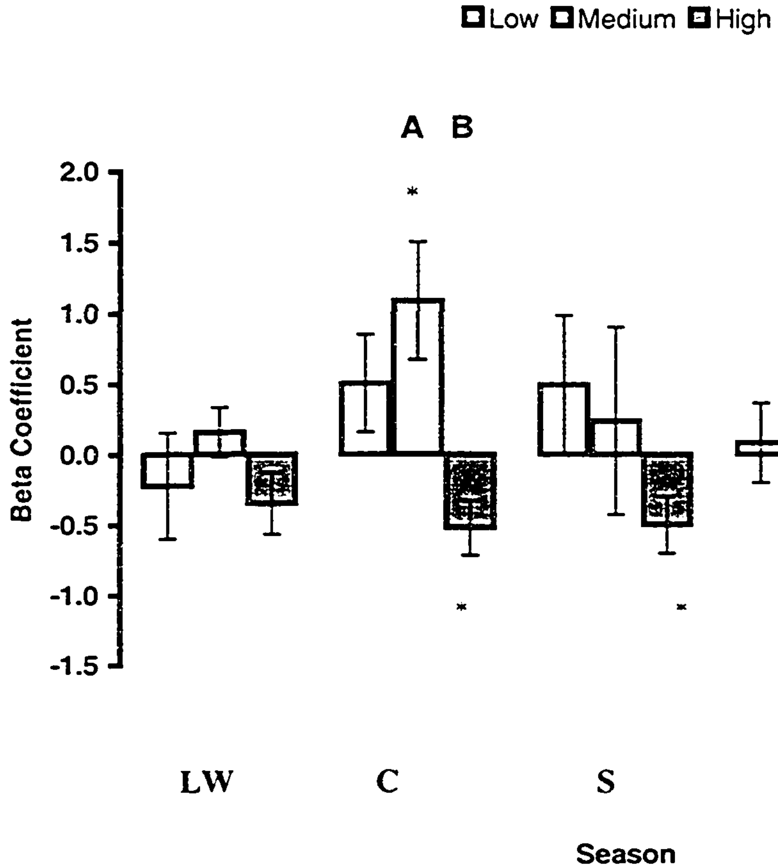

Figure 3-5. Pattern of selection of open fen habitat by woodland caribou within the West Side Athabasca Region (WSAR) in areas of varying industrial activity (Low, Medium, and High) during five seasons (Late Winter, Calving, Summer, Rut, and Early Winter) between 1998-1999. Beta coefficients below zero indicate proportionally less use of habitat than availability (implying avoidance), while coefficient above zero indicate more use of habitat than availability (implying selection). Error bars represent one standard error, and asterisks show significant differences between used and available habitat. Different letters indicate significant differences between industry classes within a season based on no overlap of 95% confidence intervals. Refer to Table 3-3 for sample size in each area of industrial activity in each season.

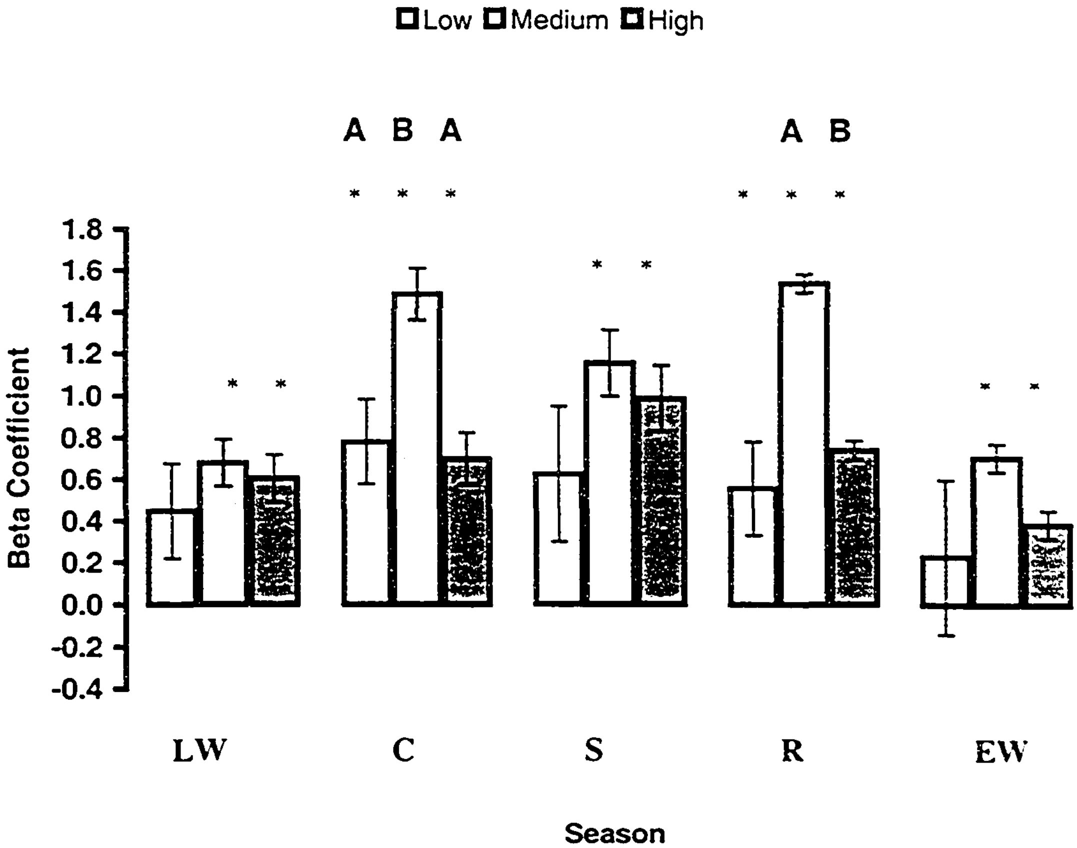

Figure 3-6. Pattern of selection of treed bog by woodland caribou within the West Side Athabasca Region (WSAR) in areas of varying industrial activity (Low, Medium and High) during five seasons (Late Winter, Calving, Summer, Rut, and Early Winter) between 1998-1999. Beta coefficients below zero indicate proportionally less use of habitat than availability (implying avoidance). Error bars represent one standard error, and asterisks show significant differences between used and available habitat. Different letters indicate significant differences between industry classes within a season based on no overlap of 95% confidence intervals. Refer to Table 3-3 for sample size in each area of industrial activity in each season.

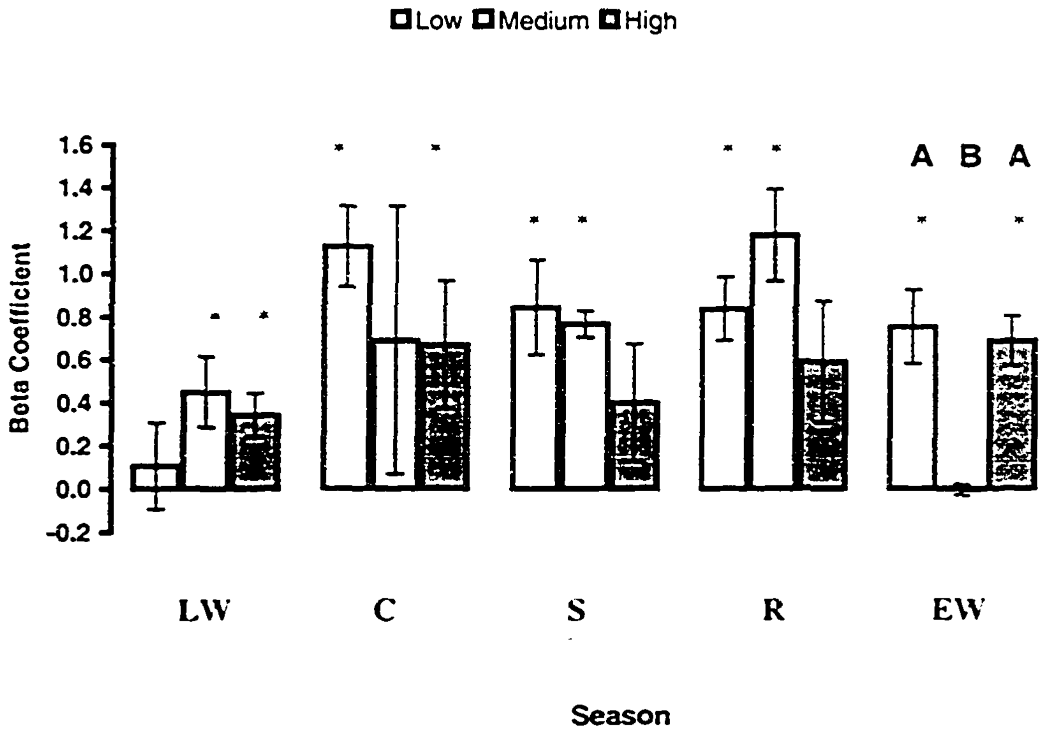

Figure 3-7. Pattern of selection of treed fen by woodland caribou within the West Side Athabasca Region (WSAR) in areas of varying industrial activity (Low, Medium, and High) during five seasons (Late Winter, Calving, Summer, Rut, and Early Winter) between 1998-1999. Beta coefficients below zero indicate proportionally less use of habitat than availability (implying avoidance), while coefficient above zero indicate more use of habitat than availability (implying selection). Error bars represent one standard error, and asterisks show significant differences between used and available habitat. Different letters indicate significant differences between industry classes within a season based on no overlap of 95% confidence intervals. Refer to Table 3-3 for sample size in each area of industrial activity in each season.

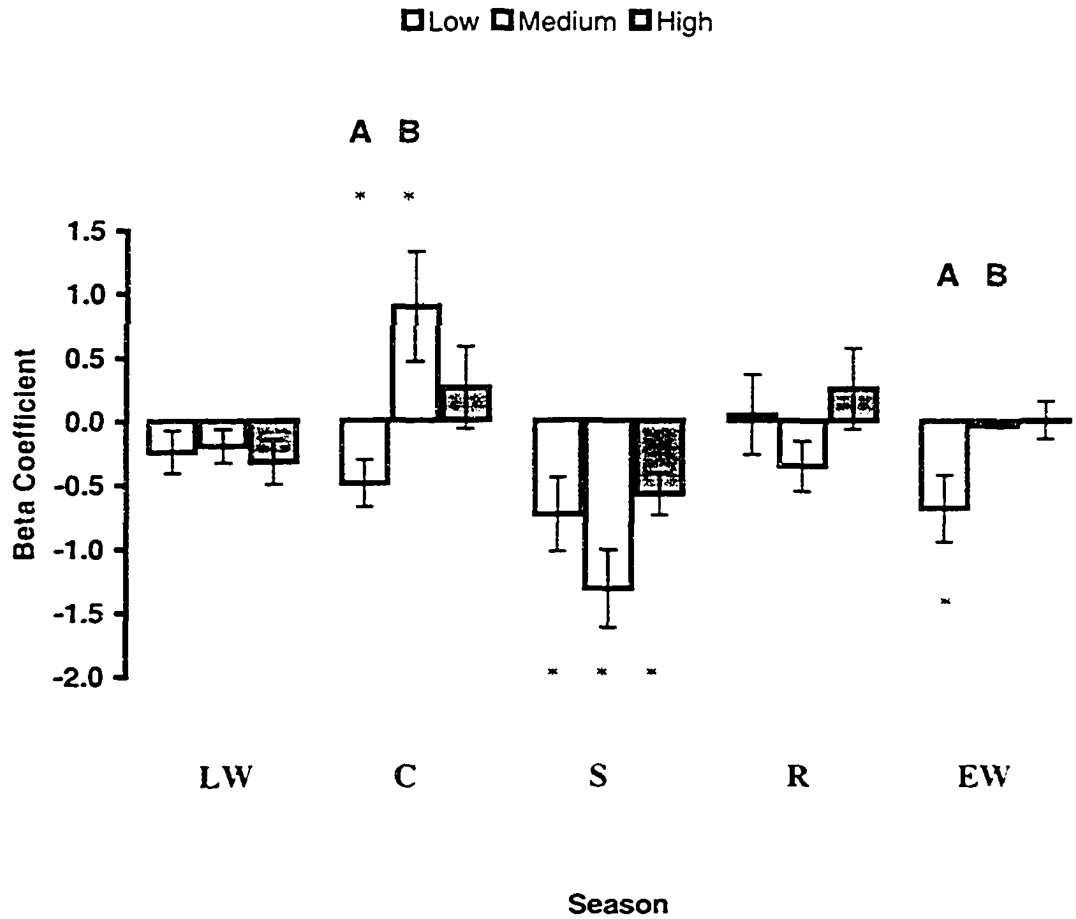

Figure 3-8. Pattern of selection of open water and wet non-peat areas by woodland caribou within the West Side Athabasca Region (WSAR) in areas of varying industrial activity (Low, Medium, and High) during five seasons (Late Winter, Calving, Summer, Rut, and Early Winter) between 1998-1999. Beta coefficients below zero indicate proportionally less use of habitat than availability (implying avoidance), while coefficient above zero indicate more use of habitat than availability (implying selection). Error bars represent one standard error, and asterisks show significant differences between used and available habitat. Different letters indicate significant differences between industry classes within a season based on no overlap of 95% confidence intervals. Refer to Table 3-3. for sample size in each area of industrial activity in each season.

Chapter 4. General conclusions and implications

4.1. Research summary and conclusions

Woodland caribou in the West Athabasca Caribou Range did not significantly change the size of their annual home range with an increase in industrial activity, nor did they abandon an area that became subject to the greatest increase in industrial activity. Caribou also remained in areas of high industrial activity on a seasonal basis, and showed no significant differences in their home range size between areas of differing industrial activity in each season. The proportion of peatland within home ranges emerged as a significant predictor of home range size on an annual and seasonal basis, therefore it may be landscape features which influence woodland caribou home range size and overlap more than direct and indirect impacts on habitat caused by the petroleum sector. Further, caribou in the area of highest industrial activity consistently avoided habitats considered less suitable, notably during the winter seasons when industrial disturbances were highest. This is in contrast to caribou in an area of low activity, which did not avoid non-peatland habitat in early and late winter. These data provide no convincing evidence that caribou remaining in areas of high industrial disturbance move into lesser quality habitats as a result of their previously documented avoidance of features and associated activities (Dyer *et al.* 2001). However, no comparison of adult survival, fecundity or calf survival was made between caribou found in the areas of different industrial activity, so it remains uncertain if caribou in the high area of industrial activity have decreased fitness as a result of their decision to remain in an area possessing linear access which may be used by predators.

4.2. Considerations for future woodland caribou conservation

It is an understatement to indicate that Alberta's economy relies on the petroleum sector, as in 2000 Alberta exported over 35 billion dollars in oil, gas, and petroleum byproducts (Schneider 2002). Globally, Alberta ranks second (after Saudi Arabia) in proven crude oil reserves which are found primarily in the oil sands deposits located under the boreal forest in the northeast of the province (Alberta Department of Energy 2003). The expansion of existing projects and implementation of future oil sands programs currently slated for development (Alberta Economic Development 2004) will make limiting industrial impacts a daunting task, as thresholds for development of features such as seismic lines have likely already been surpassed in many areas of the province (Schneider 2002).

If woodland caribou are not avoiding an area of intense industrial activity at the level of their home range in the West Athabasca Caribou Range, one *could* argue that they have adapted to industrial activities at a large spatial scale, and *may* actually tolerate a certain degree of industrial expansion. Though woodland caribou in the WSAR have displayed avoidance of industrial features and associated activities at locations within their seasonal home ranges (Dyer *et al.* 2001), caribou may also display limited avoidance of similar features in different ranges (Oberg 2001) and caribou have also been observed to display what many in industry consider habituation, and there have been questions over use of the term "avoidance" (Ernst Environmental Services 2003). Though there is room for debate over use of the term "avoidance" vs. a more complete description of caribou behaviour such as "reduced use," semantics should not impede application of possible strategies for caribou conservation, or deflect concerns over continued survival of woodland caribou in Alberta.

Though accurate estimates for the total population size of woodland caribou in Alberta are not available, there is a general consensus that caribou are declining in the province, though clarification of what the main mechanism is still being examined (Dzus 2001, Weclaw 2001, McLoughlin *et al.* 2003). If wolves and other predators are using industrial access effectively (James 1999, Dyer *et al.* 2001) then predation may be viewed as the proximate limiting factor of caribou populations (McLoughlin *et al.* 2003). Further, if predators and alternative prey species have increased their infiltration of peatland habitat (A.D.M. Latham, 2004, Pers. comm.), then declines of caribou in the province may continue as access continues to expand. Thus, even though caribou may tolerate areas of industrial activity at the level of the home range, they may still remain in areas with potentially higher risk of predation. Conservation strategies, even if experimental in nature, should continue to examine the possible link between industrial activities, predation, and population declines, with the hope that implementation of such strategies will confirm causal links, and provide a reverse in caribou population trends (McLoughlin *et al.* 2003).

Currently, models such as ALCES (Alberta Landscape Cumulative Effects Simulator, Forem Technologies 2002) and REMUS (Welcaw and Hudson 2004) are being used to identify key elements that influence caribou population dynamics, and provide simulations describing how landscape changes can affect caribou survival (Weclaw 2001). Though still hypothetical, the outputs and management recommendations from these models assist in the development of conservation measures and inform the decision making process, as the models utilize prior caribou research and will continue to be refined with collection of additional data (Weclaw 2001). In conjunction with the development of conservation strategies, review and reform of government policy in relation to industry practices must also continue (Dyer *et al.* 2001, Dzus 2001, Schneider 2002, McLouglin *et al.* 2003), as there is a lack of information on thresholds for cumulative impacts (Schneider 2002). Exploration of the efficacy of zoning and development of true protected areas should also continue, but this process must also include a political resolve to implement the recommendations (Gerrand 1997, Schneider 2002).

There are instances where the petroleum industry has committed itself to the concept of mitigating negative effects of practices on woodland caribou (McLoughlin *et al.* 2003) through advances in the implementation of so called "best practices," including the use of narrow seismic lines, reclamation of older seismic lines and wells, and reduced road infrastructure (Schneider 2002, Szkorupa 2002). Though the efficacy of some practices (such as narrow 1.75m seismic techniques) remains to be tested rigorously, the fact that some forward-thinking companies have implemented new technologies, incurring economic and procedural benefits (A. Cicoria, 2003, Lormel Consultants, Pers. comm., Suncor Inc. 2004), lends credence to the belief that some in industry may utilize options that can minimize cumulative effects (McDonald 2001, Weclaw 2001, Schneider 2002). However, despite such initiatives, the tenure system allowing petroleum exploration and extraction will continue to make efforts to limit industrial impacts a substantial challenge, as provisions to tenure agreements allow activities to continue even in protected areas (Schneider 2002).

Public concern over the use of the boreal forest can change government reluctance to implement possible land-use reforms (Schniedcr 2002). The "Alberta advantage" has afforded this province a privileged position, and I hope our surfeit has not led to the demise of the woodland caribou, or made recovery of the woodland caribou and it's habitat a goal too complex to achieve readily. Research and conservation strategies alone will not prevent extirpation of the woodland caribou (Dzus 2001, McLoughlin *et al.* 2003), for implementation of effective techniques for managing habitat and caribou populations are linked to a political will to do so. This political will can be influenced by societal values, which through public determination *can* become a legislative reality (Schneider 2002). Though I continue to question a great many things linked to petroleum extraction, both in Canada and internationally, I hope the will to seriously consider our methods and their lasting repercussions does exist. It remains to be seen if such reflection can translate into action towards the conservation of woodland caribou, or if the Taiga will remain subject to the Alberta's land use practices and the to the mandates for continued expansion which they have been awarded.

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