

**The habitat preferences of Newfoundland woodland
caribou across range components and scales:
implications for management**

Issac Hébert

A Thesis
in
The Department
of
Biology

Presented in Partial Fulfillment of the Requirements
For the Degree of Master of Science (Biology) at
Concordia University
Montreal, Quebec, Canada

September 2012

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CONCORDIA UNIVERSITY

School of Graduate Studies

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Signed by the final examining committee:

<u>Dr. Emma Despland</u>	<u>Chair</u>
<u>Dr. James Grant</u>	<u>Examiner</u>
<u>Dr. Jochen Jaeger</u>	<u>Examiner</u>
<u>Dr. Pascale Biron</u>	<u>External Examiner</u>
<u>Dr. Robert B. Weladji</u>	<u>Supervisor</u>

Approved by Dr. Selvadurai Dayanandan

Chair of Department or Graduate Program Director

September 7, 2012 Brian Lewis

Dean of Faculty

ABSTRACT

The habitat preferences of Newfoundland woodland caribou across range components and scales: implications for management

Issac Hébert

An increase in predation following forestry is thought to be the main cause for the decline of woodland caribou (*Rangifer tarandus caribou*). Identifying and protecting important habitats within caribou ranges can be used for conservation of this species. In this thesis, we constructed core areas of Newfoundland woodland caribou using both an objective and an arbitrary method, identified important habitats in different spatial and temporal components of caribou ranges, and determined if habitat preference and the proportion of cutovers changed across the range components. In addition, we determined the stand characteristics preferred by the caribou within coniferous forests (CF) and whether the cutovers regenerate into forests of similar value as those preferred by caribou. We found that the core areas defined using an arbitrary method was half the size of the core areas defined using the objective method and bogs and CF had the highest selectivity index across all of the range components. The preference for each habitat and the proportion of cutovers changed across the temporal yet not the spatial components of the range. Within the core areas, CF were used in similar proportion as cutovers however, the CF used by the caribou did not share the same characteristics with any of the cutover age categories. These results suggest that the use of arbitrary cores may underestimate the core areas and that caribou have seasonal habitat requirements. In addition, caribou utilize both cutovers and CF despite each habitat having different stand characteristics.

ACKNOWLEDGEMENTS

I would like to thank the individuals that without their support this thesis would not have been possible. First, I would like to thank my supervisor, Dr. Robert Weladji, for his guidance, support, expertise and the helpful conversations that has encouraged me all through my M.Sc. degree. I thank my committee members Dr. Jochen Jaeger and Dr. Jim Grant for their comments and recommendations throughout the stages of this degree and I give many thanks to the people and staff of the Newfoundland and Labrador government who have made this thesis possible through funding, support and the provision of data.

Specifically, I would like to thank Dr. Blair Adams for his guidance and assistance while in Newfoundland, Dwayne Goulding for his help with geographical information and Paul Saunders and Jonathan Strickland for their expertise, support and advice. I thank my field assistant Stacy Thistle for accompanying me on those long and at times treacherous drives through the bush and for all the hard work while collecting data. My lab members have given much inspiration, guidance, and at times necessary distractions which has been a great help and for that I thank you Guillaume, Natalka and Sacha.

To my partner, James Couture, I would like to thank your support and for lending your ear, without the many hours of listening to me jabber on about caribou and allowing me to repeatedly practice my presentations I would not be where I am today. Thanks for being there when times were hard and for helping me find the right balance between work and fun. I also would like to thank RB and Snorb for their constant support.

Amanda, you have my appreciation for helping with the hard to reach articles and Lacey, thanks for constant support throughout it all. Finally, I would like to thank my family and friends for their interest and support and Arcade Fire for keeping me sane.

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GENERAL INTRODUCTION

The state of woodland caribou (*Rangifer tarandus caribou*) in Canada is concerning because of drastic declines of their extent and numbers (Vors and Boyce 2009, Festa-Bianchet et al. 2011) which has given them their status as threatened in Canada (COSEWIC 2002). Of increasing concern is the Newfoundland woodland caribou population, which comprises 80% of all the woodland caribou in North America, because of recent declines (60% since 1990s) in the population despite their status being not-at-risk (Trindale et al. 2011). The major cause for the decline of woodland caribou in North America as well as Newfoundland is elevated predation pressure (Festa-Bianchet et al. 2011, Trindale et al. 2011). Therefore, increasing development in the boreal forest is a concern for all woodland caribou because of the direct consequences of habitat loss through habitat alteration yet more importantly the increase in predation which follows anthropogenic disturbances (Vors and Boyce 2009). The current most prevalent method of habitat alteration in the boreal forest is forestry (Niemela 1999, Gagnon and Morin 2001).

The maintenance of important habitats for woodland caribou is an important strategy for their conservation and management since they rely on certain habitats as refuges from predators and avoid other habitats perceived as risky (Mahoney and Virgl 2003, Fisher and Wilkinson 2005, Courbin et al. 2009, Hins et al. 2009, Bowman et al. 2010). However, the habitat preferences and life requirements of caribou can vary with space and time (Rettie and Messier 2000, Racey and Arsenaault 2007). Range components can be used in order to focus habitat selection studies and conservation efforts within important areas of the range and during sensitive time periods (Racey and Arsenaault

2007). For example, the core area is a spatial component of the range that is intensively used and likely contains valuable resources such as home sites, refuges, and dependable food sources (Samuel et al. 1985 & Boitani and Fuller 2000). Temporal ranges are also important for management of woodland caribou since their habitat preferences, resource requirements, sensitivity to disturbances, and predation risk have been shown to vary across seasons (Rettie and Messier 2000, O'Brien et al. 2006, Racey and Arsenault 2007, Briand et al. 2009, Hins et al. 2009). Thus, identifying and preserving crucial habitats in these range components can be used to reduce the impacts of forestry and to allocate efforts within more sensitive components.

Woodland caribou have shown differences in habitat selection across North America as well as with their responses to varying levels of forest harvesting. However, the avoidance of recently harvested areas is a common result with most studies (Chubbs et al. 1993, Mahoney and Virgl 2003, Courtois et al. 2008, Hins et al. 2009, Bowman et al. 2010). The avoidance of cutovers is a result of the caribou's behaviour to avoid actual and perceived predation risk (Cumming et al. 1996, Mahoney and Virgl 2003, James et al. 2004, Bowman et al. 2010). For instance, caribou avoid potential predation risk by avoiding predators such as black bears (*Ursus americanus*), wolves (*Canis lupus*) and coyotes (*Canis latrans*) who utilize cutovers (Kays et al. 2008, Mosnier et al. 2008, Boisjoly et al. 2010, Bowman et al. 2010). Caribou also avoid alternative prey (perceived risk) such as moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) (Cumming et al. 1996, Rettie and Messier 1998, James et al. 2004) because these animals attract and cause a numerical response to some predators.

However, cutovers are not forever avoided by caribou and reoccupation gradually increases as cutovers begin to develop similar characteristics as the original forests (Fisher and Wilkinson 2005). In addition, strong site fidelity (Faille et al. 2010) and the loss of quality habitat providing both forage and refuges may cause caribou to seek resources in harvested landscapes (Briand et al. 2009, Hins et al. 2009). Understanding the habitat preferences of woodland caribou within coniferous forests can be used by managers to harvest less favourable forests reducing the need for caribou to seek riskier harvested areas to satiate their dietary needs.

The purpose of this thesis is to determine the habitat preferences within different components of woodland caribou ranges and to determine if cutovers develop into the coniferous forests preferred by caribou. More specifically, in the first chapter, we used the location of 12 GPS collared caribou to construct spatial and temporal range components to determine if the habitat preferences or proportion of cutovers varied across the range components. For this chapter, we used habitat composition in order to predict that the amount of refuges and risky landscapes available within the components. We also compared the preference for each habitats and the proportion of cutovers between an arbitrary and objective method used to delineate the core areas. In the second chapter, we used the location information of the woodland caribou to determine which habitats were disproportionately used by the caribou within the core areas. We also obtained fine-scale stand characteristics of coniferous forests and cutovers to determine if caribou had a preference for certain stand characteristics within coniferous forests. These stands characteristics were also used to determine whether cutovers develop the same stand characteristics as the coniferous forests preferred by the caribou.

Chapter 1:

The effect of woodland caribou range components on habitat selection and forestry activity

Issac Hébert¹, Robert Weladji¹, and Blair Adams²

¹Department of Biology, Concordia University, 7141 Sherbrooke St W., Montreal, QC,
H4B 1R6, Canada

²Department of Natural Resources, Gander, CA

Abstract

Woodland caribou (*Rangifer tarandus caribou*) across North America are in peril mainly due to forestry and the concomitant increase in predation augmenting the need for sustainable management practices. Identifying and protecting core areas (CA) as well as important habitats can be used to lessen the impact of forestry. We determined how habitat selection and forestry activity differ between spatial components (different CA definitions and use intensities of the home range) and temporal components (seasonal CA of caribou). Objective CA's were defined using the Area Independent method and arbitrary cores were predefined using the 50% density contour. We used fixed-kernel density to create different spatial components for the calving season for 12 GPS collared female caribou and objective CA's were created for each season (calving, post calving, rut and winter). Habitat preferences were assessed using the Manly selectivity index and the proportion of cutovers was used to infer the amount forestry. Mixed models were conducted for each CA, use intensity and season. We found that the arbitrary CA was half the size of the objective CA and neither habitat preference nor the amount of cutovers changed between the spatial components while the proportion of cutovers varied with seasons. Bogs and coniferous forests had the highest selectivity indices in all range components. These results suggest that the use of arbitrary cores may underestimate intensively used areas and that the seasonal components of the range should be considered when developing management plans.

Introduction

The status of woodland caribou (*Rangifer tarandus caribou*) across North America is concerning because of major declines and local extirpations (Vors et al. 2007). The primary cause for the decline is the paired impacts of habitat loss and the concomitant increase in predation risk (Wittmer et al. 2005, Vors and Boyce 2009, Festa-Bianchet et al. 2011). Caribou reduce these impacts by finding refuge from predators in coniferous forests and by avoiding risky habitats such as harvested landscapes and roads (Mahoney and Virgl 2003, Fisher and Wilkinson 2005, Courbin et al. 2009, Hins et al. 2009, Bowman et al. 2010) making conservation and the maintenance of caribou habitats an important management strategy.

The National Boreal Caribou Technical Steering Committee in Canada recommends the use of spatial and temporal range components of caribou ranges for habitat analyses to better understand the critical habitat requirements and allow for targeted management and conservation (Racey and Arsenault 2007). Spatial range components include the entire range of the caribou population, intensively used areas (core areas), and calving sites while temporal components include seasonal ranges. Each component reflects different life requirements; for example, core areas reflect selection based on habitat quality and the seasonal components reflect the change in availability of forage and vulnerability to predation (Rettie and Messier 2000, Racey and Arsenault 2007). Thus, identifying and preserving important habitats in these range components can be used to reduce the impacts of forestry.

Though each spatial component should be considered for conservation (Racey and Arsenault 2007), core areas are deemed important because they are areas intensively used

by definition (Samuel et al. 1985, Seaman and Powell 1990, Powell 2000, Schindler et al. 2007) and contain valuable resources (Powell 2000, Racey and Arsenault 2007). The most widely used method for designating core areas is to arbitrarily choose the area within the home range, usually predefined by the 50% density contour, as per the review by Laver and Kelly (2008). However, this arbitrary method does not consider actual usage of the home range and may inaccurately estimate the use pattern, potentially giving rise to erroneous conclusions thwarting conservation efforts (Powell 2000, Vander Wal and Rodgers 2012). Therefore an objective method, such as the Area Independent (AI) method (Powell 2000), for delineating core areas is suggested by Laver and Kelly (2008) to better represent the use pattern of the animals and should be used when identifying essential habitats.

Temporal components are necessary because habitat preferences, resource requirements, sensitivity to disturbances, and predation risk vary across seasons (Rettie and Messier 2000, O'Brien et al. 2006, Racey and Arsenault 2007, Briand et al. 2009, Hins et al. 2009). In spring for instance, predation is greater on caribou (Seip 1992, Courtois et al. 2007) and their use of harvested landscapes to access green forage (Hins et al. 2009) increases their exposure to predators such as wolves (*Canis lupus*) (Seip 1992, Courbin et al. 2009), coyotes (*Canis latrans*) (Kays et al. 2008, Boisjoly et al. 2010) and bears (*Ursus americanus*) (Ballard 1994, Latham et al. 2011). In addition, caribou may be limited by food during winter (Briand et al. 2009); they therefore seek coniferous forests with high lichen biomass to satisfy dietary requirements (Terry et al. 2000, O'Brien et al. 2006, Briand et al. 2009). These examples illustrate the importance of targeting the seasonal components of woodland caribou ranges to create better suited management

plans and, with the use of core areas, conservation can be focused in important areas of each season.

This study aims to assess the consequences of using different methods to delineate core areas and to determine important habitats and the amount of cutovers across different components of caribou ranges. Our objectives are: (1) to determine the space use patterns of caribou within their home range using an objective core area method. (2) To determine how habitat selection and forestry activity differ with spatial components [three core area definitions (objective core, arbitrary core and home range) and use intensity levels]; we predict that there will be stronger selection for refuges (bogs and coniferous forests), lower preference for risky habitats (cutovers), and the amount of cutovers will be lower in areas with higher use. (3) To quantify the effect of temporal components on habitat preferences and amount forestry using different seasons; we expect a seasonal variation in the selectivity indices of each habitat and the amount of cutovers since vulnerability and life requirements vary between seasons. We assessed habitat preferences using the Manly's selectivity index at the coarse-scale because this scale allows us to determine the amount of refuges and risky landscapes available to the caribou and the proportion of cutovers was used to infer the amount forestry activity.

Study area

The study took place in central Newfoundland within the forestry management zone 5 (49°N, 56°W) and covered approximately 6737 km². The northern part was bisected by the Trans-Canada Highway and contained the towns of Bishop's Falls at the East and Millertown to the West (Figure 1.2). The topology of the area is characterized by flat to gently rolling landscape with many wet lowlands.

The major forest type was dense coniferous stands of mainly black spruce (*Picea mariana*) and some balsam fir (*Abies balsamea*) with sparse deciduous patches of trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*). Non forested areas were also common such as wetlands and shrublands. The summers are mild and wet (16°C) and the winters are cool (-7°C) with an average snow accumulation exceeding 4 m per year (Chubbs et al. 199, Mahoney and Virgl 2003). Logging operations, mainly clear cutting, have been ongoing since the 1920s in the study area focusing primarily on conifers for pulp and paper (Mahoney and Virgl 2003).

The woodland caribou in the study area are sedentary ecotypes that perform only small seasonal migrations (Bergerud 1971) and occur in small groups of 5 to 30 individuals. Light hunting is still allowed in certain districts (Wildlife Division 2011b) despite the population declining in recent years (Mahoney et al. 2008). Much of the study area is limited to human access, although some areas can be accessed by public and logging roads. Besides man, the predators of the woodland caribou include lynx (*Lynx canadensis*), black bear and the introduced coyote (Bergerud 1971, Schaefer and Mahoney 2007). Wolves were historically the major predator on the woodland caribou on the island however they were extirpated in the 1920s (Bergerud 1971). The only other ungulate on the island is the introduced moose (*Alces alces*).

Methods

Data

The location data (one location every two hours) of 12 Lotek 4400 GPS collared female caribou from five different herds (Buchans, Hodges Hill, Mount Peyton, Pot Hill and Topsails herd) were used to create the core areas for the seasonal year of 2008-2009. The

caribou were captured by the crew members of the wildlife department of Newfoundland using stratified random sampling to allow collars to be more evenly distributed across the landscape and herds and in consequence, each collared caribou represents a small herd of 5 to 30 individuals. We used the woodland caribou season dates derived by the Newfoundland and Labrador wildlife division to create the temporal components; including the calving (May 20 – June 10 2008), post calving (July 1 – August 30), fall rut (September 1 – October 31), and winter (December 16 2008 – March 31 2009) seasons. The seasons were divided by periods when the caribou are in migration or display major changes in behaviour (P. Saunders, Wildlife Division Newfoundland and Labrador Government, personal communication). Caribou locations (n = 21,858) were entered into the Geographical Information System (GIS) for analysis and defining the core areas. Of these locations, 89% (n = 19,375) were located within the study area.

The spatial components of the range (the different core areas and home range, hereafter called cores, and the use intensities) were created using fixed kernel density in the animal movement v-2.04 BETA package in ArcView v-3.2 with cell size of 100 meters. We found least squared cross validation for bandwidth selection inappropriate in this case because the core areas produced were conservative and fragmented. Therefore in order to determine the bandwidth appropriate to construct the cores, we tested several bandwidths ranging from 400 to 1200 m. We concluded the 1000 m bandwidth produced the best cores for our purpose because it obscured the fine detail while highlighting the most prominent features of the range for most individuals.

The density contours used for the cores and use intensities were 50% (the most commonly used arbitrary contour; Laver and Kelly 2008), 75% (the average density

contour across all seasons, estimated using the objective AI method; Seaman and Powell 1990, Powell 2000), and 95%, the home range (Table 1.1). The 75% contour was rounded up to the nearest 5% because of the precautionary principle and the animal movement program only creates density contours in increments of 5 percent. These density contours were also used to create the 3 use intensities; low use (75 to 95% contour), medium use (50 to 75% contour), and high use (area within the 50% contour). Figure 1.2 illustrates the density contours used to create the cores and the use intensities for each caribou within the study area. Only the objective contour was created in each of the four seasons, however the calving season was used to determine the effect of the cores and use intensities on habitat selection and proportion of cutovers because it is an important season for woodland caribou and requires a better understanding of essential habitat requirements (Racey and Arsenault 2006).

We obtained digital vegetation coverage from Newfoundland's Forest Service inventory database and classified the information into 9 general habitat categories (Table 1.2). Forests (coniferous, deciduous, disturbed and mixed) made up 36%, open habitats (barren land, bogs, cutovers, and shrubs) 56% and water bodies 8% of the study area. The mean patch size was 3.8 ha ranging from 4,678.4 to less than 0.001 hectares. The information on the vegetation coverage was obtained from aerial photointerpretation by the forestry department mainly during the years 2002, 2003, and 2004 and projected in MTM 2 (North American Datum of 1983) in a GIS. A map of all the habitats was created by merging the nine habitat categories together. The land covered by municipalities and agricultural fields were omitted from the map since they covered less than 1.0% of the study area.

We tested the accuracy of the habitat map by photointerpretation of 225 random points on aerial photographs from 2003 and 2004 (Boitani and Fuller 2000, Hansen et al. 2001). The map accuracy was 78.9% (Table 1.2). The accuracy would increase to 87.8% if the disturbed habitat type was omitted. The disturbed habitat type was difficult to distinguish from other habitats because it represented areas disturbed by fire, wind, flood or insect damage of various ages and resembled other habitat categories. However, considering the accuracy of the other habitat categories, we trust that the disturbed habitats were correctly defined and are reliable indicators of recent and historical natural disturbances.

We assessed habitat selection within the range of the caribou or the second-order level (Johnson 1980). At this scale, the available habitats are those within the study area and the used habitats are those within the range components of the caribou. We conducted the habitat selection at the second-order level because at this scale selection is driven by the most important factor influencing fitness (Rettie and Messier 2000). In addition, the composition of the home range is known to affect caribou survival and reproduction (Courtois et al. 2007, Wittmer et al. 2007, McCarthy et al. 2011). We determined the composition of the habitats in each of the range components by creating Manly's standardized selectivity indices (b_i) for each habitat as per Manly et al. (2002) and Mahoney and Virgl (2003). This method allowed us to determine the selection of the caribou ranges across the available landscape. This method is known to tolerate the exclusion of habitats not used within any of the core or use intensities but that are found within the study area (Manly et al. 2002, Mahoney and Virgl 2003).

Using the information from the habitat map, two age groups, recent cutovers (dating from 1999 to 2008) and regenerating cutovers (dating from 1960 to 1998), were used to depict the amount of forestry activity within the cores and use intensities and for each season. The total area of cuts dating from 1960 to 2008 in the study area was 37,351.9 ha where 8,120.7 ha were regenerating cutovers and 29,231.2 ha recent cutovers. The average patch size of regenerating cutovers was 11.56 ha ranging from 0.01 to 95.30 ha and recent cutovers was 11.38 ha ranging from 490.92 to less than 0.001 hectares. The proportion of cutovers was compared only among the caribou with cutovers within their home range ($n = 5$). The proportions were calculated using the area of each cut type within the cores and use intensities then dividing by the area of the cores and use intensities, respectively.

Statistical analysis

A linear mixed model (PROC MIXED in SAS 9.3; SAS Institute Inc. Cary, NC, USA) was conducted separately for the cores, use intensities and seasons with individuals as the random factor because of repeated measurement on same individual to determine if the set of b_i 's (dependent variable) differed between each habitat types (independent variable). We also conducted mixed models for each habitat type and cutover category using the b_i 's or proportion of cutovers as the dependent variable and each of the spatial or temporal components as the independent variable. This allowed us to determine if the habitat b_i 's and proportion of cutovers differed between the spatial and temporal components. We used the post hoc pairwise comparisons test, which uses paired t-tests, to compare each of the b_i 's or proportions and we controlled for type 1 error by using a

Tukey adjustment. We used 5% as the significance level for each test. The assumptions of the models were assessed using residuals plots.

Results

Spatial range components

The average density contour from the objective method was 71.5% and ranged from 55.0 to 85.0% (Table 1.1). The average sizes for the core types were 647.12 ha for the arbitrary core, 1,258.11 ha for the objective core and 3,424.35 ha for the home range. The objective core was approximately 2-times greater than the arbitrary core and 3-times smaller than the home range. The average size of the objective core for the calving season was 555.12 ha (0.082% of the study area) with a maximum of 803.22 and minimum of 382.32 hectares.

The use of different habitats was non-random for the 50% ($F_{8, 80} = 8.40$, $P < 0.001$), 75% ($F_{8, 80} = 10.46$, $P < 0.001$) and the 95% ($F_{8, 80} = 15.08$, $P < 0.001$) cores. Consistently in all three core types, bogs, coniferous forests, shrubs, and water bodies had a higher selectivity index than mixed and disturbed forests (all $P < 0.05$; Figure 1.3) and bogs were always preferred over cutovers (all $P < 0.05$; Figure 1.3).

Differential use of habitats was apparent in the high ($F_{8, 80} = 8.40$, $P < 0.001$), medium ($F_{8, 80} = 9.81$, $P < 0.001$), and low ($F_{8, 80} = 13.54$, $P < 0.001$) use intensity levels. In this case only bogs and coniferous forests consistently had higher selectivity indices than mixed, disturbed and deciduous forests (all $P < 0.05$; Figure 1.4) and again, bogs consistently had a higher selectivity index than cutover (all $P < 0.05$; Figure 1.4). Only 1

caribou had deciduous forests within the high use and 2 caribou in the medium and 3 caribou in the low.

There was no evidence that the preference for each habitat type changed across the cores or use intensities (all $P > 0.05$; Table 1.3). Similarly, the proportion of new cutovers did not vary across the cores ($F_{2,8} = 0.17$, $P = 0.846$) or use intensities ($F_{2,7} = 1.02$, $P = 0.408$) and nor did the older cutovers for either cores ($F_{2,8} = 2.71$, $P = 0.126$) or use intensities ($F_{2,8} = 2.78$, $P = 0.121$) (Figure 1.6). One caribou had much greater proportion of cutovers compared to the others with a total of 23, 18 and 26% for the high, medium and low use areas respectively (Figure 1.5).

Temporal range component

The use of the different habitats was non-random during the calving ($F_{8,80} = 10.46$, $P < 0.001$), post calving ($F_{8,80} = 4.99$, $P < 0.001$), fall rut ($F_{8,80} = 5.30$, $P < 0.001$), and winter ($F_{8,80} = 4.91$, $P < 0.001$) seasons. The habitats in calving, post calving, and fall rut seasons had the same ranking pattern as with the spatial components. Cutovers were less preferred than bogs in both calving and winter (both $P > 0.05$; Figure 1.7). For the winter season, mixed forests were ranked as third and had a similar b_i to bogs where in all other seasons mixed forests had a lower b_i than bogs (Figure 1.7).

The only b_i 's that differed between seasons were cutovers ($F_{3,24} = 5.01$, $P = 0.008$) and mixed forests ($F_{3,24} = 3.54$, $P = 0.030$). The cutover b_i 's were greater for calving ($t_{24} = 2.82$, $P = 0.044$), post calving ($t_{24} = 3.45$, $P = 0.011$), and fall ($t_{24} = 3.71$, $P = 0.005$) than for the winter season. For mixed forests, only the b_i 's of calving ($t_{24} = -3.182$, $P = 0.020$) and fall ($t_{24} = -2.76$, $P = 0.050$) were less than in the winter season.

Recent ($F_{3, 12} = 3.03$, $P = 0.071$) and regenerating ($F_{3, 12} = 0.75$, $P = 0.542$) cutovers did not differ between seasons however, when they were summed together a difference between seasons was observed ($F_{3, 12} = 4.01$, $P = 0.034$). The proportion of all cutovers for both fall ($t_{12} = 3.31$, $P = 0.028$) and post calving ($t_{12} = 2.98$, $P = 0.049$) were greater than in winter.

Discussion

To quantify the habitat requirements of caribou and allow for targeted conservation and management, spatial and temporal components of their range should be considered (Racey and Arsenault 2007). Applying an arbitrary method for the assignment of a core area can misidentify the areas of intensive use, jeopardizing management and conservation efforts. Therefore, an objective method such as the AI method is recommended for increased precision of animal space use patterns which can in turn influence the areas prioritised for protection (Seaman and Powell 1990, Powell 2000, Laver and Kelly 2008, Wilson et al. 2010). Indeed, we found the arbitrary method did not describe the space use patterns of woodland caribou within the home range, while the AI method had an area twice as large as the arbitrary method.

The caribou in this study intensively used a large portion of their home range, possibly reflecting their highly mobile nature. Their frequent movements may be a response to many factors such as predator avoidance, presence of insect pests, snow depth, or distribution of food sources (Johnson et al. 2002). The application of the arbitrary core for conservation may reduce the area available for woodland caribou to satisfy their physiological needs and hinder conservation efforts by inadvertently

including anthropogenic disturbances within the intensively used areas, potentially affecting mortality (Wittmer et al. 2007, McCarthy et al. 2011).

In our study, the spatial components of the home range did not influence the habitat selection patterns; bogs and coniferous forests were preferred over cutovers, deciduous and mixed forests, a pattern commonly observed in other studies (Bradshaw et al. 1995, Mahoney and Virgl 2003, Schaefer and Mahoney 2007, Courtois et al. 2008, Hins et al. 2009). The high preference for bogs and coniferous forests supports the anti-predator strategy that caribou display in other systems (James et al. 2004, Wittmer et al. 2007, Hins et al. 2009). These habitats provide refuge from predation and support an abundance of forage (Bradshaw et al. 1995) making them important habitats for caribou.

Contrary to our prediction, the selectivity indices did not differ across any of the spatial components of the home range. The presence of core areas and similarity of habitat preferences across the use intensity levels may indicate that the caribou select for finer scale habitat characteristics not captured by this study (Rettie and Messier 2000, Johnson et al. 2001, Racey and Arsenault 2007, Briand et al. 2009). Also, habitats may have been spatially autocorrelated within home ranges thwarting detection of any change in preferences (Legendre 1993). The autocorrelation of habitat was examined *a posteriori* using Moran's Index in ArcGIS and was found to be spatially autocorrelated (Appendix A). However, studies using other methods of capturing habitat selection such as frequency of habitat use did show a change in habitat preference across different spatial components (Mosnier et al. 2003, Hins et al. 2009). This suggests that the habitat composition may not mirror the actual use patterns of the habitats. The caribou in our study may show a

change of preference patterns across use intensities levels using techniques such as frequency of use in each habitat.

Similar to other studies (Rettie and Messier 2000, Apps et al. 2001, Mahoney and Virgl 2003, Mosnier et al. 2003, Metsaranta and Mallory 2007, Hins et al. 2009), habitat preference did change among seasons. For example, winter showed a high preference for coniferous forests, mixed forests and bogs and a stronger avoidance of cutovers suggesting the inclusion of these areas for the provision of winter food sources, shelter from snow accumulation, and refuge from predation (Rettie and Messier 2000, Johnson et al. 2001, Mosnier et al. 2003, O'Brien et al. 2006).

The avoidance of cutovers in winter has been observed in other studies (Rettie and Messier 2000, Smith et al. 2000, Hins et al. 2009) and was proposed to be a response to higher predation and higher snow accumulation. Snow accumulation is likely the major factor responsible for this avoidance in Newfoundland since the caribou's primary winter predator, the coyote, avoid cutovers in winter because of the accumulated snow that hamper movements (Thibault and Ouellet 2005). Deep snow can limit the caribou's ability to crater for food and fragments the landscape reducing access to other resources causing them to avoid areas with high snow accumulation (Johnson et al. 2001, O'Brien et al. 2006, Courtois et al. 2008). Mixed forests are generally avoided in winter (O'Brien et al. 2006) because of the higher snow accumulation and overlap with moose wintering habitats (Dussault et al. 2001).

The calving season had a stronger selection pattern for refuges than the other seasons. Calves are most vulnerable during this season (Trindale et al. 2011) and thus it

was only during calving season where both bogs and coniferous forests were preferred over cutovers. This allows the caribou to distance themselves from predators such as coyotes (Boisjoly et al. 2010) and bears (Latham et al. 2011).

Newfoundland's current forestry guidelines are to dissuade forestry and development within the 50% density contour and halt any cutting during calving, post calving and wintering seasons when caribou are seen in the area (Wildlife Division 2011a). The 80% density contour is also used as buffer areas to avoid cutting in areas where caribou are present during calving or wintering season but resume cutting once they leave. With this in mind, we expected to see a difference in the proportion of cutovers between different core definitions and for these differences to be more pronounced between different levels of use. However, this was not observed. This may be because these forestry guidelines were only implemented in 2007 and the cuts previous to this year were conducted irrespective of the location of core areas.

The similar proportions of cutovers between use intensities was not expected because of the general avoidance of cutovers observed in other studies (Smith et al. 2000, Fisher and Wilkinson 2005, Courtois et al. 2007, Courtois et al. 2008). However, a slight decrease in the proportion of cutovers with the higher use intensity levels was apparent. There was a higher proportion of cutovers in the lower use intensity levels however the proportion of cutovers did not significantly change because the lower use intensity levels were larger. This trend may become significant if more caribou were used however only 5 caribou had cutovers within their home range. Also, the incorporation of recent and regenerating cutovers has also been observed in other studies (Briand et al. 2009, Hins et al. 2009) which may be a consequence of habituation to cutovers or fidelity to historical

range selection and not the selection for cutovers (Chubbs et al. 1993, Rettie and Messier 1998, Smith et al. 2000, Metsaranta and Mallory 2007). The presence of cutovers within home ranges and core area may create an ecological trap for woodland caribou (Rettie and Messier 2000). One caribou in the study had approximately 20% of cutovers within each of the use intensity levels. The inclusion of cutovers may be because they are perceived as lower risk because of the absence of wolves and as beneficial because of available food sources (Russell et al. 1993, Briand et al. 2009) and avoidance of insect pests (Graham 1992). However, cutovers are also commonly found in the core areas of coyotes (Boisjoly et al. 2010), a significant predator on caribou in Newfoundland, supporting the theory of cutovers as an ecological trap. However, little information exists on the impact of cutovers on caribou predation by coyotes in Newfoundland.

Management Implications

Because caribou intensively use large portions of their home range, managers should consider an appropriate method for establishing the core areas since the arbitrary core was a fraction of the objective core. The inclusion of cutovers within the core areas of woodland caribou is concerning because of the potential for higher predation possibly creating an ecological trap.

Pooling all seasons for the construction of core areas may reduce the effectiveness of determining important areas per season since the length of each can differ biasing the location of the core areas. Thus, we recommend constructing core areas for each season to fully capture the different habitat components allowing managers to identify and focus management efforts within different seasonal periods.

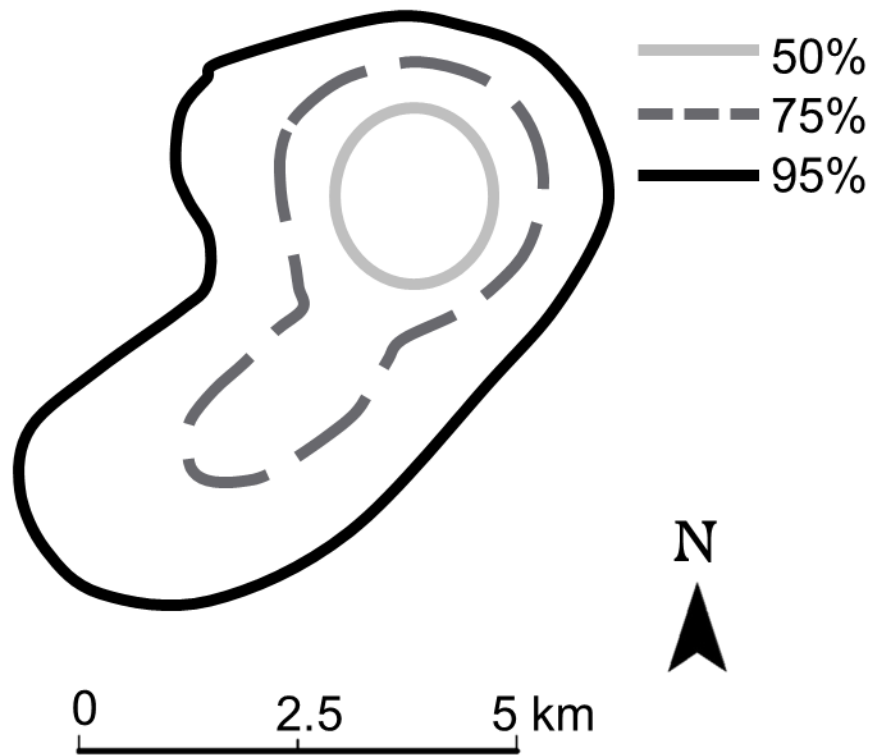
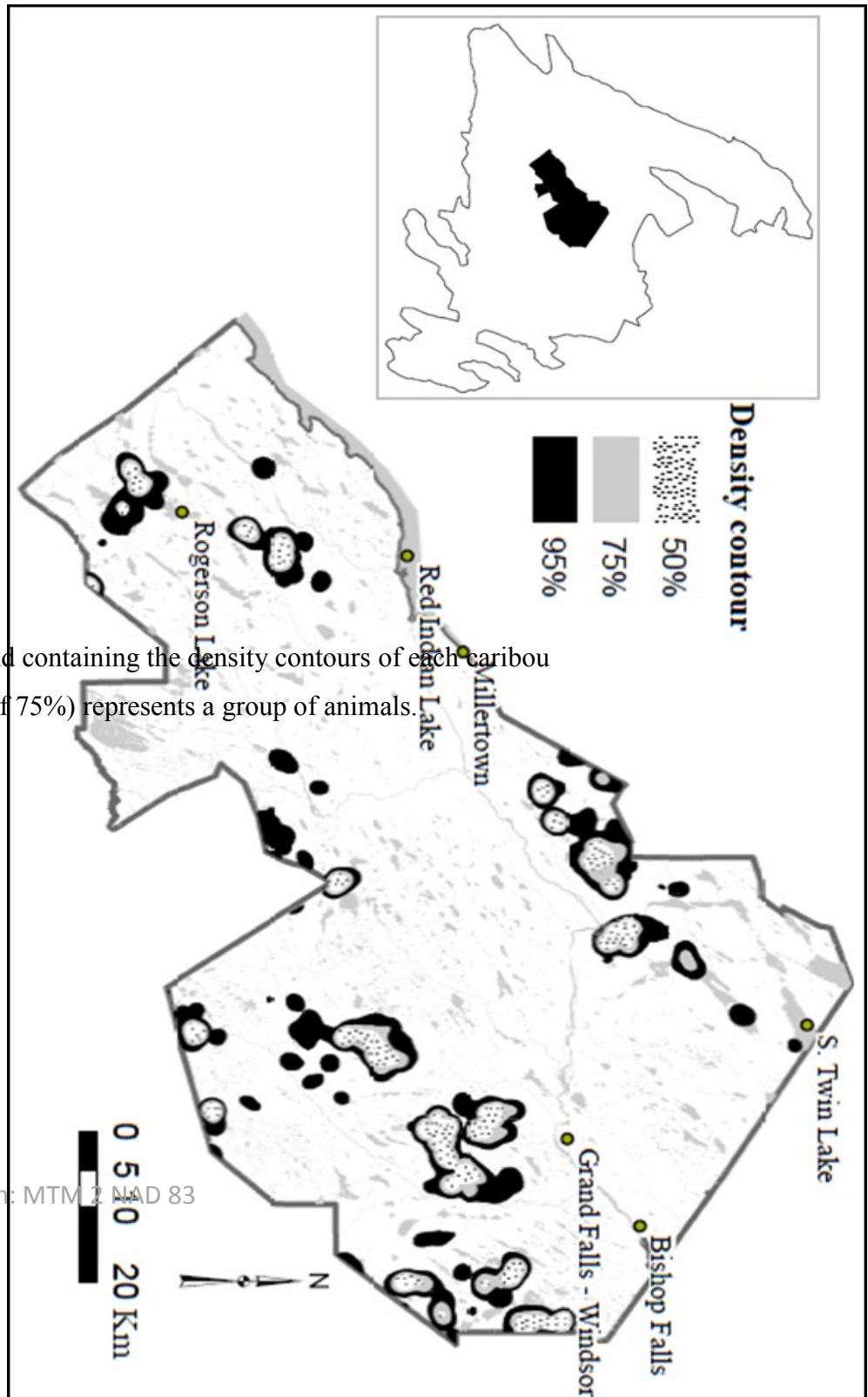


Figure 1.1: An example of a home range demonstrating the density contours used to create the core types and the use intensity levels. The 50% density contour represents the arbitrary core area and the high use intensity level. The 75% density contours was identified as the area for objective core area using the Area Independent method. The area between the 75% and 50% density contour was defined as the area in the home range with medium use intensity. The 95% density contour was used to define the home range of the woodland caribou and the area between the 95% and 75% density contour was defined as the area in the home range with low use intensity.



study zone in central Newfoundland containing the density contours of each caribou
 . Each core area (density contour of 75%) represents a group of animals.

Projection: MTM 2 NAD 83

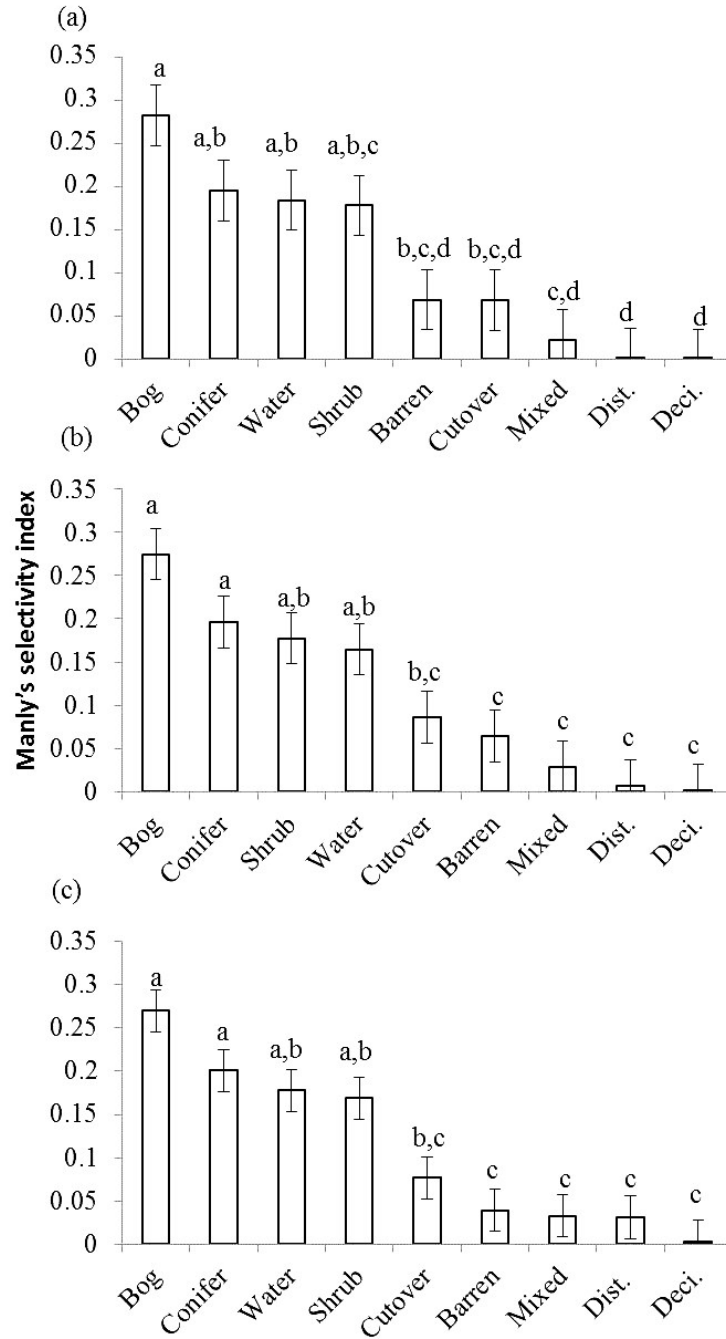


Figure 1.3: Selectivity indices of habitat types (Deci. = deciduous forests, Dist. = Disturbed forests) in the (a) arbitrary core area, (b) objective core area and the (c) home range $n = 11$. The habitat types sharing the same letter are not different based on the Tukey test.

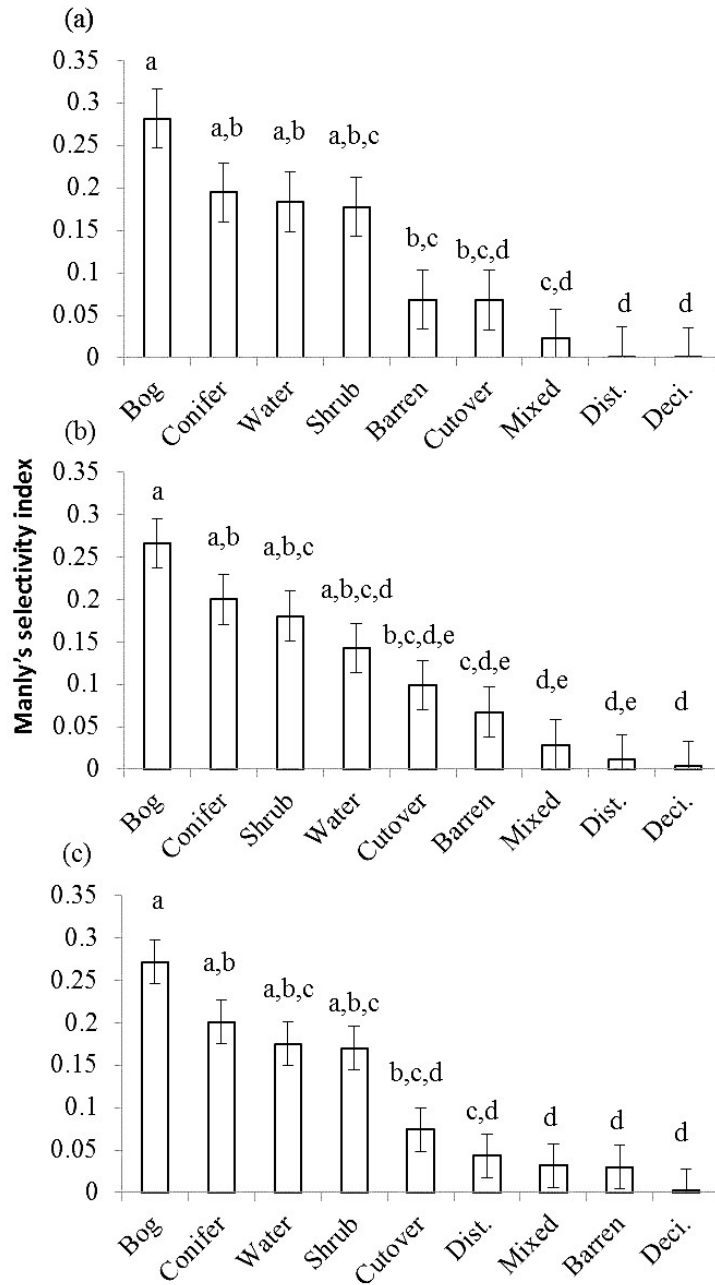


Figure 1.4: Selectivity indices of habitat types (Deci. = deciduous forests, Dist. = Disturbed forest) in decreasing order for the (a) high, (b) medium, and (c) low use intensity levels within the home range for the calving season, $n = 11$. Habitat types sharing the same letter are not different based on the Tukey test.

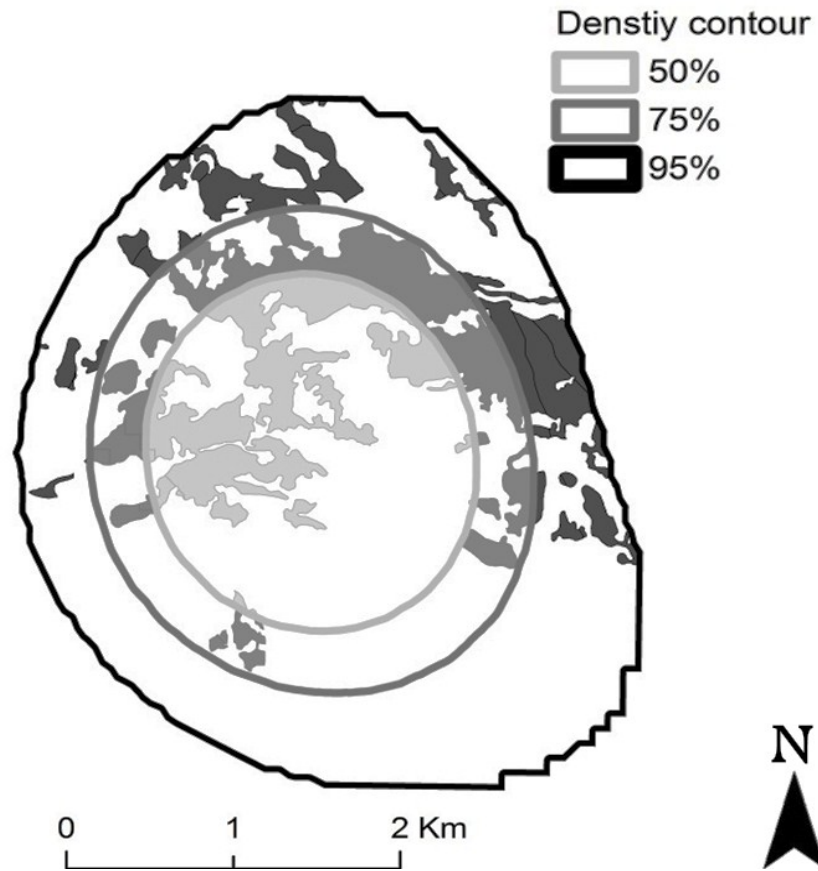


Figure 1.5: The distribution of cutovers for an individual caribou with 23, 18, and 26 % of cutovers in the high (50%), medium (75%), and low (95%) use intensity levels.

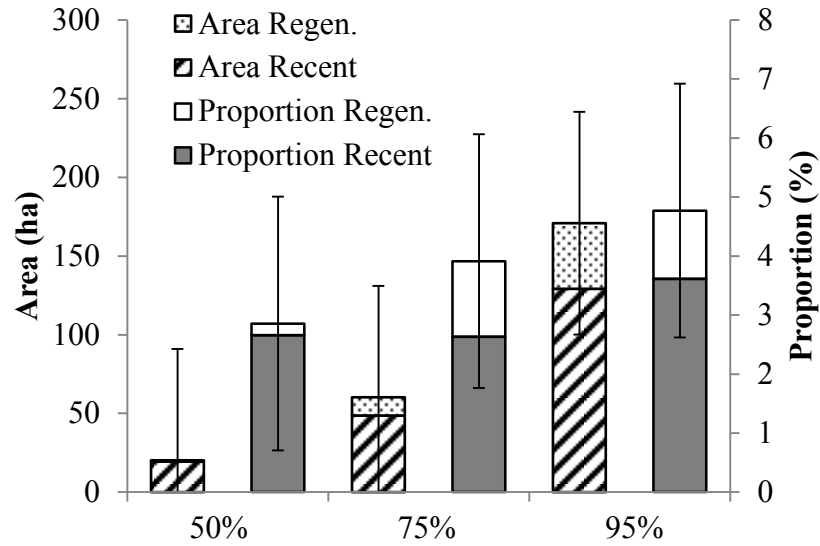
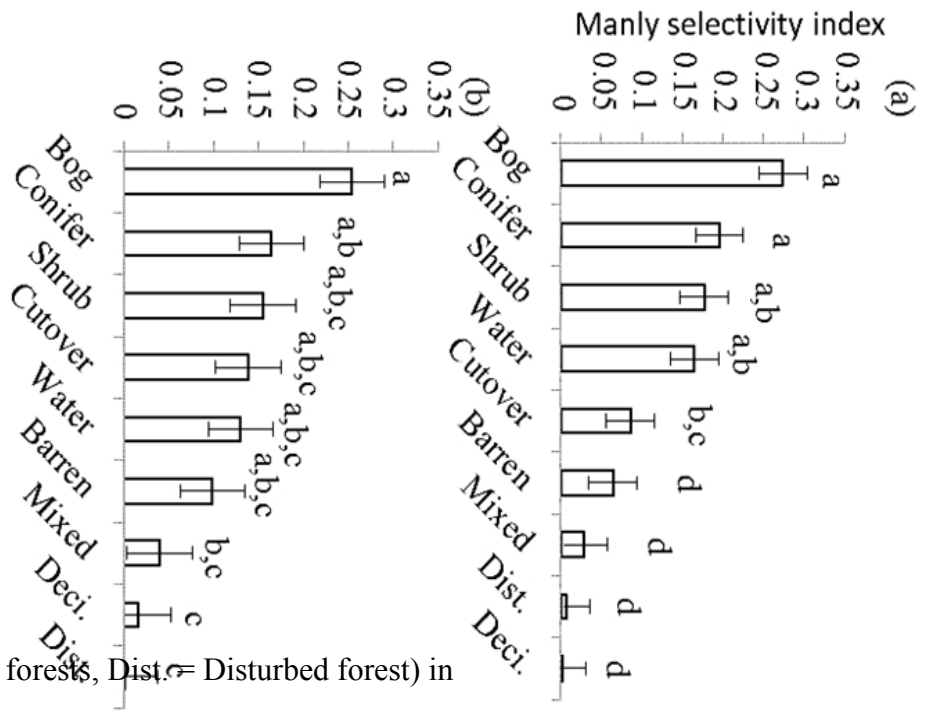


Figure 1.6: Stacked columns demonstrating the average cumulative area and proportion of cutovers for the high (50%), medium (75%) and low (95%) use intensities along with the standard error bars in the calving season (n = 5). Error bars were created for the combination of recent cutovers (recent) and regenerating cutovers (regen.) for the average area and proportion of cutovers.



indices of habitat types (Deci. = deciduous forests, Dist. = Disturbed forest) in

for the seasons (a) calving (n = 11), (b) post-calving (n = 12), (c) fall rut (n = 11), and

indices sharing the same letter are not different based on the Tukey test.

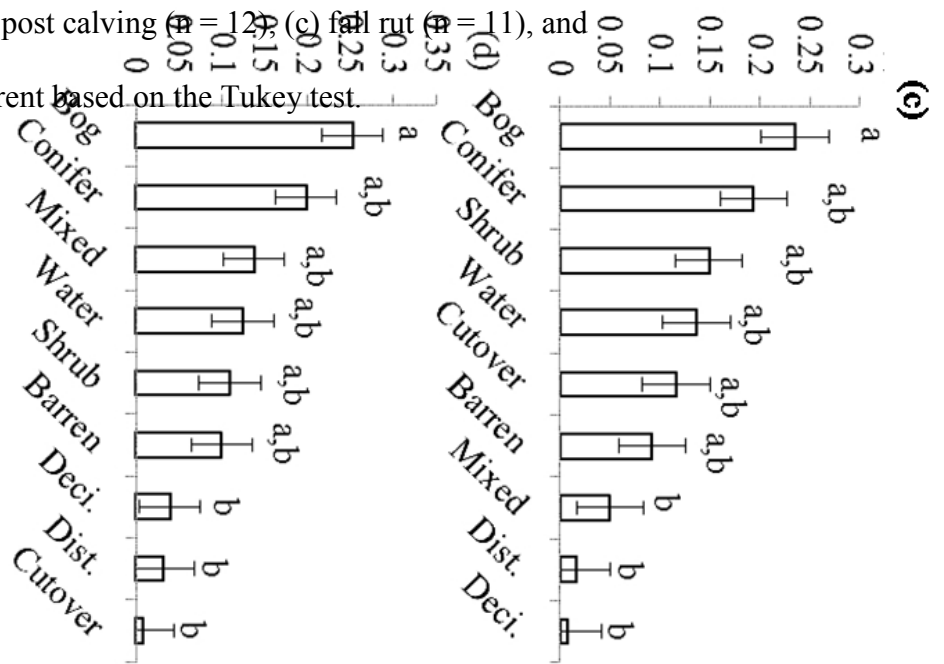


Table 1.1: Summary statistics of spatial and temporal range characteristics of the woodland caribou (n = 12) in central Newfoundland.

Range characteristics	Mean	SD	Range	
			Minimum	Maximum
Objective core area (density contour)	71.54	6.50	55.00	85.00
Caribou locations in objective core (%)	75.04	9.81	52.29	89.77
Arbitrary core 50% (ha)	647.12	463.15	382.3	3,282.5
Objective core area 75% (ha)	1,258.11	484.85	746.37	2,443.79
Home range 95% (ha)	3,424.35	1,513.90	1,292.67	7,286.35
Use intensities				
50 isotherm (ha)	508.86	228.22	402.94	803.22
50-75 isotherm (ha)	706.55	442.25	349.59	1,640.57
75-95 isotherm (ha)	2,695.75	1,472.47	1,380.11	4,842.56

Table 1.2: Habitat categories available to woodland caribou in central Newfoundland and their accuracy during validation.

Habitat Type	Description	Total area (km²)	Proportional area (%)	Validation score (%)^I
Barren	Rock, soil, sand, and barren land	166	2	83
Bog	Bog, wet bog, treed bog and other wetlands	1,169	18	100
Cutovers	Clear cuts dating from 1960 to 2008	374	6	100
Forests Coniferous	Coniferous trees make up 75-100% of the basal area	1,948	29	81
Forests Deciduous	Deciduous trees make up 75-100% of the basal area	97	2	100
Forests Disturbed	Forest fire, wind damaged, flood damaged, or insect mortality	202	3	II
Forests Mixed	Neither coniferous nor deciduous trees make up more than 75% of the basal area	227	3	89
Shrubs	Hardwood and softwood shrub with few trees	1,922	29	72
Water	Lakes and major rivers	558	8	100
Total	-	6,663	100	-

^I Validation score with disturbed habitat omitted.

^{II} We were unable to correctly identify any disturbed forests because this habitat type resembled other habitats.

Table 1.3: Statistics from the Mixed Procedure in SAS 9.3 comparing the selectivity indices for each habitat type in across the core definitions and use intensity levels for the spring season, n = 11. A significance level of $\alpha = 0.05$ was used.

Habitats	Core definitions		Use intensities	
	F_{2, 20} values	P-values	F_{2, 20} values	P-values
Barren	1.19	0.326	1.03	0.377
Bog	0.13	0.883	0.10	0.904
Conifer	0.11	0.900	0.05	0.952
Cutovers	1.17	0.329	1.74	0.201
Deciduous	1.47	0.254	0.70	0.509
Disturbed	1.25	0.309	1.12	0.347
Mixed	0.43	0.654	0.18	0.838
Shrub	0.24	0.793	0.10	0.908
Water	0.23	0.797	0.55	0.585

Chapter 2:

The use of coniferous forests and cutovers by Newfoundland woodland caribou

Issac Hébert and Robert Weladji

Department of Biology, Concordia University, 7141 Sherbrooke St W., Montreal, QC,
H4B 1R6, Canada

Abstract:

Habitat selection and preferences are driven by population limiting factors which can vary across spatial and temporal scales. For example, woodland caribou prefer coniferous forests (CF) to avoid predation at the coarse-scale and at finer scales select for forage within forests. Forestry reduces the benefits of forests and prevents the regeneration of adequate caribou habitat. We described Newfoundland woodland caribou habitat preferences across coarse and fine spatial scales and assessed whether the cutovers regenerate into forests of similar value to those preferred by the caribou. At the coarse-scale we determined if caribou preferred CF while at the fine-scale, which stand characteristics the caribou selected for within CF. Linear regression was used to determine which stand characteristics predicted the intensity of use of the CF by the caribou. The same stand characteristics were used to compare cutovers of various ages to CF using Principal Component Analyses to determine if they share similar characteristics. We found at the coarse-scale that CF were most preferred but did not differ from cutovers, and at the fine-scale caribou used CF with more forage. Cutovers did not develop into forests with similar stand characteristics as the CF selected by the caribou; the canopy of the cutovers was more closed and supported less forage than the CF. Old cutovers may act as a refuge from predation however they foster less forage for caribou which may cause them to seek forage in more risky landscapes like cutovers in order to meet dietary requirements.

Introduction

Understanding an animal's habitat requirements and the mechanisms driving the selection patterns is necessary for effective management and conservation because they provide insight on interactions with conspecifics, other species, the environment and both natural and disturbed landscapes (Samuel and Green 1988). This information can be obtained through habitat selection studies allowing managers to identify habitat requirements. Several spatial and temporal scales in habitat selection studies have been recommended in order to better capture habitat selection (Mayor et al. 2009). Indeed, the choices an animal makes when selecting habitats is a hierarchal process and can vary both spatially and temporally (Johnson 1980, Mayor et al. 2009). The selection preferences are driven by population limiting factors which can vary across both spatial and temporal scales (Rettie and Messier 2000, Mayor et al. 2009). For instance, coarse-scale habitat analyses illustrate major limiting factors across the landscape while fine-scales provide details on the factors driving the choices within a given habitat classification (Rettie and Messier 1998).

For example, predation is the limiting factor for woodland caribou and is the agreed cause for their major decline and threatened status in North America (COSEWIC 2002, Wittmer et al. 2005, Vors and Boyce 2009). Wolf (*Canis lupus*) predation has the largest impact on caribou and caribou respond to the wolf predation risk by finding asylum in coniferous forests and naturally open areas (Rettie and Messier 2000, Apps et al. 2001, Wittmer et al. 2007, Hins et al. 2009). Another limiting factor for woodland caribou is nutritional requirements (Bergerud 1996) however this factor does not limit populations as much as predation and thus is reflected only at smaller scales.

Accordingly, caribou distinguish between coniferous forests preferring those with higher amounts of forage (Serrouya et al. 2007, Briand et al. 2009, Hins et al. 2009).

The majority of habitat selection studies for woodland caribou are conducted at coarse-scales using broad habitat categories (Chubbs et al. 1993, Mahoney and Virgl 2003, Hins et al. 2009). Fine-scale habitat studies for caribou are few and the majority of those are conducted in winter on mountain caribou (Johnson et al. 2000, Terry et al. 2000, Apps et al. 2001, Johnson et al. 2001, Mosnier et al. 2003, Serrouya et al. 2007) and most demonstrate that selection is driven by dietary requirements. However, woodland caribou may be more limited by forage potential during snow free periods (Bergerud 1996) despite their broad food preference (Russell et al. 1993). Therefore, snow free periods may better illustrate the selection pressures at finer scales.

In addition, forest harvesting, the most prevalent method of habitat alteration in the boreal forest (Niemela 1999, Gagnon and Morin 2001), drastically alters the level of predation risk and forage potential (Bergerud 1996, Wittmer et al. 2005, Vors and Boyce 2009, Festa-Bianchet et al. 2011) influencing caribou habitat preferences. Forestry can increase predation risk directly by attracting other ungulates along with their predators (Courtois et al. 2004, Wittmer et al. 2005, Mosnier et al. 2008, Vors and Boyce 2009, Boisjoly et al. 2010); increasing access for predators and hunters to caribou through logging roads (James and Stuart-Smith 2000, Sorensen et al. 2008); and by removing refuges from predators (Wittmer et al. 2007, Courtois et al. 2008). The increase in predation risk often causes caribou to flee from harvested areas (Chubbs et al. 1993, James and Stuart-Smith 2000, Schaefer and Mahoney 2007, Vors et al. 2007). However, the combination of strong site fidelity (Faille et al. 2010) and the loss of quality habitat

providing both forage and refuges may cause caribou to seek resources in harvested landscapes (Briand et al. 2009, Hins et al. 2009). Hence, the understanding of habitat requirements within coniferous forests may allow managers to strategically harvest less favourable forests, reducing the need for caribou to seek harvested areas to satiate their dietary needs. Moreover, harvested areas may also pose a long term reduction in quality of caribou habitats as it develops into mature forests which can cause differential use between successional stages (Hins et al. 2009).

In this study, our aim is to determine whether (1) coniferous forests are selected at the coarse-scale during the summer, (2) caribou select for stand characteristics within these forests and (3) cutovers regenerate into forests of similar stand characteristics as those preferred by the caribou. We predict that at the coarse-scale, coniferous forests will be the habitat most preferred by caribou in comparison to 8 other habitat types because these forests are a refuge from predation despite their main predator, the wolf, being absent from the island. At the fine-scale, we predict that caribou will select for forage within coniferous forests because these forests are already preferred to avoid predation. We also predict that older cutovers will be most similar to un-harvested coniferous forests though they will not share the same stand characteristics as the coniferous forests preferred by the caribou.

Study area

The caribou in this study were located within the forestry management zone 5 (49°N, 56°W) in central Newfoundland. The northern part was bisected by the Trans-Canada Highway and contains the towns of Bishop's Falls at the East and Millertown to the West

(Figure 2.1). The topology of the area is characterized by flat to gently rolling landscape with many wet lowlands.

Refer to the study area section in chapter 1 for additional information on the study area and the caribou herds.

Methods

Delineation of Use Intensity Levels

Woodland caribou have high site fidelity allowing for the quantifying of use intensity levels to demonstrate their relative use patterns (North and Reynolds 1996). We used fixed-kernel density in the animal movement v-2.04 BETA package in ArcView v-3.2 with cell size of 100 m to construct the use intensity levels using the location data (one location every two hours) of 12 Lotek 4400 GPS collared female caribou within the study zone. We found least squares cross validation for bandwidth selection inappropriate in this case because the core areas produced were conservative and fragmented. Therefore, in order to determine the bandwidth appropriate to construct the cores, we tested several bandwidths ranging from 400 to 1200 m. We concluded the 1000 m bandwidth produced the best cores for our purpose because it obscured the fine detail while highlighting the most prominent features of the range for most individuals. The density contours used to create the use intensity levels included the 95% for low use, 75% for medium use and 50% contour for high use. The home range was defined as the area within the 95% density contour as suggested by Laver and Kelly (2008) and the core areas were defined as the area within 75% density contour using the objective Area Independent method for each caribou (Seaman and Powell 1990, Powell 2000). Figure 2.1 illustrates the density

contours used to create the cores and the use intensity levels during the post-calving season for each caribou within the study area.

Coarse-scale habitat selection

We obtained digital vegetation coverage from Newfoundland's Forest Service inventory database and classified the information into 9 general habitat categories (Table 1.2). The information on the vegetation coverage was obtained from aerial photointerpretation by the forestry department mainly during the years 2002, 2003, and 2004 and projected in MTM 2 (North American datum 1983) in a Geographic Information System. The land covered by municipalities and agricultural fields were omitted from the map since they covered less than 1.0% of core areas.

We tested the accuracy of the habitat map by photointerpretation of 225 random points on aerial photographs from 2003 and 2004 (Boitani and Fuller 2000, Hansen et al. 2001). The map accuracy was 78.9% (Table 2.1). The accuracy would increase to 87.8% if the disturbed habitat type was omitted. The disturbed habitat type was difficult to distinguish from other habitats because it represented areas disturbed by natural phenomenon and thus resembled other habitat categories. However, considering the accuracy of the other habitat categories, we trust that the disturbed habitats were correctly defined and are reliable indicators of recent and historical natural disturbances.

The coarse-scale habitat selection was assessed at the second-order (Johnson 1980), which pertains to the habitats used by the animals within their range. This was performed using the composition of the core areas to represent the available habitat and the proportion of points within the habitats in the core areas as the used habitats. These

were then used to calculate Manly's standardized selectivity indices (b_i) for each habitat in each of the caribou core areas as per Manly et al. (2002). This method allowed us to determine which habitats were used more than others within the core areas and tolerated the exclusion of habitats not used within any of the core areas but that are found within the study area (Manly et al. 2002, Mahoney and Virgl 2003).

Fine-scale habitat selection

Our fine-scale habitat analysis does not fall within the orders described by Johnson (1980). Since it assesses resource distribution within a particular habitat, however, it falls within the fine-scale category described by Wiens (1989). The fine-scale habitat analysis was conducted in coniferous forests because caribou select this habitat as refuge from predation (Rettie and Messier 2000) and we used use intensity levels to infer the amount of use of each forest. Sample stations were placed on the study map within coniferous forests that were accessible by foot or quad prior to visiting the field. We visited 15 coniferous forests in the high use area, 19 in the medium and 29 within the low use intensity levels. To assess the differences between use intensity levels, 11 different stand characteristics (Table 2.1) were sampled throughout the summer of 2011 within coniferous forests. The use intensities were constructed using GPS data from 2008 yet our fine-scale habitat data were collected in 2011. Despite the three year difference, we assume that no major changes took place within the forests that would drastically alter the stand characteristics within this time frame. Therefore, the forests sampled in 2011 should be adequate representatives of the forests in 2008.

At each of the sample stations 11 stand characteristics were measured in attempt to illustrate the amount of cover from predators, forage availability and other

environmental characteristics which woodland caribou may select for within coniferous forests (Table 2.1). Canopy closure (CANOPY) was estimated by counting the number of points covered by the canopy at 1 m intervals along a 20 m transect oriented east-west and centered on the sampling station (Masse and Cote 2009). A factor 2 prism was used to determine the basal area of conifers (BACON) and deciduous trees (BADEC). The stand height (TREEH) was measured using a clinometer on a tree representative of the stand. Lateral cover (HORIZ) was measured by placing a 25 m transect oriented north to south and noting the distance at which a person wearing an orange vest is no longer visible (Masse and Cote 2009). Ground forage cover (GRD) such as forbs, grasses and sedges and moss cover (MOSS) was estimated as a percentage of coverage in a box of 1 m² centered on the sampling station. The percent of above ground forage such as shrubs and saplings less than 4 m tall was also estimated using a 1 m x 1 m plot oriented east west and centered on the sampling station. The above ground forage was divided into the percentage of deciduous (DSHRUB) and coniferous (CSHRUB) shrubs/saplings. Using the same plot, the amount of coarse woody debris (CWD) was estimated using the line intersect sampling method (Bebber and Thomas 2003). The percent coverage of lichen was estimated in a 1 m² plot and used to determine the lichen biomass (LICHEN). This was done using a linear regression formulated from biomass measurements and percent coverage obtained from 16 subplots within the 1 m² plots. The percent coverage and average lichen mat height (cm) were measured within the subplots and all of the lichen from the subplots were harvested then dried and weighed (g) to obtain a biomass measurement. The average height was obtained by measuring the height at three random locations within the lichen mats. Biomass (B) was estimated for the 16 subplots using the

formula $B = C \times H \times W$ where C is coverage, H is average height, and W is dry weight. Using the 16 biomass estimations derived from the previous equation, we obtained a positive linear regression ($B = 0.082C - 0.42$, $R^2 = 0.702$). This linear regression was then used to estimate the lichen biomass from the percent coverage for all of the 1 m² plots.

Cutover succession

The same variables were also sampled within cutovers of various stages of succession. This allowed us to illustrate the changes in stands variables between successional periods and whether the cutovers increased in similarity with those within the core area. Table 2.2 lists and describes the age categories used. The information concerning forest age and cutover age was obtained from the digital vegetation coverage and harvesting data provided by the Newfoundland's Forestry Service. The cutover age classes were derived from the year it was cut to 2011 and the forest age classes were created by the forestry department for forests using tree height as proxy for age.

Statistical analysis

To determine if the b_i 's of each habitat differed between one another, a general mixed model was conducted using PROC MIXED in SAS 9.3 (SAS Institute Inc. Cary, NC, USA) with the individual caribou as random factor. In addition, post hoc tests were used to determine which habitats were different from one another. The habitats were then ranked based on their b_i value.

A series of stepwise logistic regressions were used to assess the stand characteristics between the use intensity levels using PROC LOGISTIC in SAS (SAS

Institute Inc. Cary, NC, USA). This function was used because it allowed us to relate the use intensity (ordinal categories) to the stand characteristics. Binary logistic regressions were also used to directly compare two density contours and a polytomous logistic regression (PLR) was used to compare across all three use intensities. The estimates and 95% critical interval were reported for each of the variables selected by logistic regressions. Multicollinearity was a concern between the variables within the model since several of the variables were highly correlated among each other (Appendix A). Hence, multicollinearity between the variables was assessed using variable inflation factor (VIF), but all the variables had a VIF lower than 5, suggesting lack of multicollinearity (Montgomery and Peck 1992). Accordingly, all the variables were included in the stepwise models.

Three principal component analyses (PCA) were conducted in SAS using PROC PRINCOMP to see which variables explained the variance between (1) stand age categories, (2) forested stands (old cutovers, mature and over-mature forests), and (3) between old cutovers and forests within the core areas. We used significant variables [those with eigenvectors greater than 0.30 (McGarigal et al. 2000)] to define the axis for the first PC and then the eigenvalues for the first PC were used in an ANOVA and paired contrasts to determine if the average eigenvalue differed between the stand categories. The first PC for the PCA comparing all stand ages explained 30% of the variation; for the second PCA comparing the forested age classes the first PC explained 26%; and the first PC for the PCA comparing between old cutovers and forests within core areas explained 25%. The eigenvectors for the first three axes are reported in Appendix B.

Results

Coarse-scale habitat selection

The caribou had non-random use of habitats within their core areas ($F_{8, 88} = 8.50$, $P < 0.001$). Coniferous forests b_i was higher than that of cutovers, deciduous forests, barrenlands, mixed forests, water bodies and disturbed landscapes but did not differ from shrublands or bogs (Figure 2.2). Cutovers and deciduous forests were ranked similar to all other habitats excluding coniferous forests.

Fine-scale habitat selection

The stand characteristics were able to predict the use intensity level of the forests when comparing the high to low use intensities ($\chi^2_2 = 6.13$, $P = 0.047$; Table 2.3b); medium to low use intensity ($\chi^2_3 = 9.00$, $P = 0.029$; Table 2.3d); high and medium to the low use intensity ($\chi^2_4 = 12.61$, $P = 0.009$; Table 2.3e) and across all three use intensity levels ($\chi^2_4 = 11.46$, $P = 0.022$; Table 2.3f). However, the variables were unable to predict which use intensity level the forests were in when comparing high to medium use intensity ($\chi^2_1 = 1.70$, $P = 0.193$; Table 2.3a) and high to medium and low use intensity levels ($\chi^2_1 = 3.01$; $P = 0.083$; Table 2.3c).

The probability of a coniferous forests being located in the high use intensity as compared to the low use intensity level increased with the tree height [estimate = 1.295; 95% CI (1.028; 1.631); Table 2.3b] but was not influenced by lichen biomass ($P > 0.05$; Table 2.3b). When comparing the medium to the low use intensity level the probability of a coniferous forest being in the medium use increased for lichen biomass [estimate = 1.576 95% CI (1.032; 2.407; Table 2.3d)] and ground cover [estimate = 1.020 95% CI (1.001; 1.040) ; Table 2.3d] and tree height had no effect ($P > 0.05$; Table 2.3d). The

probability of the forests within the core area (low and medium use intensity levels) as compared to the low use intensity level increased with lichen biomass [estimate = 2.678; 95% CI (1.150; 6.235); Table 2.3e] and tree height [estimate = 1.231; 95% CI (1.029; 1.473); Table 2.3e] but was not influenced by ground and moss cover (both $P > 0.05$; Table 2.3e). For the polytomous logistic regression, the probability of a forest being in the high use intensity or the high and low use intensity as compared to the low use intensity increased with lichen biomass [estimate = 2.096; 95% CI (1.019; 4.308); Table 2.3f] and tree height [estimate = 1.246; 95% CI (1.051; 1.477); Table 2.3f], but was not affected by moss cover and deciduous shrubs (both $P > 0.05$; Table 2.3f).

Cutover succession

For the first PCA, which compared all of the cutover and forest age classes, the loadings which explained the variation in the first axis included canopy cover with an eigenvectors of 0.51, coniferous basal area with 0.49, tree height with 0.42 and deciduous shrubs with -0.37. Positive eigenvalues for the first axis then relate to stands with trees and canopy cover and the negative eigenvalues pertain to open shrubby areas with no trees. The average eigenvalue differed between the stands ($F_4 = 58.62$, $P < 0.001$) where forested stands (old cutovers, mature forests, and over-mature forests) differed from new and regenerating cutovers (Figure 2.3; left panel). This clearly demonstrates that cuts of up to 40 years do not resemble un-harvested forests yet cutovers older than 40 years do have some resemblance to uncut forests.

The second PCA compared the stands with trees (old cutovers, mature forests, and over-mature forests) and the loadings that explained the variation of the first axis included canopy cover with an eigenvector of 0.51, coniferous basal areas with 0.46,

deciduous shrubs with -0.38, coniferous shrubs with -0.33 and lichen biomass with -0.31. The positive eigenvalues for this axis are related to forests with closed canopies and high basal area and the negative values are related to forests with open canopy and with more forage. Again, the average eigenvalue differed among the stands ($F_2= 4.71$, $P = 0.011$) yet in this case, only mature forests differed from old cutovers (Figure 2.3; middle panel).

For the third PCA comparing the old cutovers to the un-harvested forests within the core areas, the loadings that explain the variation in the first PC include canopy cover with an eigenvector of 0.51, coniferous basal area with 0.38, tree height with 0.32, and deciduous shrubs with -0.41. For this PC, the positive eigenvalues are forests that have closed canopies, high basal area and tall trees and the negative eigenvalues are forests with more deciduous shrubs. The two forests types differed from one another ($F_1= 4.11$, $P = 0.047$; Figure 2.3; right panel); old cutovers are closed dense forests and have less forage than the forests within the core areas.

Discussion

Coarse-scale habitat selection

We were able to observe selection across the different scales. Similar to other studies, we found that caribou were associated with coniferous forests (Chubbs et al. 1993, Apps et al. 2001, Mahoney and Virgl 2003, Wittmer et al. 2007, Hins et al. 2009), and showed a slight preference for bogs/wetlands (Rettie and Messier 2000, James et al. 2004). These results are in agreement with our prediction that caribou select habitats at the coarse-scale to avoid predation. It was expected that coniferous forests be preferred over cutovers because of the higher abundance of caribou predators such as black bears (Mosnier et al. 2008) and coyotes (Boisjoly et al. 2010) in these areas.

Although our caribou did prefer coniferous forests, most caribou with cutovers within their core area did have locations within them. When the selectivity indices of only the caribou with cutovers within their home range were compared *a posteriori* (Appendix C) we saw that the selectivity indices did not differ between cutovers or coniferous forests indicating that these caribou use cutovers and coniferous in similar proportions compared to their availability during the post-calving season. Moreover, all of the caribou that were observed in the field in 2011 were found within cutovers.

However, the high use of cutovers was not seen in other studies conducted in Newfoundland (Chubbs et al. 1993, Mahoney and Virgl 2003, Schaefer and Mahoney 2007) which may be a result of different scales, methods or caribou herds used in these studies. Different scales for instance can result in different conclusions (Mayor et al. 2009); for example, Schaefer and Mahoney (2007) found that Newfoundland caribou avoided cutovers but did not differentiate between seasons. Yet in Quebec, when seasons were differentiated the avoidance of cutovers was seasonal (Hins et al. 2009).

The caribou may use the harvested blocks because: they are forced to traverse them in order to reach old-growth forests (Briand et al. 2009, Hins et al. 2009); use forestry roads for easy travel (Saunders 2007); or use the cutovers to access forage (Fisher and Wilkinson 2005, Briand et al. 2009, Hins et al. 2009). Caribou consume a variety of plants, in addition to lichen, (Russell et al. 1993) many of which are common within cutovers. The results from our PCA highlight the availability of forage in cutovers with the higher amounts of shrubs. In addition, recent cutovers can also share similar vegetation as old-growth forests (Niemela 1999) until they are replaced by more shade-intolerant plants which may attract caribou to these areas to forage. Caribou showed a

preference for cutovers of certain age category; caribou in Quebec used very young cuts in similar proportions to their availability and the use of older cutovers was more variable (Hins et al. 2009). The high use of cutovers as well as coniferous forests may demonstrate that the driver for habitat selection at this scale is not predation risk since they use cutovers despite the elevated risk of predation.

The caribou may cue into the potential benefits of the cutovers which may cause the animal to misjudge the costs and benefits of cutovers. For example, caribou may also forage in cutovers to compensate for loss of foraging areas in coniferous forests. They may also use these areas because of better predator detection (Ouellet et al. 1996) yet, are unable to flee the predator efficiently because mobility is hindered by coarse woody debris.

Fine-scale habitat selection

In support of our prediction, we found that the location of the coniferous forests within the use intensity levels was best predicted by forage variables. Forests in higher use intensity levels had higher amounts of lichen and ground cover and shorter trees indicating that caribou appear to intensively use forests with higher quantities of forage. Contrary to our findings, Briand et al (2009) found that during snow free periods, caribou did not show a preference for either forage or predation cover though there was a pattern to avoid forage used by alternative prey such as moose.

Moose forage, such as deciduous and coniferous shrubs, was not selected in the models, indicating no relationship between forest use and amount of moose browse. In eastern Quebec caribou avoided areas with high moose browse to potentially avoid

contact with moose, an alternative prey for wolves (Briand et al. 2009). The avoidance of moose and moose habitat has also been observed elsewhere (Cumming et al. 1996, James et al. 2004, Bowman et al. 2010). However, this avoidance is unnecessary here because there are no wolves on the island of Newfoundland and coyotes seldom prey on moose (Boisjoly et al. 2010). However, caribou do share a predator with moose since bears are known to prey on moose calves in spring (Boutin 1992). We expected all summer forage to be included within the models. However, shrubs were not observed within any of our models and ground cover was seldom within our models despite them being prominent part of caribou diets (Russell et al. 1993). This may indicate that the caribou may not select primarily for forests with these forage types because they are abundant elsewhere. Caribou are known to forage in risk sensitive areas such as within cutovers (personal observations; Briand et al. 2009, Hins et al. 2009) and along the road sides (Saunders 2007). Caribou can deplete green forage within forests during the summer (Bergerud 1996) and may seek cutovers because of the abundant amount of green forage thereby trading off good forage with predation risk. Cutovers therefore, may act as ecological traps because they may be perceived as beneficial despite elevated predation risk (James and Stuart-Smith 2000, Courtois et al. 2007, Schaefer and Mahoney 2007, Vors et al. 2007, Wittmer et al. 2007).

Cutover succession

It is well known that forestry has a significant effect on the landscape, local environment and the biotic community (Niemela 1999, Fisher and Wilkinson 2005) which may hamper the natural succession of these forests. From our PCAs we were able to obtain a picture of the development of cutovers in Newfoundland.

Cutovers up to 40 years remain open reducing the protection from predators yet supporting a large amount of shrub and green forage, which may explain the use of cutovers by caribou. However, once the cutovers mature and the coniferous trees grow, the cutovers develop into forests that are dense and closed with less forage potential for caribou than un-harvested forests. The similarity of plant communities is often only 50 to 70% between mature forests and old cutovers (Niemela 1999). We observed a difference in the amount of vegetation between all un-harvested forests and those within core areas in comparison to old cutovers suggesting that cutovers may take longer than expected to regenerate into adequate caribou habitat.

The amount of canopy cover within forests plays an important role in the development of the understory; closed canopies result in dark humid forests with bryophytes dominating (Rettie et al. 1997) while open canopies allow light to penetrate the forest floor necessary for lichen, herbaceous plants and shrubs to grow (Harper et al. 2002, Hart and Chen 2006, Serrouya et al. 2007). Canopy closure thus reduces the amount of understory explaining the negative correlation we found between forests with high canopy closure and amount of forage opportunities. Forests with open canopies are important for caribou in different seasons. Caribou select open canopy forests in winter, because of the higher amounts of food accessible through cratering, and in the spring and summer, they take advantage of the higher diversity of forage plants there (Hins et al. 2009). Therefore the maintenance of old-growth forests with open canopies is important for the conservation and management of woodland caribou. However, the canopy of cutovers takes longer to “open up” (Apps et al. 2001) than un-harvested forests making them less valuable habitat for woodland caribou. The succession of cutovers may be

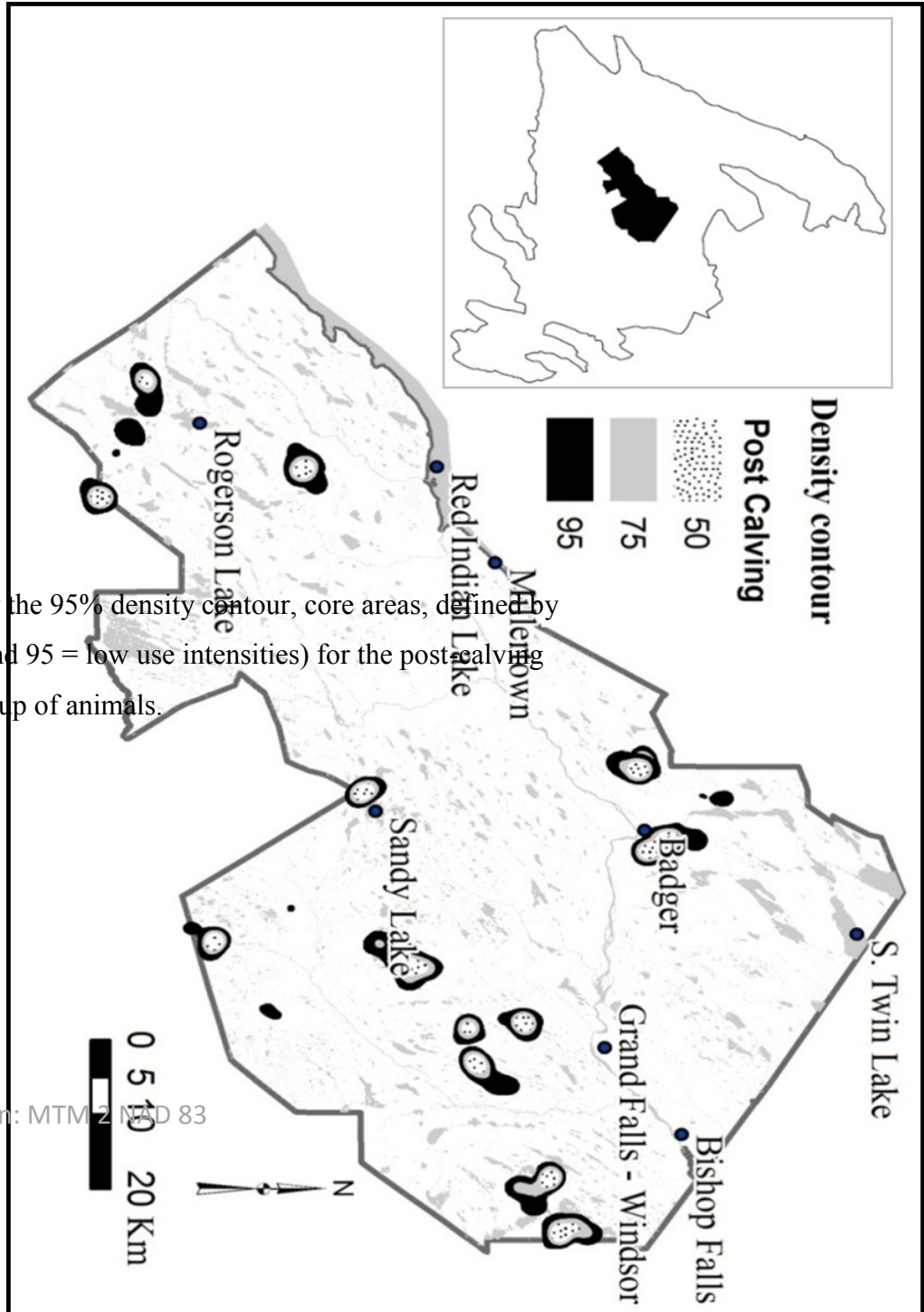
longer because they attract moose impeding the growth of deciduous trees (Thompson et al. 1992). These trees allow more light to penetrate to the ground than coniferous trees (Hart and Chen 2006).

This study illustrates the preferred habitats of woodland caribou across different scales and the development of cutovers. At first glance, our prediction appeared to be satisfied because when considering all of the caribou, they preferred habitats with low predation risk such as coniferous forests. However, an *a posteriori* test revealed that our prediction was not supported since the selection indices of coniferous forests and cutovers did not differ. At a finer scale, caribou used forests with higher amounts of forage as predicted. In support of our final prediction, we observed that cutovers do not develop the same stand characteristics as un-harvested forests or those within caribou cores.

Management implications

We recommend that old-growth forests be protected from harvesting in order to provide caribou with forests with sufficient forage and cover. Ideally, new cutover operations should be grouped together and located away from core caribou activity in order to allow for conservation of large un-fragmented old-growth forests within the core areas. In addition, recent cutovers should be burned in order to replicate the natural succession of coniferous forests (Hart and Chen 2006) and to possibly deter caribou from these sites by eliminating any vegetation in the cutovers that are remnants from the forest.

caribou home ranges, defined by the 95% density contour, core areas, defined by use intensities (50 = high, 75 = medium and 95 = low use intensities) for the post-calving period. Each core area represents a group of animals.



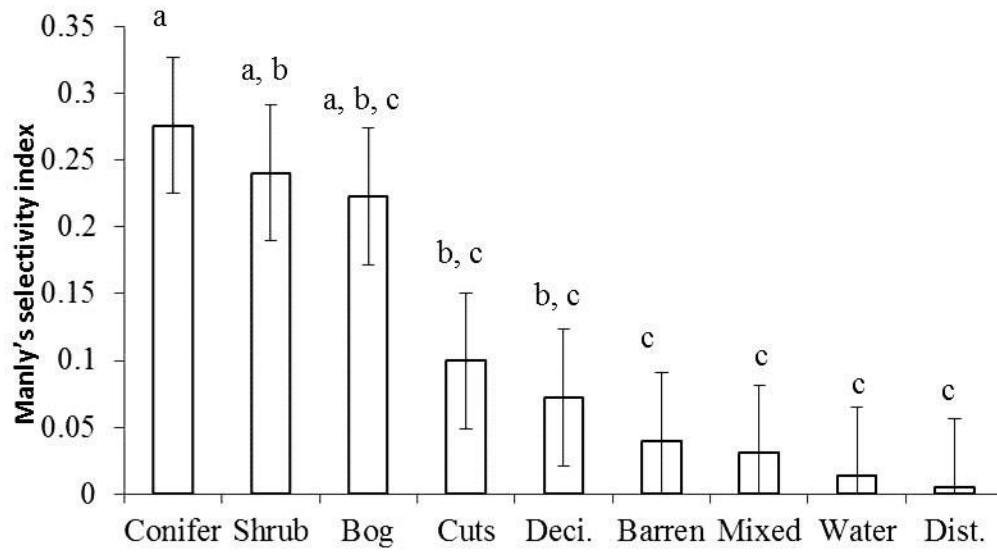


Figure 2.2: Selectivity indices of habitat types in decreasing order of rank for the coarse-scale habitat analyses. The habitat types sharing the same letter are not different based on the Tukey test, $n = 12$.

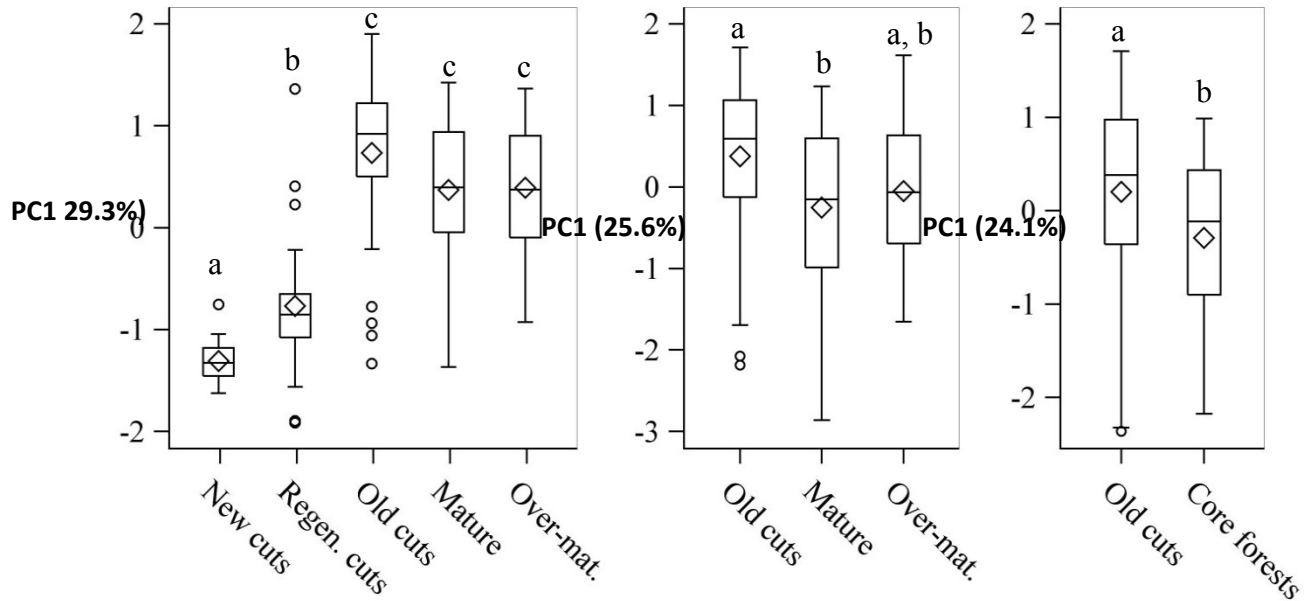


Figure 2.3: Box-plot displaying the average first principal components (PC) derived from a Principal Component Analysis of 11 stand characteristics measured for all stand types (left panel, $n = 144$); between old cutovers ($n = 39$), mature forests ($n = 52$) and over-mature forests, ($n = 26$) (middle panel, $n = 117$); and between old cutovers and un-harvested forests within the core areas ($n = 27$) (right panel, $n = 66$). Circles represent the outliers and diamonds represent the mean principal component. The positive y-values for the PC in the left panel represent high amounts of canopy cover, coniferous tree basal area, and tree height while negative values represent high amounts of deciduous shrubs. The positive y-values for the PC in the middle panel represent high values of canopy cover and coniferous basal area and the negative values represent the higher amounts of forage. The positive y-values for the PC in the right panel represent high values of canopy cover, coniferous basal area, and tree height while the negative values higher deciduous forage. Stand types sharing the same letter are not different based on the Tukey test.

Table 2.1: The fine-scale stand characteristics collected within the different use intensity levels and stand ages during the summer of 2011 in central Newfoundland. All of the stand characteristics describe the local environment while some can also be used to describe resources such as the amount of forage, FOR, and cover/protection from predators, COV. Resources can either increase (+) or decrease (-) with stand characteristics. EV1 and EV2 represent the eigenvectors obtained for each stand characteristic from the Principal Component Analysis between all stand types (EV1) and forested stands only (EV2).

Stand Characteristic	Description	Resource described	EV1	EV2
BACON	Basal area of coniferous trees measured with a factor 2 prism	COV (+)	0.494 ^I	0.463 ^I
BADEC	Basal area of deciduous trees measured with a factor 2 prism	COV (+)	0.132	0.159
CANOPY	The proportion of points along a transect where the canopy was closed	II	0.506 ^I	0.505 ^I
CSHRUB	The percent coverage of coniferous shrubs and saplings	COV (-)	-0.077	-0.332 ^I
CWD	The volume of coarse woody debris such as snags and large branches	COV (-)	-0.014	0.138
DSHRUB	The percent coverage of deciduous shrubs and saplings	COV (-) FOR (+)	-0.370 ^I	-0.385 ^I
GRD	The percent coverage of ground cover, herbaceous plants less than 1 m tall	FOR (+)	-0.283	-0.197
HORIZ	The distance a person wearing an orange hunting is obscured from vision	COV (+)	0.004	0.138
LICHEN	Biomass of lichen	FOR (+)	-0.127	-0.308 ^I
MOSS	The percent coverage of moss	II	0.263	0.029
TREEH	The height of a tree characteristics of the stand	II	0.417 ^I	0.273

^I Eigenvectors greater than 0.30 that were used in the interpretation of the first principal components derived from the principal component analyses.

II Stand characteristics not considered to describe the amount forage or cover/protection from predators.

Table 2.2: A description of the stand types used in each of the analyses. The years used to date the cutovers and forests are in respect to summer 2011 (date of the study). The ages of the forests are estimated based on tree height obtained from the digital vegetation coverage in GIS.

Stand type	Stand age (in years)	Description	n
New cutovers	< 21	Coniferous forests cut within the last 20 years	32
Regenerating cutovers	21 to 40	Coniferous forests that have been cut between 21 and 40 years prior to study	21
Old cutovers	> 40	Coniferous forests that have been cut more than 40 years prior to study	39
Mature forest	40 to 80	Mature coniferous that have not been documented as ever being cut	52
Over-mature forest	> 80	Over-mature coniferous forests that have not been documented as ever being cut	26
Forests in core	> 40	Includes both mature and over-mature coniferous forests only within the core areas	27

Table 2.3: Parameter estimates, standard errors (SE) of the parameter estimates, and P-values for the top models selected using stepwise logistic regression with significance level of 0.2 as the selection criterion. The analyses are modeling the probability that the location of coniferous forests be located within different use intensity levels of woodland caribou home ranges.

Variables	Parameter estimates	SE	P value
(a) Coniferous forests in high vs. medium use intensity level			
Intercept	-1.307	0.919	0.155
Coniferous basal area	0.025	0.020	0.205
(b) Coniferous forests in high vs. low use intensity level			
Intercept	-3.752	1.330	0.005
Lichen biomass	0.504	0.313	0.112
Tree height	0.259	0.118	0.028
(c) Coniferous forests in high vs. medium and low use intensity levels			
Intercept	2.972	1.042	0.004
Tree height	0.162	0.096	0.091
(d) Coniferous forests in medium vs. low use intensity level			
Intercept	-3.210	1.195	0.007
Lichen biomass	0.455	0.216	0.035
Tree height	0.150	0.100	0.131
Ground cover	0.020	0.010	0.041
(e) Coniferous forests in high and medium vs. low use intensity level			
Intercept	-7.105	3.175	0.025
Lichen biomass	0.985	0.431	0.022
Moss cover	0.044	0.030	0.141
Tree height	0.208	0.091	0.023
Ground cover	0.015	0.008	0.080
(f) Coniferous forests in high vs. medium vs. low use intensity levels ¹			
Intercept high use	-7.839	2.897	0.007
Intercept medium use	-6.475	2.858	0.024
Lichen biomass	0.740	0.368	0.044
Tree height	0.220	0.087	0.011
Moss cover	0.030	0.026	0.137
Deciduous shrub	0.011	0.008	0.183

¹A polytomous logistic regression.

GENERAL CONCLUSIONS

The alarming global decline of caribou has triggered many studies to determine which habitats are most important to woodland caribou. For effective management and conservation of this species, it is recommended by the National Boreal Caribou Technical Steering Committee in Canada to use various spatial and temporal components when determining the important habitats of woodland caribou (Racey and Arsenault 2007). Core areas are a spatial component often used to determine the habitats within intensively used areas of the home range; however, studies seldom use objective methods to define the areas intensively used (Laver and Kelly 2008). The caribou in this study intensively used large portions of their home range; the core areas created using the objective area independent method were bounded by the 75% density contour and were twice as large as the predefined 50% density contour core areas often used in other studies. We also found that despite the size difference between the different core types, the method used to create the core areas did not influence the proportion of cutovers or the habitat preferences. This was also apparent across the other spatial components used however the habitat preference and proportion of cutovers did change across temporal components. This indicates that the caribou have seasonal habitat requirements regarding the composition of their core areas. In each of the range components, habitats that act as refuge (bogs and coniferous forests) had the highest selectivity indices.

Coniferous forests are important for woodland caribou not only as a safe haven from predation but also to satiate dietary needs (Rettie and Messier 2000, Briand et al. 2009). Forestry is particularly detrimental to woodland caribou because mortality of caribou increases near harvested landscapes through increased exposure to predators and

can influence the available forage (Bergerud 1996, Wittmer et al. 2005, Vors and Boyce 2009, Festa-Bianchet et al. 2011). This often causes caribou to be extirpated from harvested areas or to flee to neighbouring forest patches (Chubbs et al. 1993, Smith et al. 2000, Mahoney and Virgl 2003, Vors et al. 2007). The severity of forestry on the status of woodland caribou is well reflected by this statements from Festa-Bianchet et al (2011): “caribou are at risk of extirpation where industrial activities alter habitat causing a shift in predator-prey dynamics... it is currently impossible for high levels of industrial activity and Boreal or Mountain caribou to co-exist”. However, we found that caribou used coniferous forests in similar proportion to cutovers which may be due to the lack of their primary predator, the wolf, on the island of Newfoundland. Cutovers may also foster green forage (Hins et al. 2009; this study) that can be used by woodland caribou. The caribou may take advantage of this available forage within cutovers at the expense of higher predation.

Harvested areas can also reduce the quality of the habitats available to woodland caribou even as it develops into coniferous forests which can cause differential use of successional stages (Hins et al. 2009). Cutovers may not develop the same stand characteristics as mature coniferous forests and often only share a fragment of the plant community as mature coniferous forests. We observed that cutovers increase in similarity with un-harvested coniferous forests as they develop. Cutovers greater than 40 years were the most similar to coniferous forests however these cutovers were more closed and supported less caribou forage than the forest blocks within caribou core areas. The effect of harvesting on woodland caribou in Newfoundland is not well understood because of the apparent use of cutovers by woodland caribou and the recent introduction of a new

predator, the coyote. In the rest of North America, cutovers are recognized as a major factor contributing to the decline of woodland caribou indirectly through the increase of predation. However, little information exists on the impact of cutovers on caribou in relation to predation in Newfoundland especially in regards to the coyote.

MANAGEMENT IMPLICATIONS

Caribou intensively use a large portion of their home range that was not confined within the core areas created using the predefined 50% density contour. Therefore, managers should use objective methods to delineate the core areas such as the area independent method in order to accurately define the amount of the home range that is intensively used. The objective method should also be used when one animal may indicate a group of animals, such as our case, since it may produce more conservative core areas than the area defined by the 50% density contour. With respect to the Newfoundland forestry guidelines, we recommend that the 75% density contour be used to limit development and cutting.

The pooling of temporal data for the construction of core areas should be avoided because there is a seasonal change in risks and habitat requirements for woodland caribou. In addition, the length of each season may differ thus biasing the location of the core areas. For example, the intensively used areas in short seasons, such as the calving season, may be overshadowed by longer seasons if the location data is pooled across all seasons. Longer seasons have higher number of locations which would influence the location of the core areas. This can be detrimental for Newfoundland caribou because calving is the most sensitive season for these caribou given the extremely high calf mortality (Trindale et al. 2011). Thus, we recommend constructing core areas for each

season to fully capture the different habitat requirements and prevent the overrepresentation of certain seasons.

Refuges (bogs and coniferous forests) had the highest selectivity indices in each seasons however, preferences for these habitats was strongest during calving. Therefore, we recommend that no harvesting or development should take place within the 75% density contour in order to conserve these refuges and reduce the amount of risky landscapes within the core areas. However, the use of cutovers and their inclusion within the core areas of woodland caribou is concerning because of the potential for higher increase in predation in these areas possibly creating an ecological trap.

Cutovers can have attractive forage for caribou and they may access this forage at the expense of higher predation. Therefore, the planning of future harvesting operations should consider the use of cutovers by caribou, the long period required to develop similar stand characteristics as preferred coniferous forests and their potential as an ecological trap. Woodland caribou use coniferous forests as a means to avoid predation and to acquire food. Old cutovers may act as a refuge from predation however they have fewer forage options for woodland caribou which may cause them to seek food sources in more risky landscapes in order to meet dietary requirements. Therefore, it would be important to understand how coyote predation on adults and calves is influenced by cutovers and forestry roads since they can occupy the same areas.

We recommend that old-growth forests be protected from harvesting in order to provide caribou with forests with sufficient forage and cover. Ideally, new cutover operations should be grouped together and located away from core caribou activity to

allow for conservation of large un-fragmented old-growth forests within the core areas. In addition, in order to replicate natural succession, recent cutovers could be burned (Hart and Chen 2006). This may also deter caribou from these sites by eliminating any vegetation remaining from the forest prior to the cut. These recommendations would allow the development of open canopy forests within the core areas providing sufficient amount of forage and cover for woodland caribou while reducing the amount of cutovers in the core areas.

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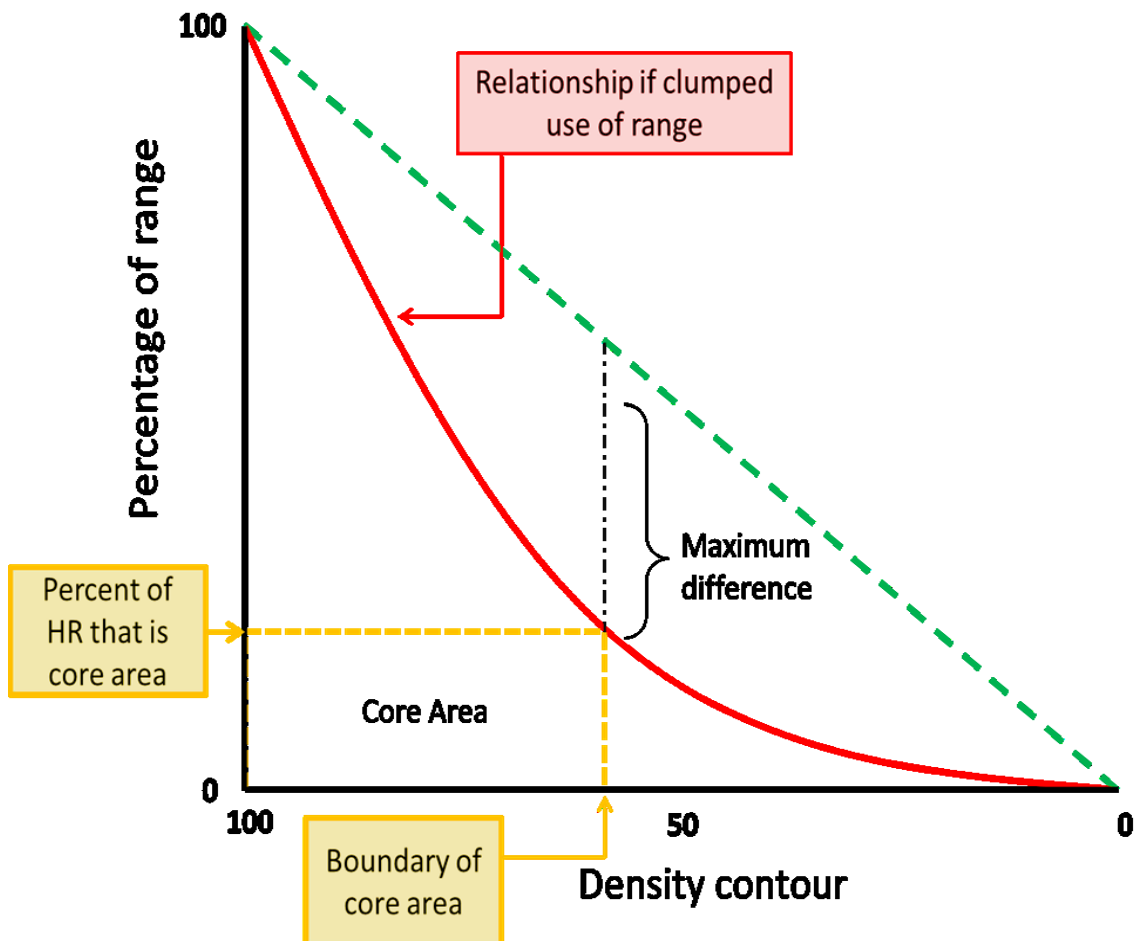
APPENDICES

Appendix A

The spatial autocorrelation was assessed in ArcGIS v. 9.2 using the Moran's Index tool which measures the autocorrelation based on the location of the habitat types. This method determines whether the habitats were clustered, dispersed or randomly distributed. It provides a Z score and the Moran's Index. The Z score was used to determine whether the Moran's Index differs from the null hypothesis: there is no spatial clustering (*i.e.* the habitats are not spatially autocorrelated). A Moran's Index value of +1.0 indicates clustering and a value of -1.0 indicates dispersion. We obtained a Moran's Index of 0.08 ($Z = 66.85$, $P = 0.01$) using the habitats within the home ranges of all of the caribou ($n = 12$) indicating that our habitats were spatially autocorrelated.

Appendix B

The Area Independent method used to identify the density contour to create the objective core area (modified from Powell [2000]). If the relationship of the size of the different density contours (solid red line) creates a curve that is depressed, then the animal disproportionately uses areas within its home range (HR). The location on this curved that is furthest from a straight line of slope -1.0 (green dashed line) is identified as the area that is most intensively used within the home range. The x and y -axis value of this point represent the density contour used to create the objective core area and the size of the core area respectively.



Appendix C

The correlation matrix for the 11 stand variables using the PROC CORR command in SAS 9.3, n= 101. The numbers in bold are the r coefficients and the numbers in italics below the r coefficients are their corresponding p-values.

Variables	1	2	3	4	5	6	7	8	9	10	11
1 BACON	1.00										
2 BADEC	0.17 <i>0.087</i>	1.00									
3 CANOPY	0.60 <i><0.001</i>	0.08 <i>0.437</i>	1.00								
4 CSHRUB	-0.34 <i>0.001</i>	-0.11 <i>0.290</i>	-0.35 <i><0.001</i>	1.00							
5 CWD	0.01 <i>0.891</i>	0.00 <i>1.000</i>	0.14 <i>0.164</i>	-0.03 <i>0.785</i>	1.00						
6 DSHRUB	-0.44 <i><0.001</i>	-0.09 <i>0.354</i>	-0.40 <i><0.001</i>	-0.14 <i>0.151</i>	-0.13 <i>0.187</i>	1.00					
7 GRD	-0.10 <i>0.297</i>	0.12 <i>0.239</i>	-0.23 <i>0.022</i>	-0.08 <i>0.424</i>	-0.07 <i>0.471</i>	0.27 <i>0.006</i>	1.00				
8 HORIZ	0.25 <i>0.013</i>	0.08 <i>0.449</i>	-0.01 <i>0.890</i>	-0.12 <i>0.225</i>	0.17 <i>0.095</i>	-0.11 <i>0.280</i>	0.17 <i>0.094</i>	1.00			
9 LICHEN	-0.35 <i><0.001</i>	-0.05 <i>0.588</i>	-0.28 <i>0.004</i>	0.25 <i>0.013</i>	-0.11 <i>0.290</i>	-0.05 <i>0.632</i>	-0.22 <i>0.029</i>	-0.04 <i>0.715</i>	1.00		
10 MOSS	0.20 <i>0.049</i>	0.06 <i>0.563</i>	0.20 <i>0.042</i>	-0.16 <i>0.111</i>	0.08 <i>0.406</i>	0.07 <i>0.503</i>	0.08 <i>0.406</i>	0.08 <i>0.430</i>	-0.77 <i><0.001</i>	1.00	
11 TREEH	0.40 <i><0.001</i>	0.11 <i>0.289</i>	0.29 <i>0.004</i>	-0.03 <i>0.801</i>	0.30 <i>0.003</i>	-0.31 <i>0.002</i>	0.03 <i>0.752</i>	0.36 <i><0.001</i>	-0.24 <i>0.014</i>	0.16 <i>0.121</i>	1.00

Appendix D

The eigenvectors for the first three principal components for the Principal Component Analysis of 11 stand characteristics measured for all stand types (PCA1, n = 144); between old cutovers (n = 39), mature forests (n = 52) and over-mature forests, (n = 26) (PCA2, n = 117); and between old cutovers and un-harvested forests within the core areas (n = 27) (PCA3, n = 66).

Variables	PCA1			PCA2			PCA3		
	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
LICHEN	-0.127	0.615	0.166	-0.308	0.511	-0.114	-0.256	-0.508	0.014
GRD	-0.283	-0.386	-0.256	-0.197	-0.284	0.449	-0.246	0.455	0.287
MOSS	0.263	-0.189	-0.493	0.029	-0.609	0.008	-0.113	0.471	-0.476
CSHRUB	-0.077	0.571	-0.236	-0.332	0.219	0.061	-0.266	-0.264	-0.273
DSHRUB	-0.370	-0.163	-0.237	-0.385	-0.251	0.104	-0.415	0.230	0.294
CWD	-0.014	-0.138	0.446	0.138	0.112	0.444	0.121	-0.011	0.151
CANOPY	0.506	0.013	-0.021	0.505	0.046	-0.169	0.508	-0.147	-0.125
HORIZ	0.004	-0.228	0.513	0.138	0.264	0.509	0.246	0.176	0.536
TREEH	0.417	0.075	-0.054	0.273	0.132	0.492	0.316	0.098	0.063
BACON	0.494	-0.057	-0.057	0.463	-0.118	-0.077	0.381	0.280	-0.279
BADEC	0.132	-0.064	0.289	0.159	0.245	-0.193	0.201	-0.224	0.349

Appendix E

We calculated the selectivity indices for only caribou with cutovers within their core area to obtain a better picture of cutover use. Half of the caribou ($n = 6$) had cutovers within their core areas and of these, 5 had location within cutovers. We isolated the selectivity indices for each of the 6 caribou and compared them using a general mixed model, PROC MIXED in SAS 9.3. Again, we used the individual caribou as random factor and we used post hoc tests to determine which habitats were different from one another. The habitats were then ranked based on their b_i value.

When comparing the selectivity indices for only caribou with cutovers within their core, we see that despite that they have differential use of habitats ($F_{8,40} = 8.95, P < 0.001$), cutovers and coniferous forests in similar proportions ($t_{40} = 1.06, P = 0.977$) compared to their availability. Cutovers only differed from mixed forests ($t_{40} = 3.32, P = 0.045$), water ($t_{40} = 3.48, P = 0.030$), disturbed land ($t_{40} = 3.62, P = 0.021$ and deciduous forests ($t_{40} = 3.82, P = 0.012$).

