SITE FIDELITY AND HABITAT CHARACTERISTICS OF WOODLAND CARIBOU (*RANGIFER TARANDUS*) NURSERY AREAS IN WABAKIMI AND WOODLAND CARIBOU PROVINCIAL PARKS, NORTHERN ONTARIO

BY

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Abstract

To prevent further range recession, habitat features essential to the life history requisites of woodland caribou (*Rangifer tarandus caribou*) such as calving and nursery areas need to be protected for the persistence of the species. Forest-dwelling woodland caribou may minimize predation risk during calving by either spacing out or spacing away from predators in the forest to calve on islands, wetlands, or shorelines.

The first objective of this thesis was to determine if in fact the same female caribou was using the same area for calving and nursery activity year after year. Caribou faecal samples for DNA extraction were collected from nursery areas in 2 provincial parks in northern Ontario: Wabakimi and Woodland Caribou Provincial Parks. Extraction yield was poor in summer-collected faecal samples and site fidelity on a specific lake could not be demonstrated. However, differentiation of caribou DNA samples between parks suggests that caribou may be exhibiting female philopatry during the nursery period: female caribou typically return to a particular area year after year for calving and nursery activities (Brown and Theberge 1985, Gunn and Miller 1986, Fancy and Whitten 1991).

Another objective was to determine the fine-scale characteristics of shoreline habitats used as calving and nursery areas by female woodland caribou in the 2 parks. Detailed vegetation and other site characteristics were measured at shoreline nursery sites used by cow-calf pairs and compared to shoreline sites that were not used by caribou within each park. Important characteristics were used to develop and evaluate Resource Selection Functions (RSFs) for calving woodland caribou in northern Ontario. Habitat characteristics determined at nursery sites were postulated to reflect predator avoidance strategies. Observed differences in habitat variables selected by female caribou in the 2 study areas primarily reflected broad ecoregional differences in vegetation and topography rather than differences in female choice. In Wabakimi Provincial Park, higher understorey tree density and lower ground detection distance played key roles in distinguishing nursery sites from sites that were not used. In Woodland Caribou Provincial Park, groundcover vegetation and shrub density were important in the selection of nursery sites by female caribou. Generally, female caribou in both parks selected nursery sites with greater slope, lower shrub density, but thicker groundcover vegetation, and higher overstorey cover than shoreline sites that were not used.

The last objective was to determine what physical characteristics caribou might be using at a larger scale (i.e., distance to nearest land feature from nursery sites, distance to closest fly-in outpost from nursery sites). In Woodland Caribou Provincial Park more nursery sites occurred in the coniferous forest landcover type when compared to unused or random sites. In Wabakimi Provincial Park, there was no difference between nursery activity and landcover types randomly available in the study area. Generally, female caribou in both parks selected nursery sites with shorter escape distances than provided by unused or random sites, and islands were the feature type most frequently used for nursery activity. Female caribou also used clusters of land features within shorter distance of one another as compared to random points along the shoreline. Caribou cow-calf pairs typically used areas for nursery activity that were 9.0km (± 6.5km, range 2.3-20.6km) in Wabakimi Provincial Park and 10.0km (± 6.9km, range 0.7 – 32.6km) in Woodland Caribou Provincial Park from any human recreational disturbance.

The identification of these important characteristics of caribou nursery areas at 2 different spatial scales provides baseline information that may be used to predict the locations of potential caribou nursery sites both within protected area boundaries and across the broader range of this valued species in northern Ontario. It is suggested that a first iteration spatial model be developed from the outcomes of this study to enable validation and refinement and to enhance the management and understanding of this critical life history requisite.

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Preface

In 2001, Ontario Parks received funding from the Ontario Ministry of Natural Resources Species at Risk program to identify nursery areas for forest-dwelling woodland caribou (*Rangifer tarandus caribou*) in both Wabakimi and Woodland Caribou Provincial Parks. This sub-species of caribou has been designated as "threatened" by both the Committee on Species at Risk in Ontario (COSSARO) and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). By identifying these nursery areas and examining their characteristics, as well as traditional use and characteristics of these sites, management decisions can be made to protect habitat essential to this threatened species.

Calving sites are generally taken to be locations at which parturition occurs, whereas nursery sites are areas occupied by cow-calf pairs during the post-partum period (Lent 1974, Addison et al. 1990, Schaefer et al. 2000). Calving and nursery sites cannot always be readily distinguished by physical evidence (i.e., calf beds, pellets, or tracks) observed in transect surveys. No direct evidence of parturition was seen in this study. Therefore, all cow-calf sites were classified as nursery sites, even though birthing activity may have taken place as well. Absence sites were defined as areas with no evidence of use by caribou.

The primary intent of this study was to examine the physical and vegetation characteristics, as well as traditional use, of woodland caribou nursery areas. The general research hypothesis was that woodland caribou use the same nursery areas year after year and that these areas may have particular vegetation and topological features (e.g., on an island or peninsula) that may minimize predation risk. Chapter 1 investigates the traditional use of nursery sites. Chapter 2 examines the fine-scale attributes of vegetation and physical features at nursery sites in comparison to unused "absence" sites and, finally, Chapter 3 investigates the landscape-scale characteristics of these sites.

General Introduction

Mortality rates of animals in the first stages of life are often quite high and the proliferation of a species depends on some animals surviving this critical phase. Predation is a major selective force and many adaptations we see in organisms, such as warning coloration, have their explanation in predator-prey coevolution (Krebs 1994). Therefore, species must develop strategies that minimize the risk of predation of their offspring during this stage. Given a choice, animals should opt for areas that are most likely to improve survival and reproduction (Festa-Bianchet 1986). Animals that choose poor, marginal habitats will not raise as many progeny and consequently will be selected against (Krebs 1994). Natural selection may act directly upon the behaviours that result in habitat choice, or it may select for individuals that have the capacity to learn which habitat is appropriate (Krebs 1994).

Predators can kill more than 50% of young ungulates in free-ranging populations (Bergerud 1971). Ungulates appear to be particularly vulnerable in the first few weeks of life when they are old enough to flush from hiding, but are still too young to outrun predators (Fitzgibbon 1990). Year round studies of moose (*Alces alces*) and caribou (*Rangifer tarandus*) report that calves are most vulnerable to brown bear (*Ursus arctos),* (Stuart-Smith et al. 1997), black bear (*Ursus americanus*) (Ballard 1994, Ballard and Van Ballenberghe 1998), and wolf (*Canis lupus*) (Bergerud and Page 1987, Messier 1991) predation in their initial weeks of life. Similarly, elk (*Cervus elaphus*) calves are most susceptible to bear and coyote (*Canis latrans*) predation in the first month following birth (Singer et al. 1997). As well, white-tailed deer (*Odocoileus virginianus*) fawns are most frequently predated upon by wolf, bear, and coyote in their first summer (Kunkel and Mech 1994).

Caribou have developed space-use strategies to avoid predation (Bergerud et al. 1990, Rettie and Messier 2001), which is considered the main proximate factor of population limitation of woodland caribou across North America (Bergerud 1974a, Seip 1992, Ouellet et al. 1996, Stuart-Smith et al. 1997, Rettie and Messier 1998). Female caribou are thought to minimize predation risk during calving by either "spacing out" (individuals separating from each other) or "spacing away" (dispersing across the landscape) from predators (Bergerud 1985). In this regard, woodland caribou behave differently at calving time across Canada. "Sedentary" caribou are known to space out in the forest to calve individually on islands, small openings in wetlands, or along lakeshores, which are considered relatively safe habitats (Bergerud 1985, Bergerud et al. 1990). "Migratory" caribou may space away from wolves and non-calving caribou by migrating several hundred kilometres to tundra calving grounds (Heard et al. 1996). In mountainous terrain, sedentary caribou space away from wolves, alternate prey, and non-calving conspecifics to calve at high elevation away from the travel routes of wolves in valleys and moose in forested areas (Bergerud and Butler 1984, Bergerud 1985). If they inhabit lowland forests without mountains, caribou disperse widely at calving (Fuller and Keith 1981, Brown and Theberge 1985). Female caribou in herds in areas where there are no mountains, and situated far enough north that lakes are frozen at calving time, disperse to small openings in wetlands (Fuller and Keith 1981, Brown et al. 1986). Many of these small openings could allow females to see an approaching predator and many of these small openings contain small ponds that become free of ice earlier than the larger lakes and may allow females to more readily see an approaching predator. The woodland caribou that migrate to mountains or small wetlands to calve are more dispersed at calving than in any other season (Fuller and Keith 1981, Bergerud and Butler 1984, Brown et al. 1986, Edmonds 1988).

Densities of caribou populations spacing away from predators on tundra calving grounds are generally higher than those of caribou populations spacing out to calve on mountains, which in turn are higher than those spacing out in forests (Bergerud and Page 1987). Woodland caribou may spatially separate themselves from other ungulates that provide prey for wolves and bears (*Ursus* spp.) by using lakeshores and islands (Bergerud 1985, Cumming and Beange 1987) or bog complexes (Valkenburg et al. 1996, Stuart-Smith et al. 1997) in the spring. Sexual segregation alone cannot explain this behaviour since bulls are often found in the same area as cows, such as in the vicinity of Lake Nipigon where male and female caribou live on islands from April to December and then move off islands when ice forms (Bergerud and Butler 1984, Cumming and Beange 1987, Bergerud *et al.* 1990). One possible explanation for this activity could be that the wolf population on the mainland is extremely high and male caribou give up more suitable foraging areas, along with the females, in order to occupy a safer habitat during summer.

Female caribou selection of lakeshores and islands for calving may be unique to the Cambrian Shield area, where lakes and associated islands are numerous (Ferguson and Elkie 2005). Calving sites in Manitoba (Shoesmith and Storey 1977) and Ontario (Bergerud 1985) often include shorelines and islands in large lakes, which are thought to reduce predation risk. Large lakes are not numerous in Alberta and Saskatchewan where woodland caribou select open fens for calving (Stuart-Smith et al. 1997). Darby and Pruitt (1984) found that woodland caribou in southeastern Manitoba used mature coniferous uplands more than any other habitat type, except during October, December, and January when semi-open and open bogs were used more frequently. Caribou calved in early May and surveillance of islands and lakeshores revealed that caribou did use lakes in the late spring and summer, but less than reported previously by Shoesmith and Storey (1977) in central Manitoba. Hillis et al. (1998) studied woodland caribou habitat utilization in northern Ontario using satellite telemetry and found that between June 1 and August 31 the common land classifications utilized were treed bogs (18.7%), mixed deciduous forest (16%), dense coniferous spruce forest (14.8%), shorelines (13.3%), and dense coniferous pine forest (10.2%). In Alberta and Saskatchewan, female woodland caribou selected both black spruce dominated stands and peatlands during calving and post-calving and throughout the rest of the year (Stuart-Smith et al. 1997). Bergerud (1974a) hypothesized that the calving distribution of sedentary caribou east of the Rocky Mountains is related to the presence of muskegs with open water at calving to reduce predation.

Studies have reported distinct summer and winter ranges (Edmonds 1988) and that female woodland caribou exhibit selectivity for specific calving and summer ranges (Brown et al. 1986). Nelson and Mech (1999) found that a single matriline of white-tailed deer repeatedly occupied the same summer range for over 20 years and suggested that matriarchal behaviour and philopatry are deep-seated genetic traits of ungulates; the long-term products of evolution.

This study examines the characteristics of the habitat used by caribou during the nursery season in 2 areas that are not directly disturbed by industrial activity. It is important to identify these nursery areas to ensure that adequate protection is given to these sites in order that they may be continually used. Disturbances caused by landscape exploitation surrounding Wabakimi and Woodland Caribou Provincial Parks and human encroachment, both outside and within the 2 study area boundaries, may prevent female caribou from returning to previously used calving sites on shorelines, forcing them to use less suitable habitats, which can lead to greater predation and reduced population viability. Protection of calving and nursery sites is critical for caribou due to their threatened status and low fecundity rate compared to other ungulate species. Caribou have a low reproductive potential compared to other ungulates, generally giving birth for the first time around 28 months of age and usually to only 1 calf a year (Bergerud 1980). Species at Risk (SAR) surveys in Wabakimi and Woodland Caribou Provincial Parks have focused on lakes because of their high recreational use by humans and their known importance to caribou cow-calf pairs. This thesis makes use of data obtained in 3 years of SAR surveys in both parks, to examine site fidelity and nursery site characteristics at both the fine-scale and at landscape levels. Site fidelity has been quantified as the percentage of animals returning to a specific range or site or the frequency distribution of between-year distances of animals returning to a given area (Brown and Theberge 1985). By identifying some of the important features of caribou nursery areas, higher protection can be considered in future management policies and legislation.

To address site fidelity of the threatened woodland caribou populations in both parks, I hypothesized that I would find traditional use of nursery areas by female caribou, not necessarily on the exact same nursery island but possibly on the same nursery lake, in at least 2 nursery seasons over the 3 years of study. Lent (1964) and Skoog (1968) were among the first to emphasize that annual use of calving grounds was one of the most consistent behavioural characteristics of caribou, and called this use "traditional".

Therefore, the first objective of this study was to determine if in fact the same female was using the same area for calving and nursery activity year after year. My second objective was to determine the characteristics of shoreline habitats used as calving and nursery areas by female woodland caribou in the 2 parks. Habitat characteristics selected at nursery sites have been hypothesized to reflect predator avoidance strategies (Bergerud 1974a, 1985; Bergerud et al.1990) and thus their protection in future management policies and legislation would have the greatest impact on population persistence. And finally, my third objective was to determine what physical characteristics caribou were using at a larger landscape scale (i.e., distance to closest land feature from nursery sites, distance to closest fly-in outpost from nursery sites). I hypothesized that caribou use landscapes consisting of particular interspersion of features with minimum escape distances in order to flee from predators.

To accomplish these objectives, I: (1) tested site fidelity by collecting woodland caribou faecal samples in Wabakimi and Woodland Caribou Provincial Parks for DNA extraction and analysis; (2) measured detailed vegetation and other site characteristics at nursery sites used by cow-calf pairs in Wabakimi and Woodland Caribou Provincial Parks for comparison with shoreline sites that were not used, then developed and evaluated Resource Selection Functions (RSFs) for calving woodland caribou in each park; and (3) I examined differences in the interspersion of landscape features among used, unused, and available (random) caribou nursery sites on lakes in Woodland Caribou and Wabakimi Provincial Parks using a Geographic Information System (GIS).

Study Areas

Wabakimi Provincial Park

Wabakimi Provincial Park, located in northern Ontario, about 200km north of Thunder Bay (Figure 1) was established in 1983 at a size of 155,000ha and was expanded in 1997 to roughly 892,000ha (Duinker et al. 1996). One of the main reasons that the park was expanded was to protect woodland caribou. Wabakimi Provincial Park extends from 50° 00'N to 51° 30'N, with the Albany River providing part of the northern boundary. From west to east, the Park extends from 90° 30'W to 88° 30'W. The nearest community to the western boundary of the park is Savant Lake and the nearest community to the eastern boundary is Armstrong.

The Park is bounded to the east, west, and south by a number of forest management units (FMUs) including: Armstrong, Brightsand, Black Sturgeon (Caribou East block), Caribou, and Ogoki. Moose guidelines for forest management (OMNR 1988) are applied to the Armstrong and Brightsand FMUs, while forestry guidelines for woodland caribou (Racey et al. 1999) are applied to the Armstrong, Caribou East, Brightsand, Caribou, and Ogoki FMUs.

The average July temperature in Wabakimi Provincial Park is 16°C, while the average January temperature is -17 to -20°C (Chapman and Thomas 1968). Total annual precipitation is approximately 750mm, which is considered moderate relative to other parts of the province, with approximately two-thirds falling from May to September (Chapman and Thomas 1968). Tree species include white spruce (*Picea glauca*), black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), white pine (*Pinus strobus*), and red pine (*Pinus resinosa*) (Harris and Foster 2005). Mosses are a conspicuous cover over much of the forest floor, while patches of ground lichen (*Cladina* spp.) are common on jack pine-dominated sand flats and under open spruce stands on bedrock (Harris and Foster 2005). The fire regime of this ecoregion is characterized by numerous small fires (<1,040ha) and few large fires (>5,000ha), but most of the total area burned is in large, intense fires (Beverly 1998). Beverly (1998) found that the total area burned in the park decreased steadily from the 1930s to the 1960s, but increased in the 1990s. The estimated fire cycle range for Wabakimi Provincial Park ranges from 65-250 years (Ride et al. 2004).

The ecological site regions represented in the park are 2W-3, 3W-1, 3W-2, and 3S-4 (Crins 2000). These ecological zones are classified according to natural features including landforms, soil, water, vegetation, and climate (Crins 2000).

The human activities in the park consist of 44 fly-in outposts, 4 private cottages, and 7 private main base lodges. For backcountry camping in 2006 there were approximately 650 visitors with a total camper night number of approximately 3,200 and half of these visitors went to the park in August.

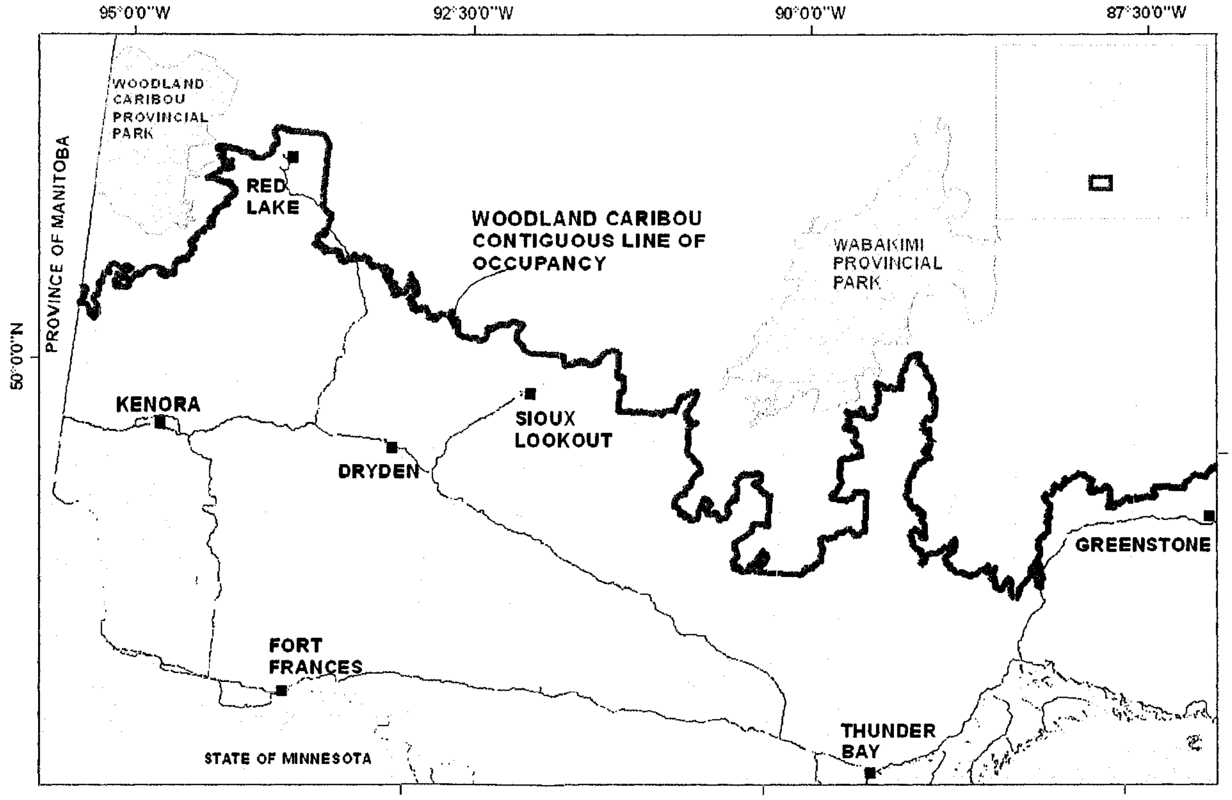


Figure 1. Locations of Wabakimi and Woodland Caribou Provincial Parks in relation to the southern limit of contiguous range occupancy of woodland caribou in northern Ontario (Ontario Woodland Caribou Recovery Team 2007).

Woodland Caribou Provincial Park

Woodland Caribou Provincial Park is 450,000ha in size and is located between Red Lake and the Manitoba border in northwestern Ontario, about 500km northwest of Thunder Bay (Figure 1). The area to the north remains largely undeveloped with the exception of remote tourism development, although a new Forest Management Unit, the Whitefeather Forest, is being planned northeast of the park. The Red Lake, Whiskey Jack, and Kenora FMUs border it to the east and south. The moose guidelines (OMNR 1988) are applied to all of the Whiskey Jack and almost the entire Kenora Forests. Both the woodland caribou (Racey et al. 1999) and moose guidelines have been applied to the Red Lake Forest. Access in the Ontario portion of the study area is limited to floatplane and 3 areas of road access on the eastern boundary.

The average July temperature in Woodland Caribou Provincial Park is 18.4°C while the average January temperature is -20.4°C (OMNR 2004). Average annual precipitation is approximately 609mm, which is very low for Ontario (Brunton 1986). Vegetation of the area consists of typical boreal tree species such as jack pine, black spruce, balsam fir, and trembling aspen dominating upland sites, with black spruce and larch (*Larix laricina*) characterizing the wet, organic deposits commonly found in bedrock depressions (OMNR 2004). The park is situated on a relatively flat plateau and soils are thin when present at all (1986). The slightly elevated position of the park has resulted in a greater than normal incidence of dry upland forest, so jack pine is more dominant than black spruce (Brunton 1986). Ground lichen is dominant in older jack pine forests and a dense ground cover of feather moss is common in black spruce forests (Brunton 1986). This park is significantly affected by its proximity to the Prairie Provinces, resulting in a dry, hot growing season creating "boreal prairie" forests that experience a greater frequency of naturally occurring forest fires, in contrast with the more moist boreal forests further east (OMNR 2004). The wilderness landscapes of this park have been strongly influenced by wildfire (Harris et al. 2001). Brunton (1986) noted that most of the park had been burned between 1956 and 1986 and frequent and repeated burns appear to be representative of the area's natural cycle of burning since deglaciation. The estimated fire cycle range for Woodland Caribou Provincial Park ranges from 40-110 years (Ride et al. 2004).

The human activities in the park consist of 15 fly-in outposts, 16 private cottages, and 4 private main base lodges. For backcountry camping in 2006 there were approximately 725 visitors with a total camper night number of approximately 4,700 with no pattern to the most camper nights in any particular summer month.

Chapter 1. Nursery Site Fidelity of Woodland Caribou in Northern Ontario

Introduction

Many species of birds and mammals are faithful to their natal and breeding sites (Greenwood 1980). Primates are often faithful to territories or home ranges and boundaries between adjacent individuals or groups can be stable for long periods (Greenwood 1980). The reuse of suitable habitat that has previously led to successful breeding can reduce the costs of searching and relocation (Greenwood 1980). Using a familiar site involves less risk than using an unknown site that may prove to be unfavourable (Welch 2000). The consequences may be particularly detrimental if specific features are needed to meet important life history requirements such as breeding and parturition (Welch 2000). Therefore, preservation of habitat used for parturition can have important conservation implications for the productivity of a population (Welch 2000).

For caribou with limited suitable range, habitat displacement, or loss thereof, could result in higher mortality rates due to increased predation risk and poorer forage quality (Webster 1997). A study in West Greenland modelling critical caribou summer ranges illustrated that *R. t. groenlandicus* were much more selective in choosing their habitat in July than in late summer (Tamstorf et al. 2005). Long-term displacement from a home range over several years (especially during the calving period) may result in increased mortality, decreased reproductive success, increased predation, altered habitat use, and decreased caribou densities (Webster 1997).

Female caribou typically exhibit strong philopatry to a particular area for calving and nursery activities (Brown and Theberge 1985, Gunn and Miller 1986, Fancy and Whitten 1991). Site fidelity has been quantified as the percentage of animals returning to a specific range or site or the frequency distribution of between-year distances of animals returning to a given area (Brown and Theberge 1985).

Bergerud (1974b) suggested 3 different hypotheses to explain caribou fidelity to calving grounds in open habitats:

1) a homing of individuals with learning and traditions involved,
2) the "funneling" or directing of movements by topographic features with caribou recognizing the calving ground through phylogenetic imprinting, and
3) the movement of animals from a pre-calving range in a traditional direction (presumably determined by imprinting), which brings them to the same general area each year).

Fidelity occurs in many other ungulate species such as deer and moose. Welch et al. (2000) suggested that calving site fidelity in moose may be related to past reproductive success. Testa et al. (2000) found a high directional change in female moose movements prior to parturition, perhaps due to a predator avoidance strategy. Testa et al. (2000) also reported low fidelity in female moose and a high dispersion pattern in birthing sites for those females that had lost a calf in the previous calving season. Moose cows in Sweden were found to return to the same summer range each spring and were solitary during these months after they dispersed over the range (Cederlund et al. 1987). Welch et al. (2000) found calving fidelity in moose in northwestern Ontario, with distances ranging from 56m-12km between sites used for calving in consecutive years. Summer fidelity has also been described in female black-tailed deer (*Odocoileus hemionus columbianus*) (Weckerly 1993), white-tailed deer (Tierson et al. 1985), and mule deer (*Odocoileus hemionus hemionus*) (Garrott et al. 1987).

Many studies of barren ground caribou (*R. t. groenlandicus*) also demonstrate the use of traditional calving sites (Pare and Huot 1985). Cameron et al. (1986) found that their study of summer fidelity in barren-ground caribou in Alaska supported Bergerud's (1974b) hypothesis #1, through "homing", without being influenced by topography or by a "traditional" orientation of movement. Heard et al. (1996) also found that migratory barren-ground caribou cows sacrificed foraging benefits, which would have been available to them if they migrated as the bulls did. Female barren-ground caribou migrate in the spring and return to specific calving grounds in the arctic (Bergerud 1974b). Gunn and Miller (1986) found that barren-ground caribou in the Northwest Territories exhibited long-term fidelity to a specific calving area, but location changes did occur. They found that the calving experience of a female and environmental pressures may modify her use of a previous calving ground.

Site fidelity differs among individuals and habitat shifts are also known to occur in calving areas, as described by Valkenburg et al. (1988). Their study involved a habitat shift where all caribou (*R. t. granti*) gathered near a retreating snowline, minimizing predator contact. Cameron et al. (1986) also found over 80% of the female barren-ground caribou returned to the same calving grounds in Alaska for at least 3 or more summers over a 7-year span.

Schaefer et al. (2000) proposed that site fidelity may confer reduced predation risk to females and their calves, although the notion has not been tested. Their study demonstrated that migratory woodland caribou calving fidelity disappeared when viewed at a smaller scale, corroborating the findings of Fancy and Whitten (1991) and Bergerud (1996) that females are philopatric to their traditional calving grounds but not to precise locations on these grounds. In contrast, the philopatry pattern of sedentary woodland caribou persisted across all scales, indicating consistent site fidelity from calving to breeding periods (Schaefer et al. 2000). The sedentary woodland caribou distributed south of the tree line also make directional movements in the spring to return to specific calving locations (Brown and Theberge 1985, Edmonds 1988, Fuller and Keith 1981). Brown et al. (1986) found that individuals in 4 woodland caribou herds in Quebec showed site fidelity over a 3-year period and were widely dispersed at calving. Poole et al. (2000) found that 3 out of 9 caribou calved within 1.1km of their previous calving site; all the others were within 9km. Brown and Theberge (1985) found that woodland caribou in Central Labrador used the same calving area (within 10km of the previous calving area) 63 – 68% of the time in the course of 3 seasons.

Ferguson and Elkie (2004) found that there was a long distance movement spike by woodland caribou females a week prior to June 1, followed by 3 days of little movement, suggesting a mean calving date of June 1. The most dispersion of females occurred during calving, while the smallest seasonal range was occupied and a strong fidelity to calving areas occurred in contrast to the highly variable year-to-year location of winter ranges (Ferguson and Elkie 2004). Group size, movements, and spatial distribution suggested individual female caribou may be spreading out or distancing themselves from conspecifics in summer to reduce predation risk (Ferguson and Elkie 2004). Ferguson et al. (1998) found greater linearity of female caribou travel routes in early spring and autumn, suggesting more directed movements to particular habitats.

Conservation ecology is increasingly adapting genetic analysis to complement and enhance the knowledge of wildlife population dynamics (Hedrick and Miller 1992). This is critical to the study of endangered animal populations, which necessitate less invasive approaches to gather information. A non-invasive approach to study site fidelity is to examine animal movements through DNA analysis of faecal pellets. Faecal samples include cells that are shed from the intestinal lining and contain DNA that can be extracted (Flagstad et al. 1999). Both mitochondrial and nuclear DNA can be gathered from these samples (Ball 2002). Mitochondrial DNA is useful in determining direct genetic lineages, since it is maternally inherited and enables differentiation of populations based on maternal lineages, as well as determination of female movement among wildlife populations (Kocher et al. 1989). Nuclear DNA analysis using microsatellite markers enables researchers to obtain information on specific individual movements, sex, and parentage, as well as to assess genetic diversity through quantification of allele polymorphisms (the number of different alleles within a population) (Hedrick and Miller 1992). Microsatellite DNA allows the measurement of variation within and among caribou populations and can be used to distinguish separate populations at the genetic level (Kushny et al. 1996, Zittlau et al. 2000).

This study used caribou faecal samples obtained from Wabakimi and Woodland Caribou Provincial Parks from 2001-2003 during site fidelity and metapopulation studies. I hypothesized that I would find traditional use of nursery areas by female caribou, not necessarily on the exact same nursery island, but possibly on the same nursery lake, in at least 2 nursery seasons over the 3 years of study.

Methods

Field Collection Protocol

Faecal samples were collected in the freshest possible form, which was determined from the moistness of the mucosal coating of the pellets. These pellets were collected when they were encountered on transects that were walked in summer to identify nursery sign (Chapter 2). Samples were only collected from faecal piles and not collected if dispersed over a wide area, in order to not compromise the individuality of the sample through contamination. A different pair of latex gloves was used each time to collect each sample. Eight to 10 pellets were collected from each site and placed into plastic tubes. These tubes were immediately placed next to cold packs to prevent DNA degradation, but in high summer heat this storing method was not optimal. Samples were kept as cold as possible until they were returned from the field and frozen until shipping to the Natural Resources DNA Profiling and Forensic Centre (NRDPFC) at Trent University, Peterborough, Ontario.

Laboratory Protocol

DNA extraction from faecal pellets was performed utilizing a pellet wash modified from Flagstad et al. (1999). All eluted samples were stored frozen. To determine successful extraction of caribou DNA, the control region of the mitochondrial DNA (mtDNA) was amplified. MtDNA control region amplified product for each sample was loaded onto a 1.5% agarose gel stained with ethidium bromide. Samples showing positive mitochondrial amplification were chosen for nuclear microsatellite amplification. All samples exhibiting successful microsatellite amplification through agarose electrophoresis were submitted for genotyping using an automated fluorescent unit. Once the individuality of each sample was confirmed through genotyping, those samples were selected for sequencing of the mtDNA control region. Each sample was then given a numerical haplotype designation according to the results and the frequencies of the different haplotypes were then derived within each region and compared. Detailed laboratory methodology is provided in Appendix 1.

Results

Field Results

A total of 137 faecal samples were collected throughout the 3 summers of study in both parks. In Wabakimi Provincial Park the numbers of samples collected were as follows for each study year: 9 (2001), 30 (2002), 28 (2003). In Woodland Caribou Provincial Park the numbers of samples collected were as follows for the study years: 5 (2001), 37 (2002), 28 (2003).

Laboratory Results

Microsatellite Analysis

Genotypes with at least 3 of 5 loci (Rt6, Rt9, Map2c, BM4513, and RT30) were chosen for this analysis. However, due to low sample sizes, additional optimization was required to provide sufficient amplification for complete individual identification. In the end, the total number of individuals used for microsatellite analysis was 29. Confirmed genotypes for each of the samples showed that all samples were from different individuals.

Mitochondrial DNA Control Region Analysis

The mitochondrial control region analysis for all 29 individuals produced only 21 samples with high quality sequence DNA. Successful amplification was achieved for mitochondrial DNA in 11 samples from Woodland Caribou Provincial Park and 10 from Wabakimi Provincial Park. Analysis of the sequences derived from these samples showed that there were a total of 7 different haplotypes in the 2 parks. Sample sizes were low, but there were enough samples to provide sufficient data to examine structure and dispersal between these areas. Examination of haplotype occurrence in each of the regions showed that one haplotype was shared among individuals in Woodland Caribou and Wabakimi Provincial Parks. When the study lakes inside and outside of the parks were grouped into 6 broad regions, 2 haplotypes were shared between individuals in the Woodland Caribou Provincial Park region and the Wabakimi Provincial Park region.

Discussion

Technical Considerations

The quality of faecal samples is of critical importance to DNA profiling and the fresher the sample the better the DNA extraction (Ball and Wilson 2004). The DNA is from cells in the film of mucous covering the faecal sample and not within the faecal matter itself (Ball and Wilson 2004). The mucosal coating is vulnerable to many environmental variables such as rain, heat, and UV radiation, which can remove this layer or cause severe degradation of its DNA (Flagstad et al. 1999). Summer-collected samples are problematic due to environmental conditions that may rapidly degrade DNA on faecal pellets. Logistically, it is much more difficult to collect fresh faecal samples in the summer than in winter because of the need to keep the samples ice cold while sampling in remote areas. Furthermore, the summer diet of caribou also changes the consistency of faecal pellets, making them more likely to break during the DNA extraction process, compromising later procedures. Through the DNA collections in both protected areas and a collaborative project with Manitoba and the NRDPFC at Trent University, it has been determined that the optimal sampling time for faecal collections occurs during the mid-winter months (January-February) (Morrill et al. 2005). During this time, faeces quickly freeze on being deposited, thereby preserving the mucosal coat of the pellet and permitting high quality/quantity DNA extraction. Winter-collected faeces are superior to summer collections for successful amplification of mitochondrial and nuclear DNA (Morrill et al. 2005).

Since the dispersion of individual female caribou is greatest in the calving season (Ferguson and Elkie 2004), a study that concentrates on one lake at a time could include pellets from the same individual several times, thereby compromising the possibility of identifying the numbers of females using each lake and establishing the level of philopatry. Funding was the greatest constraint in this study and optimally one would randomly select areas throughout both parks to survey and then re-survey with a large buffer around first-collection sites. Brown and Theberge (1985) suggested that woodland caribou demonstrated site fidelity when calving 10km from the calving location the year before. Thus, one would have to re-survey with a buffer of at least 10km from the last calving location and systematically survey many sites within that buffer area.

The low success in amplifying nuclear DNA from summer-collected faecal samples places some limitations on our ability to individualize each sample (Morrill et al. 2005). Without this information, frequency data regarding mtDNA haplotypes risk becoming over-inflated due to multiple sampling from the same individual (Ball and Wilson 2004). However, the use of critical movement thresholds to determine sample individuality is currently being assessed (Ball and Wilson 2004). This premise would work under the assumption that females and their calves are not pre-disposed to move long distances post-calving and will remain in a relatively small area (Ball and Wilson 2004). If such is the case, then there is the potential to exclude samples of identical haplotype as being from the same individual if the spatial distance between collection sites exceeds a predetermined movement threshold (Ball and Wilson 2004). Using this premise, the mitochondrial sequence data could be utilized for site fidelity analysis, minimizing sampling bias for multiple sampling of an individual (Ball and Wilson 2004). An effective strategy to confidently determine confidence limits for this spatial threshold is being developed (Ball and Wilson 2004). More recent methodology (Ball et al. 2007) also has more DNA markers and may be used to successfully extract microsatellite DNA from summer collected samples, so the samples collected in this study should be re-analyzed in the near future.

Site Fidelity

The mitochondrial DNA (mtDNA) analyses suggest that there is genetic differentiation of caribou between Woodland Caribou and Wabakimi Provincial Parks (Ball and Wilson 2004). These differences suggest that caribou within these areas are exhibiting female philopatry in the nursery period (Ball and Wilson 2004). The haplotype frequency data suggests that the study areas are exhibiting concentrations of maternal haplotypes that are not shared across the region. As mtDNA is maternally inherited in caribou (Avise 1995), these data indicate that females of specific mtDNA lineages are not exhibiting dispersal events between Wabakimi and Woodland Caribou Provincial Parks separated by approximately 300km. One common haplotype was found in individual samples in Woodland Caribou and Wabakimi Provincial Parks (Ball and Wilson 2004). Males carry mtDNA haplotypes from their maternal lineage, but these are not inherited by their offspring (Avise 1995). Any sharing of haplotypes between the 2 parks is therefore likely due to male dispersal, as males have higher rates of movement from May to November compared to females (Ferguson and Elkie 2004); however, gender could not be determined from the summer-collected samples in my study so this hypothesis could not be confirmed. In any event, these findings suggest that there is a level of philopatry by females to the nursery-grounds, that these herds are not isolated, and that male dispersal events are taking place between the 2 parks (Ball and Wilson 2004). To confirm female philopatry within caribou populations, it is necessary to determine the gender of these samples (Ball and Wilson 2004). By determining the gender of samples, we would be better able to assess the structure and movement of caribou among regions (Ball and Wilson 2004). Currently, the only available method to determine the gender of DNA samples involves the use of a large sex chromosome marker (ZFX-ZFY, approximately 950 base pairs) (Shaw et al. 2003), which is unsuitable for samples with degraded DNA. In any case, due to limitations in response to the condition of DNA extracted from summer samples, we need to determine if genetic differences are due to population structuring or calving ground philopatric behaviour (Ball and Wilson 2004). For clarification it will be critical to obtain information from nuclear DNA markers in order to determine the fine-scale structure of caribou populations in northern Ontario, through analyses of microsatellite loci (Ball and Wilson 2004). Ball et al. (2007) document that winter-collected caribou faecal samples have the same quality of DNA as those collected using invasive methods such as blood, tissue, and bone samples. This method also allows a greater collection of samples as compared to commonly used methods such as radio collaring. Future studies could also examine reproductive hormones in faecal samples and attempt to relate pregnancy rates to rearing success of calves. Thus, I recommend future sampling should concentrate on winter collections from each of the caribou herds in northern Ontario (Ball and Wilson 2004). In response to the high success of genetic analyses from winter-collected faecal samples from elsewhere in Ontario and Manitoba (Morrill et al. 2005), it is hoped that extensive winter sampling in Ontario will provide enough genetic material to thoroughly investigate the population structure of woodland caribou at various scales using both mtDNA markers as well as numerous microsatellite loci (Ball and Wilson 2004). Furthermore, success in obtaining reliable microsatellite genotypes and gender identification from winter-collected samples indicates this approach could be used for monitoring genetic diversity, dispersal patterns, and population size estimates through mark-recapture surveys (Ball and Wilson 2004).

Since both parks have high recreational use in the summer months, it is important to manage these nursery areas appropriately. The DNA results did not prove that an exact lake was being used for 2 summers by the same female caribou; however, Wabakimi Provincial Park had an extremely high rate (95%) of nursery site re-use over 2 summers based on field observations (Morrill et al. 2005). Woodland Caribou Provincial Park only had a nursery site re-use percentage of 33% based on field observations (Morrill et al. 2005). Morrill et al. (2005) speculated that this difference may be attributed to nursery sites being more available in Woodland Caribou Provincial Park than Wabakimi Provincial Park and that a female has more options from year to year. This repeated nursery use in both parks suggests that these sites are providing important summer habitat during this critical calving and nursery period for this threatened species. These re-used nursery sites provide important information for park management and should be protected as sensitive values. If the re-used nursery sites have some similar features, potential calving and nursery areas in both parks can be identified and protected.

Chapter 2. Habitat Characteristics of Woodland Caribou Nursery Sites in Northern Ontario

Introduction

Site-attribute studies differ from use-availability studies in that they measure a multitude of habitat-related variables at specific sites and attempt to identify the variables that best characterize sites that are used most often by a particular animal species for a specific activity (Garshelis 2000). According to Garshelis (2000), site-attribute studies may include evaluating breeding territories, drumming sites, roosting sites, feeding sites, calving and nursery sites, food storage sites, resting sites, wintering sites, recolonization sites, and shelters. The statistical approach most often used in these studies is Discriminant Function Analysis (DFA) with logistic regression as an alternative (Garshelis 2000). With this design, the dependent variable is not the amount of use but simply whether sites are used or unused (Garshelis 2000). Site attribute studies often focus on sites of biological importance and may provide more direct insights into habitat variables that affect fitness based on the assumption that used sites are in suitable habitats and that unused sites are in unsuitable habitats (Garshelis 2000).

McLellan (1986) argued that observed use is a better indicator of habitat selection than use relative to availability. He reasoned that an animal familiar with its home range knows the availability and location of resources, so an animal's location at any given moment represents selection, which would improve fitness.

Fitness certainly was enhanced for a herd of caribou in Ontario that spent most of its time on an island (Ferguson et al. 1988). The nearby mainland had higher-quality forage, but also a high density of wolves. Ferguson et al. (1988) found that the island occupants sacrificed nutrition, which is reflected in smaller body and antler size as well as starvation of their calves, for overall higher survival, which enabled this population to persist while herds that remained on the mainland perished from predation.

Predation is the chief limiting factor in the survival of cervid neonates in systems that still have natural predators (Bergerud and Elliot 1986) and wild ungulates are most vulnerable to predation during their first few months of life (White et al. 1972, Lingle 2000). Thus, features of ungulate calving and nursery areas could play an important role in the continuance of a species.

Maternal cows should take actions to reduce the success rates of wolves and bears in encountering, detecting, and killing calves (Bergerud and Page 1987). The characteristics of being close to the water and dense vegetation could provide escape once a calf is spotted by a predator; the calf may drop down out of sight and take a hiding position, keeping the head low to the ground and remaining motionless (Fitzgibbon 1990). Reduced movement would reduce encounters with mobile predators if an appropriate initial location was chosen that minimized encounters with predators (Bergerud and Page 1987).

Moose calving site habitat selection studies have produced highly variable results (Addison et al. 1990, Welch et al. 2000). Leptich and Gilbert (1986) found that cow moose in northern Maine seeking secluded areas, selected peninsulas and islands close to the shoreline. Wilton and Garner (1991) found that moose calving sites were not always situated on the highest point of an island or peninsula, but often on a knoll approaching the highest point, which provided easy escape in all directions and easy detection of predators. Wilton and Garner's (1991) study suggests islands were the preferred choice in comparison to peninsulas, if water is a deterrent to predators. Addison et al. (1990) surveyed islands and peninsulas for moose calving sites and found that all but 2 calving sites occurred on hills. In a mechanical manipulative habitat study, Bowyer et al. (2001) found that female moose in Alaska used fewer optimal foraging sites by choosing sites with more concealment cover. Protective cover inhibits prey detection, facilitates escape, and reduces the capture efficiency of visually oriented predators for maternal moose (White and Berger 2001). There are variations in these findings, however, and predators can use lateral cover to avoid being detected by prey (Moreno et al. 1996). This same lateral cover may also obstruct the flight escape of the prey (Lima 1992).

Mortality rates appear to be greater in areas where woodland caribou calve in forested habitats in close proximity to predators and moose (Seip 1992, Seip and Cichowski

1996). Caribou populations with calving sites in alpine areas, islands, and rugged mountains experience lower mortality and are generally stable or increasing (Seip, 1992, Seip and Cichowski 1996). The density of caribou populations in British Columbia appears to be related to their ability to become spatially separated from predators during the summer months (Seip 1992, Seip and Cichowski 1996). Seip et al. (1996) found that it was common for about 40% of adult females that were pregnant to lose their calves by the end of the calving period.

Frid (1999) suggests that due to the risk of predation, Andean deer (*Hippocamelus bisulcus*) utilize higher rocky slopes instead of valley-bottom habitats. Similarly, woodland caribou in British Columbia go to higher elevations to avoid predators, increase predator-searching time, and increase distance from alternative prey (i.e., moose) (Bergerud and Page 1987, Poole et al. 2000). Ouellet et al. (1996) found that the woodland caribou of Gaspé also used higher elevations during calving and distanced themselves from alternative prey (moose and white-tailed deer) and reduced predation by coyotes and black bears. Bergerud and Butler (1984) found that caribou cow-calf pairs that moved to valley bottoms in June suffered greater mortality from wolf and bear predation than those that stayed at high elevations. Barten et al. (2001) found that only female caribou with a calf moved to higher elevations where there were fewer predators and forage quality was comparably lower; the use of this habitat was not for forage but probably to reduce the chance of an encounter with a predator. As well, higher elevation with analogous terrain and snow patches that is similar in colour to caribou may provide cryptic background, making it easier to escape detection by a predator (Barten et al. 2001). Barten et al. (2001) suggest that a female caribou that lost her calf would leave the higher elevation for a lower site.

Ferguson and Elkie (2005) found that previous research in Ontario has led resource managers there to assume that summer woodland caribou habitat use primarily consists of lakeshores and islands, and fens secondarily, during calving (parturition and early lactation). The use of shorelines in summer also appears to be an effective anti-predator calving strategy where animals can avoid predators by using islands and peninsulas, or seek water in escape flights (Bergerud 1985, Cumming and Beange 1987, Ferguson et al. 1988). Bergerud (1985) and Ferguson et al. (1988) found that female woodland caribou at Pukaskwa National Park and Neys Provincial Park used islands during the calving season. Bergerud (1974a) hypothesized that a relic herd would survive in an area with moose and wolves only if there were escape features in the habitat to provide protection against wolves during calving time in the summer. Similarly, Ferguson et al. (1988) found that the remnant population of woodland caribou on Pic Island in Lake Superior persisted on this island due to reduced predation, at the cost of a reduced variety and phytomass of forage. Predator simulation studies using dog chases on Pic Island showed caribou generally followed the shoreline, running into the water or up a steep slope, suggesting that females with calves select safe habitats such as shorelines and hills on this island in the summer months (Ferguson et al. 1988).

The objective of this chapter is to describe fine-scale habitat characteristics of woodland caribou nursery sites on lake habitat used by cow-calf pairs in Wabakimi and Woodland Caribou Provincial Parks that might be useful in future studies to evaluate predictors of potential calving and/or nursery areas. Comparisons are made between the high use areas of nursery sites and "absence" sites. Absence sites in this study are defined as areas with no evidence of use by caribou. Habitat characteristics determined at nursery sites are theorized to reflect some of the predator avoidance strategies discussed above.

Methods

Pre-stratification

Survey areas were first selected based on previous MNR summer caribou calving and nursery surveys. A range of additional data sources were also used to assist in the identification of sites including: (1) habitat that was recorded as having calving potential; (2) moose and caribou population survey information; and (3) previous caribou sighting reports from owners and guests of outpost cabins in the parks. All of the caribou information was recorded on maps and survey areas were selected in order of priority based on the total number of previous sightings. Lakes were further prioritized according to calving potential (where calving potential = total number of sightings of calves/total number of human visits to the site). The number of islands and peninsulas on each lake, the reliability of information, and access and development impacts were also taken into consideration.

Survey Methodology

Previous studies suggest calves are born between the last week of May and first week of June (Bergerud 1975, Ferguson and Elkie 2004). To limit the potential effects of human disturbance on the behaviour of calving caribou or physical disruption of nursery sites (e.g., by walking systematic transects, using motorboats, canoeing), surveys started in the middle of June each year and most finished by the end of July. All surveys were a week long to allow for access time and bad weather. The survey methodology was consistent for each survey. Canoes were used on all surveys except when safety and time considerations were important, in which case motorboats were used. Each member of the crew was able to distinguish caribou tracks and pellet groups from those of other ungulates.

The methodology for this survey followed the “Identification of Woodland Caribou Calving and Nursery Sites” from MNR’s Selected Wildlife and Habitat Features: Inventory Manual (Timmermann 1998). Along the shorelines of lakes and islands larger than 500m in width or length, 100m-transects perpendicular to the shoreline were set every 1-2km and surveyed for physical evidence of use (Timmermann 1998). Islands less than 500m in width or length were surveyed for nursery sites by walking transects, set perpendicular to the shoreline at 1km-intervals, across the entire island. Island and mainland transects were re-surveyed in subsequent years to determine whether or not nursery sites were used in the second and third year of the study. Absence sites were then identified as transects that were surveyed in at least 2 consecutive years without finding any physical evidence of caribou activity. Caribou sign included adult/calf tracks, adult/calf beds, hair, pellets, shed antlers, and tree rubs. Any tracks (cow-calf), calf pellets, calf hair found in beds, or shed female antlers were classed as nursery habitat (areas being occupied by cow-calf pairs during the summer months). When tracks were found in moss or lichen, they were followed, noting any additional sign. Most sand beaches were surveyed due to the easy identification of tracks and freshness. Most beaches were submerged due to the high water level on all trips in 2002 in Wabakimi Provincial Park. All locations of caribou sign were recorded using a GPS unit (Garmin, eTrex, Olathe, Kansas, USA). Lichens were also noted, to establish the potential for winter use. Pellet counts (faecal droppings) can be used to determine preferred habitat types and seasonal use patterns (Neff 1968). Fresh pellets were collected along transects and immediately placed next to cold packs to prevent DNA degradation and to keep them as cold as possible until they were returned from the field and frozen up to 3 weeks until they were sent on dry ice in a cooler to the NRDPFC at Trent University (Peterborough, Ontario) for DNA analysis (Chapter 1).

Six lakes had nursery sign along island and mainland shorelines in 2001 and 2002 in Wabakimi Provincial Park while 16 lakes had nursery sign in these years in Woodland Caribou Provincial Park. Based on these previous observations of caribou cow-calf activity, lakes ranging in size from approximately 127ha to 11,050ha were selected for detailed plot study within each park; 4 lakes (approximate mean size 6,828ha) in Wabakimi Provincial Park and 10 lakes (approximate mean size 1,193ha) in Woodland Caribou Provincial Park. The majority of lakes surveyed in both locations were in areas of high recreational use by lodges and outposts where caribou have been monitored in the past.

A total of 15 previously identified nursery and 15 absence sites were surveyed for detailed habitat characteristics in Wabakimi Provincial Park and 15 nursery and 15 absence sites in Woodland Caribou Provincial Park. Equal numbers of nursery sites and absence sites were assessed on each lake within each park; e.g., if a lake had 5 nursery sites then those areas were assessed along with 5 absence sites randomly chosen from among those identified in previous transect surveys on the same lake.

Site Measurements

Three 10m-radius vegetation plots were completed at each site (Figure 2.1). At absence sites, the centre of the plot began in the middle of the 100m transect that was surveyed in at least 2 consecutive years without finding any physical evidence of caribou activity. The geographic coordinates and elevation of the centre point of the first plot were determined with a handheld GPS unit. The slope was recorded using a clinometer at plot centre. The direction of "downhill" (i.e., aspect) was noted in 45-degree intervals (i.e., N, NE, etc.) relative to the evidence of cow-calf activity.

Each plot was divided into 4 quadrants to measure tree and shrub density and species composition (Figure 2.2). Table 1 (Results Section) provides a list of the interval-scale variables measured in each plot at the calving and absence sites (Leptich and Gilbert 1986, Addison et al. 1990, Langley and Pletscher 1994, Welch 2000). The second and third plots were 30m from the centre point of the first plot (Figure 2.1), both at a random compass direction as long as there was no water and no overlap between plots. The centre point of the first plot was situated where the highest amount of calf sign was found. If no calf bed was found, then the next sign of calving activity (such as calf pellets or calf tracks) was used as the centre of the primary plot. The measurements from the 3 plots were averaged to obtain overall values for the site (Langley and Pletscher 1994).

Vegetation Measurements

Overstorey and understorey canopy cover were estimated occularly, using a 10cm x 4cm cardboard tube, at plot centre and at points 30m from plot centre in each of the 4 cardinal compass directions. These cover estimates were later averaged to obtain a single percent cover estimate for each plot (Welch 2002b).

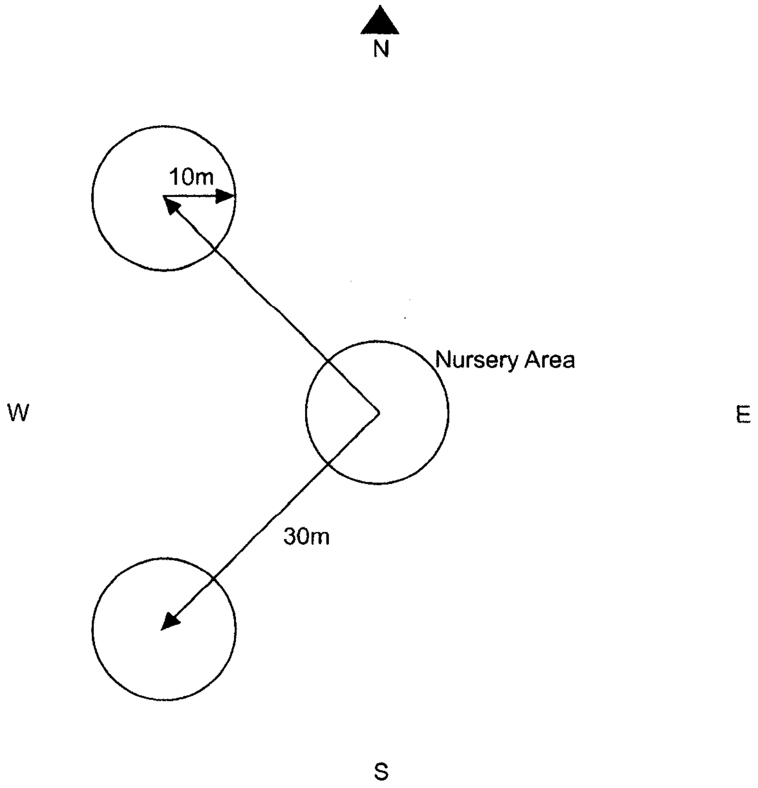


Figure 2.1. Schematic of the three 10m-radius sampling plots used to collect detailed vegetation data and other site characteristics at caribou nursery sites and randomly chosen absence sites on lakes in Wabakimi and Woodland Caribou Provincial Parks, northern Ontario.

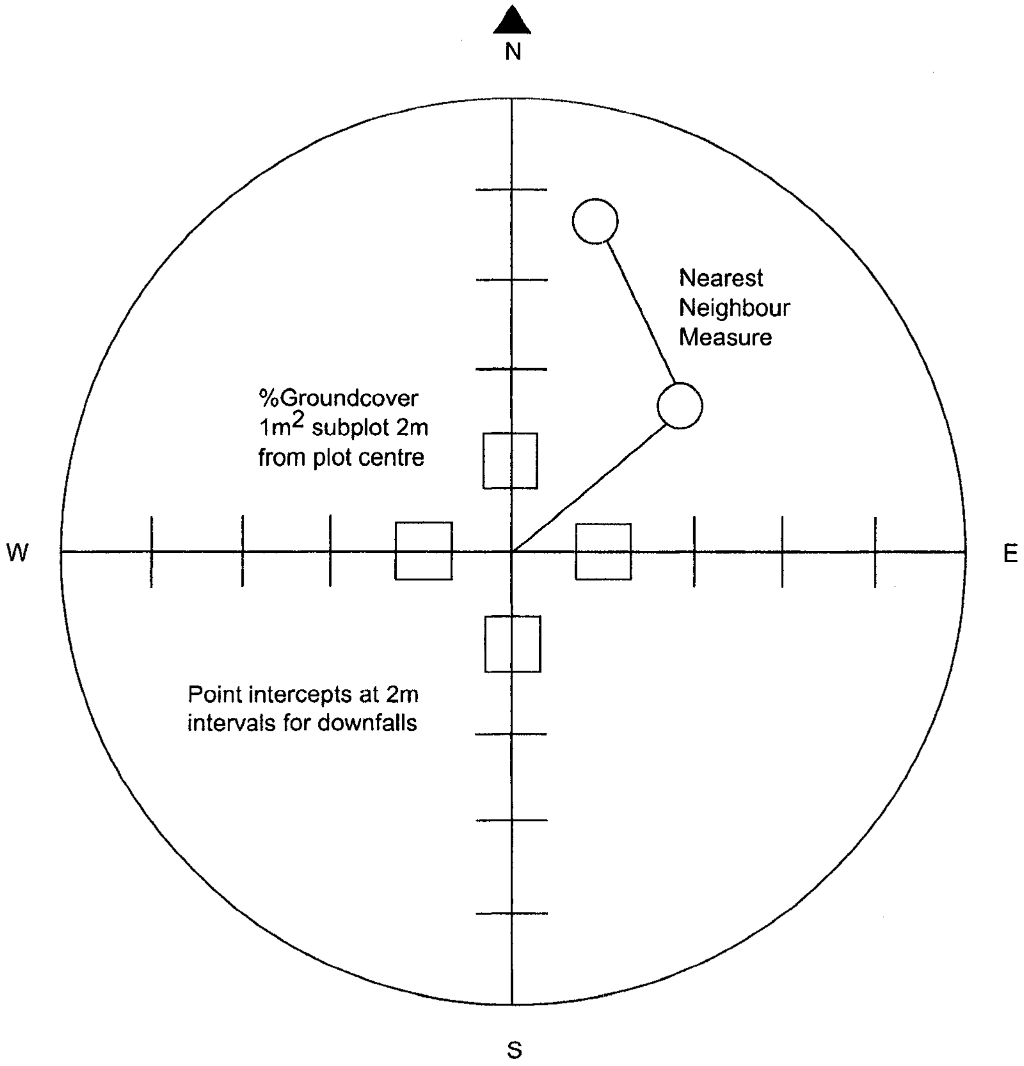


Figure 2.2. Schematic of detailed vegetation measurements made within 10m-radius sampling plots at caribou nursery sites and randomly chosen absence sites on lakes in Wabakimi and Woodland Caribou Provincial Parks, northern Ontario.

Ground detection distances were used as a means of quantifying the density of vegetation, viewed horizontally, surrounding the centre of each plot. The minimum distance at which an orange card measuring 0.5m wide and 1m high was completely hidden from view to an observer moving away from plot centre along each of the 4 cardinal compass directions was recorded at 2 heights. The observer used a 1m-high pole to standardize the heights at which the card was viewed. This procedure was repeated with the bottom edge of the card on the ground, then with the card held on top of a 1m-high pole. These measurements were used as an index of lateral detection distance at 0-

1m and 1-2m high views through the vegetation surrounding the nursery area (adapted from Addison et al. 1990). An average of the 4 measurements at each card height was used as an index of horizontal foliage density or "hiding cover".

The total number of standing dead trees (>1m in height; ≥5cm dbh; and >30 degrees up from the plane of the ground) and the number of stumps (<1m in height) in each plot were recorded. Each plot was assigned a "V-type" and "S-Type" using the Forest Ecosystem Classification (FEC) for Northwestern Ontario (Sims et al. 1997), as well as an Ecosite type using Terrestrial and Wetland Ecosites of Northwestern Ontario (Racey et al. 1996).

The dominant species of overstorey (≥5m in height and ≥5cm dbh) and understorey (>2m and <5m in height and <5cm dbh) woody vegetation (Rodgers et al. 1997) within each quadrant were recorded and a T-square nearest-neighbour sampling method (Hays et al. 1981) was used to estimate density. Two plants in each category were selected for measurement. Using the centre point of each plot as a reference point, the distance to the base of the nearest woody stem or trunk was measured (Figure 2.2). The first overstorey or understorey plant selected was the plant nearest to plot center in each quadrant and the second plant was the nearest neighbour from the first plant within a 180° arc perpendicular to the line from plot center to the first plant. Distances from plot center to the base of the first plant and from the base of the first to the base of the second plant were used to estimate density of overstorey and understorey woody vegetation in each quadrant. Diameter at breast height (dbh) was recorded for overstorey trees used to estimate density of overstorey and understorey woody vegetation in each quadrant. Arboreal forage lichen was also measured on the overstorey trees by the T-square nearest neighbour sampling method. The amount of arboreal forage lichens on trees with a dbh of at least 5cm was indexed (0-5, 0 being the lowest) by estimating the amount available up to a height of 3m while, looking at the side of the tree with the most lichen cover (adjusted from Stevenson et al. 1998 for Ontario tree species).

The dominant species in all plots were also noted as "dominant tree species (>10m)", "dominant tall shrubs/small trees (2-10m)", "dominant medium shrubs (0.5-2m)", "dominant low shrubs (<0.5m)", and "dominant herbs/graminoids", to provide general cover characteristics and species composition at sites.

One 20m transect line, bisecting the centre of each plot (north-south), was used to record the number and species, consisting of woody vegetation >0.4m and <2m in height (Rodgers et al. 1997). A 1m ruler was centred over the transect line (protruding 0.5m on each side) and the number of plants in the shrub category contacting the ruler (counting only the base, not the branches) by walking with it along the length of the line were recorded (Rodgers et al. 1997). Each species counted in this manner was recorded (some species such as willow, *Salix* spp., only to the genus level due to identification difficulties).

Line intercept methods (Hays et al. 1981) were also used to quantify downfalls and browse (herbaceous and woody shrubs). At 2m intervals along the intersecting (diameter) transect lines (Figure 2.2) the number of downfalls and stumps crossing the line were recorded, along with their height from the ground and their diameter. Downfalls were distinguished as logs/trees ≥1m in length and ≥5cm in diameter, lying horizontally along the ground or at an angle of 30 degrees or less up from the plane of the ground (Rodgers et al. 1997). The diameter of the log was determined at its maximum along its length. Total height from the ground was measured as the distance from the ground surface to the top of the fallen log or logs if there were several overlying layers, and the number of layers was recorded.

One 30 m transect was walked that started at the centre of a plot and ran in the direction that had the most uniform ground distribution of lichens in the area of the 3 plots. At every 1 m, at the tip of the right toe (2cm-spot), presence or absence of lichens was recorded and, if present, the lichen species (Lance and Eastland 2000).

Square-metre sub-plots

Four quadrats of 1-square-metre each were placed 2m from the central point along each of the 4 cardinal compass directions (Figure 2.2). A grid of 20cm x 20cm squares within the square meter plot was used to estimate percent cover (Rodgers et al. 1997). The dominant (most abundant) herbaceous species and woody plant species (<0.4m in height) were also recorded (Rodgers et al. 1997), along with an estimate of their percent cover in each of the square-metre plots. Percent ground cover, consisting of bare rock, gravel, soil/litter, wood, grass, rushes, sedges, herbs, shrubs, ferns/allies, fungi, moss/liverworts, and lichen were estimated within each quadrat. The percent coverage data from the subplots were averaged for each of the 10m radius plots.

Statistical Analyses

All tests were completed using the Statistical Package for the Social Sciences (Version 14.0, SPSS Inc., Chicago, Illinois).

Nominal Scale Data

Aspect, V-type, ES-type, S-type, dominant tree, dominant tall shrub, dominant medium shrub, dominant low shrub, dominant moss/lichen, dominant herbs/graminoids, dominant shrub from transects, arboreal lichen classes, dominant overstorey species, and dominant understorey species all produced nominal data that were compiled into frequency distributions. Species occurring with expected frequencies of <2 were combined into another category (Zar 1999). These frequency distributions were then compared using a chi-square test (Zar 1999) to examine possible differences between absence and nursery sites in both Wabakimi and Woodland Caribou Provincial Parks.

Interval Scale Data

Prior to statistical analyses and model development, I examined the variance and normality of all interval scale variables. Log, square root, and arcsine transformations were performed when data were not normally distributed. I determined that the groundcover percent coverage variables were highly variant and could not be normalized, in spite of transformations. Since caribou eat opportunistically and quite broadly with regard to vegetation types in the summer months (Ahti and Hepburn 1967), groundcover variables were grouped into open (i.e., bare rock, gravel, soil/litter, wood) or vegetation (i.e., grass, rushes, sedges, herbs, shrubs, ferns/allies, fungi, moss/liverworts, and lichen) groundcover categories, leaving a total of 18 interval scale variables for analysis (Table 2.1).

Correlation matrices were examined to identify variables that were highly related. The variables for ground detection distance at the 0-1m and 1-2m level were highly correlated, as might be expected, but I conducted further preliminary analyses before deciding which of these to remove. To determine if the measured habitat variables differed between both study sites and if habitat variables differed between caribou nursery and absence sites, I used 2-way multivariate analysis of variance (MANOVA) with "parks" as a blocking factor. To identify habitat variables important for differentiating between nursery and absence sites, a Discriminant Function Analysis (DFA) was used separately for each protected area after the MANOVA. A DFA was also used to determine if the park differences or the absence and nursery site differences explained most of the model variance and which habitat variables were most important in explaining park and absence and nursery site differences. An individual DFA for each park demonstrated the importance of the 0-1m ground detection distance variable in Wabakimi Provincial Park to distinguish between nursery sites and unused absence sites, but not in Woodland Caribou Provincial Park. Thus, I removed the 1-2m ground detection distance variable and used the remaining 17 variables in further DFA analyses.

Principal Components Analysis was also explored as a method of interpreting the importance of combinations of variables at each type of site in each park. In general, these PCA results indicated that this data reduction technique was not useful for these data because the PCA did not reduce the number of variables in order to simplify further analysis. In the moose calving site study by Addison et al. (1990) the results were similar, where the PCA was found to be ineffective in reducing variables in the data set.

The results of both the MANOVA and DFA suggested there were greater differences between the 2 parks than between nursery and absence sites within each, so I developed separate Resource Selection Functions (RSFs; Boyce et al. 2002, Manly et al. 2002) for each park following the model selection procedure suggested by Shtatland et al. (2003). This procedure maximizes variable selection strengths of stepwise regression in predictive and exploratory studies (Menard 1995) while avoiding arbitrary alpha values by using an information-theoretic approach (Burnham and Anderson 1998, Vander Wal 2004). Models were subsequently evaluated using a combination of Akaike Information Criteria (AIC; Burnham and Anderson 2002), Receiver Operating Characteristic curves (ROCs; Pearce and Ferrier 2000), and k-fold cross-validation (Fielding and Bell 1997).

Variable Reduction

Because of potential statistical biases caused by the large number of independent variables (18) measured relative to the sample sizes (15 nursery sites and 15 absence sites) in each park (Peduzzi et al. 1996), I sought to reduce the number of variables used for model development. Initially, data for all 18 variables were combined for nursery and absence sites within each park and included in multivariate linear regressions. I followed this with a series of steps to reduce the number of variables used in the final model selection procedure (Shtatland et al. 2003). This series of steps removes multicollinearity among independent predictors by examination of variance inflation factors (VIFs) in linear regression analysis, average linkages in hierarchical cluster analysis, and condition numbers in principal components analysis (PCA). I used 18 variables in the hierarchical cluster analysis to ensure that all variables were considered.

VIFs were obtained from multivariate linear regressions of all 18 independent variables in each park that were subsequently related by dendrograms in hierarchical cluster analyses and subsequently in logistic regression models (Menard 1995, Allison 1999, Shtatland et al. 2003). Collinearity can cause predictors to compete and make the selection of "important" variables arbitrary. To remove potential multicollinearity, variables with VIFs > 2.5 that were strongly linked in dendrograms were removed from further analyses (Allison 1999).

To validate the non-multicollinearity assumption in the VIF approach, condition numbers (k) were calculated using PCAs (Belsley et al. 1980). The condition number is a measurement of the magnitude of collinearity among variables represented by the degree of separation between the largest and smallest eigenvalue (Williams 2005). When there is no collinearity, the eigenvalues, condition indices, and condition number will all equal 1 (Williams 2005). As collinearity among variables increases, eigenvalues and condition indices will both be greater and smaller than 1 (values close to zero indicate multicollinearity) and the condition number will increase (Williams 2005). The condition number is equal to the square root of the largest eigenvalue (λ_{max}) divided by the smallest eigenvalue (λ_{min}):

$$k = \text{SQRT}\ (\lambda_{max} / \lambda_{min}).$$

As a rule of thumb, if the condition number is less than 15 then multicollinearity among variables is not a concern (Williams 2005). Only subsets of variables with condition numbers less than 15 were used in subsequent analyses. The preceding process reduced the number of variables from 18 to 9. As all condition numbers for the 9 remaining variables in each park were less than 15, multicollinearity among variables was apparently removed by the VIF approach (Williams 2005) and no further variables were removed prior to model development and evaluation. The 9 different variables used for each park in model development are identified in Table 2.1.

Automatic Model Selection Procedure

Akaike's information criterion (AIC) is an automatic model selection procedure described by the equation:

$$AIC = -2(\text{log-likelihood}) + 2K,$$

where K is the number of estimated parameters included in a model and the log-likelihood of the model reflects the overall fit of the model (Mazerolle 2004). Model selection using AIC essentially penalizes the addition of parameters (Mazerolle 2004). For small sample sizes (i.e., when $n < 40$), Hurvich and Tsai (1989, 1991), Burnham and Anderson (2002), and Shtatland et al. (2003) recommend using a corrected AIC (AIC_c):

$$AIC_c = -2\ (\text{log-likelihood}) + 2K + 2K\ (K+1)/(n\text{-}K\text{-}1),$$

where n is the sample size. Akaike's information criterion for small sample size (AIC_c) was used to select the most parsimonious model from the subset of models with different combinations of predictor variables in each park. Forward stepwise selection produces a sequence of models beginning with the null model and culminating with a model that includes all predictor variables and maximizes the likelihood at each step (Shtatland et al. 2003, Mazerolle 2004). AIC_c produces an evidence ratio identifying the most parsimonious of the logistic models. Evidence ratios were calculated by dividing a model's Akaike weight by the largest Akaike weight in the set of possible models (Burnham and Anderson 1998).

Model Development and Evaluation

Predictive model development using forward conditional logistic regression and automatic selection procedures was applied following variable reduction (Menard 1995, Simonoff 2000, Shtatland et al. 2003). The data set was randomly subdivided into a model building subset and a model validation subset for Woodland Caribou and

Wabakimi Provincial Parks. Two-thirds (*n*=20) of the data from each park were dedicated to model development and the remaining one-third (*n*=10) were used to evaluate the resulting models for each park.

Stepwise logistic regression of the 9 habitat variables associated with two-thirds of the caribou nursery and absence sites in each park was used to produce subsets of models with different combinations of predictor variables.

Akaike's Information Criterion for small sample size (AIC_c) and associated evidence ratios were used to select the most parsimonious model from among the models with statistically significant coefficients produced by stepwise logistic regression (Burnham and Anderson 1998, 2002).

Candidate models were next evaluated using ROC curves. These curves allow evaluation of the predictive power of the logistic regression models and reflect how accurately and robustly models classify the data (Boyce et al. 2002) with k-fold cross validation (Fielding and Bell 1997). Before calculating the ROC curve, the discriminatory ability of each model was evaluated graphically by comparing the distributions of predicted probabilities of nursery and absence sites (Pearce and Ferrier 2000). A model with no discriminatory ability will produce a curve that follows a 45° line whereas ideal discrimination (i.e., perfect separation) is indicated by a line with a constant y value of 1.0 (Swets 1988, Pearce and Ferrier 2000). Validation data, representing the remaining one-third of the caribou nursery and absence sites in each park, were substituted into their respective models and tested by examining the predictive probabilities of each model (i.e., proportions of sites correctly or incorrectly classified as nursery or absence sites).

Results

Nominal Scale Data

Appendix 2 provides common and scientific names of all plant species recorded in the study. Appendix 3 provides tabular data of the frequencies and percentages of all nominal scale data recorded in each of the 10m-radius sample plots.

Each of the 3 sample plots at each site was classified using FEC V-types (Sims et al. 1989; Appendix 5). In comparing the V-type frequency distributions between nursery and absence sites within each park, a chi-square test produced a significant result for both Woodland Caribou Provincial Park ($\chi^2 = 11.193$, 4 d.f., $p=0.024$) and for Wabakimi Provincial Park ($\chi^2 = 19.078$, 8 d.f., $p=0.014$) (Figure 2.3). In Woodland Caribou Provincial Park the greatest differences occurred in the number of plots classified as V32 (Jack pine – Black spruce / Ericaceous shrub / Feathermoss) at nursery sites (46%) and absence site plots (13%). In Wabakimi Provincial Park the greatest differences occurred in the number of plots classified as V34 (Black spruce / Labrador tea / Feathermoss / Sphagnum) at nursery sites (27%) versus none classified as such in the absence site plots.

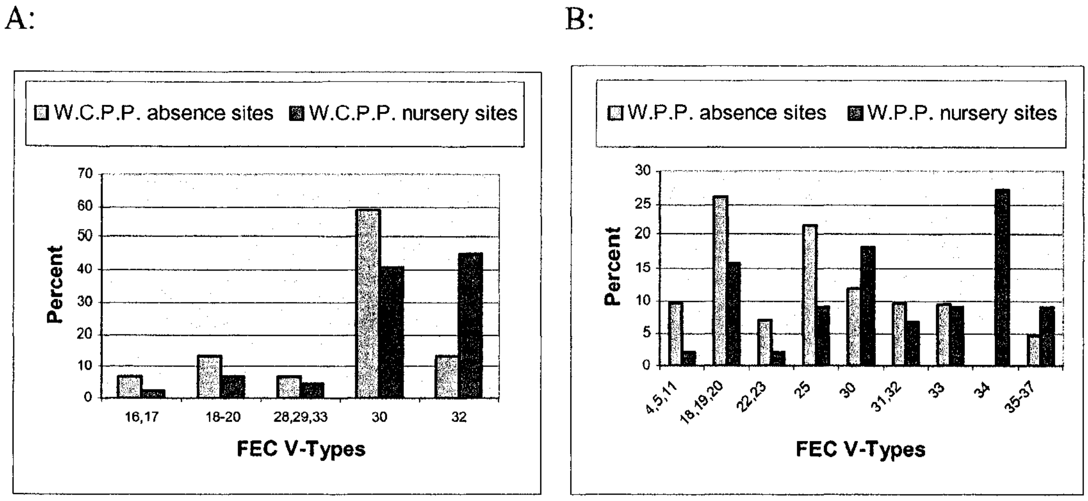


Figure 2.3. Relative abundance of FEC V-types (%) in 10m-radius plots at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44).

The Ecosite (ES) type (Racey et al. 1996; Appendix 7) percentages recorded in each of the sample plots at nursery sites and absence sites are shown in Figure 2.4. In comparing ES-type frequency distributions between nursery and absence sites in each park, a chi-square test produced a non-significant result for both Woodland Caribou Provincial Park ($\chi^2 = 0.51$, 1 d.f., p=0.474) and for Wabakimi Provincial Park ($\chi^2 = 0.462$, 1 d.f., p=0.497).

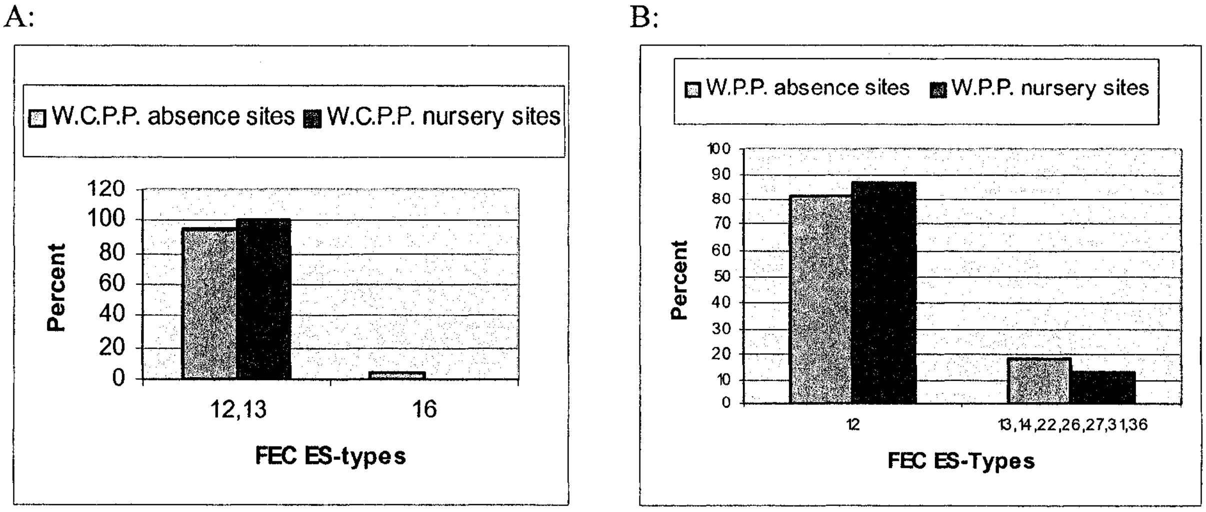


Figure 2.4. Relative abundance of FEC ES-types (%) in 10m-radius plots at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44).

Each of the 3 sample plots at each site was classified using FEC S-types (Sims et al. 1989; Appendix 6) and the percentages are given in Figure 2.5. In comparing the frequency distributions of S-types between nursery and absence sites in each park, a chi-square test produced a significant result for Woodland Caribou Provincial Park (χ^2 = 7.222, 2 d.f., p=0.027) but was not significant for Wabakimi Provincial Park (χ^2 = 0.484, 2 d.f., p=0.785). In Woodland Caribou Provincial Park, the greatest difference occurred in the number of plots classified as SS1 (discontinuous organic mat on bedrock) at nursery sites (21%) versus absence site plots (43%); another large difference occurred in the number of plots classified as SS2 (extremely shallow soil on bedrock) at nursery sites (61%) versus absence site plots (34%).

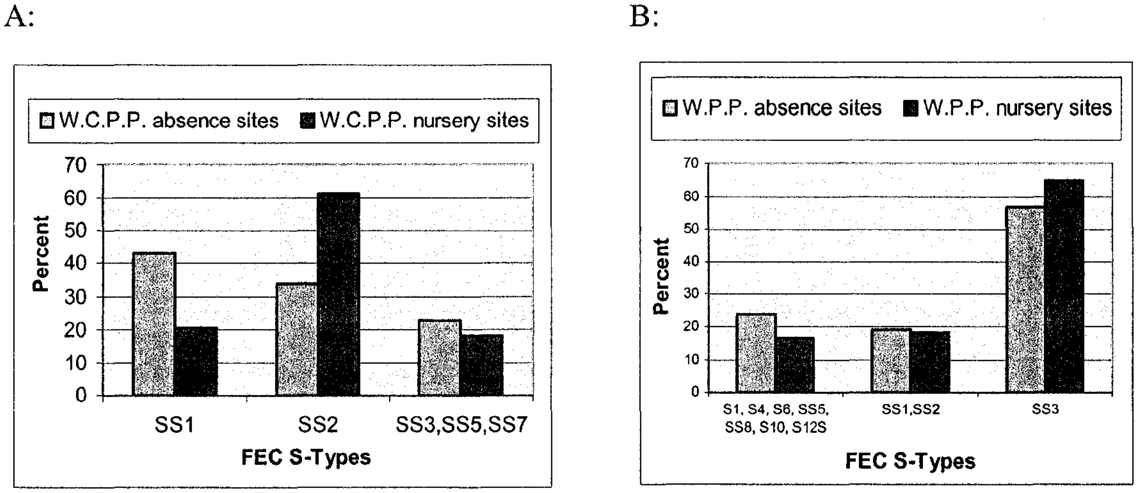


Figure 2.5. Relative abundance of FEC S-types (%) in 10m-radius plots at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44).

Aspect was also recorded as nominal scale data (Appendix 3.4). Comparisons of the frequency distributions of aspects produced a non-significant chi-square result between nursery and absence sites in both Woodland Caribou Provincial Park (χ^2 = 7.671, 4 d.f., p=0.104) and Wabakimi Provincial Park (χ^2 = 5.717, 4 d.f., p = 0.221) (Figure 2.6).

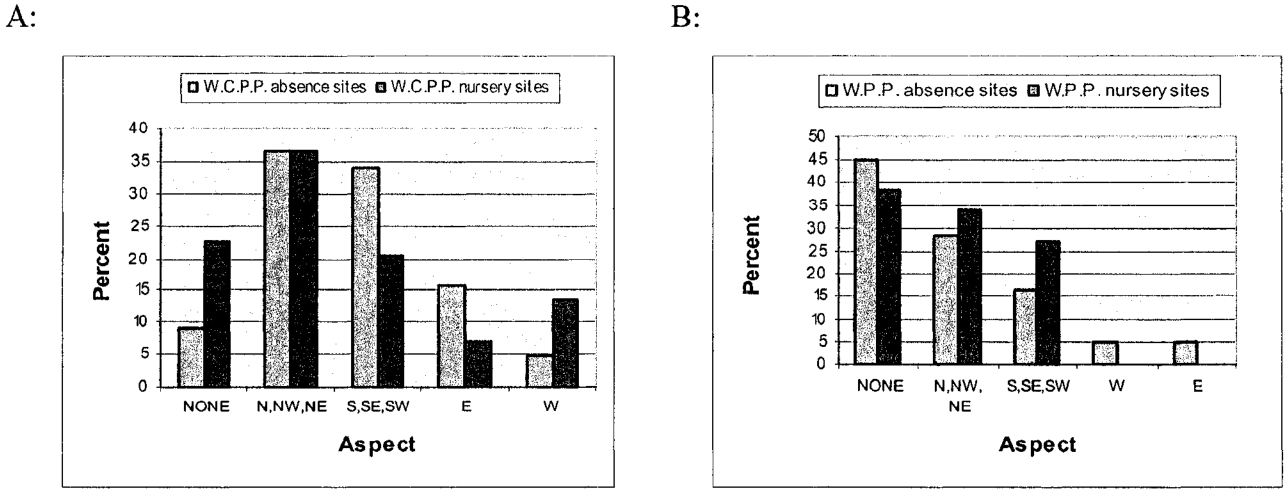


Figure 2.6. Aspect (%) of 10m-radius plots at (A) Woodland Caribou Provincial Park absence sites (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence sites (*n*=42) and nursery sites (*n*=44).

A shrub transect was traversed through each plot and the percentage occurrence of each shrub species is shown in Figure 2.7 (and Appendix 3.7). In comparing the frequency distributions of shrub species between nursery sites and absence sites in each park, a chi-square test produced a significant result for both Woodland Caribou Provincial Park ($\chi^2 = 203.16$, 11 d.f., $p<0.001$) and Wabakimi Provincial Park ($\chi^2 = 120.599$, 10 d.f. $p<0.001$). In Woodland Caribou Provincial Park, one of the greatest differences occurred in the number of plots with beaked hazel at absence sites (21%) versus none in the nursery site plots. All shrub species were higher at absence sites, with some exceptions such as spruce, jack pine, and balsam fir in both parks. However, in Wabakimi Provincial Park, nursery sites also had slightly more white cedar/willow and green alder than absence sites.

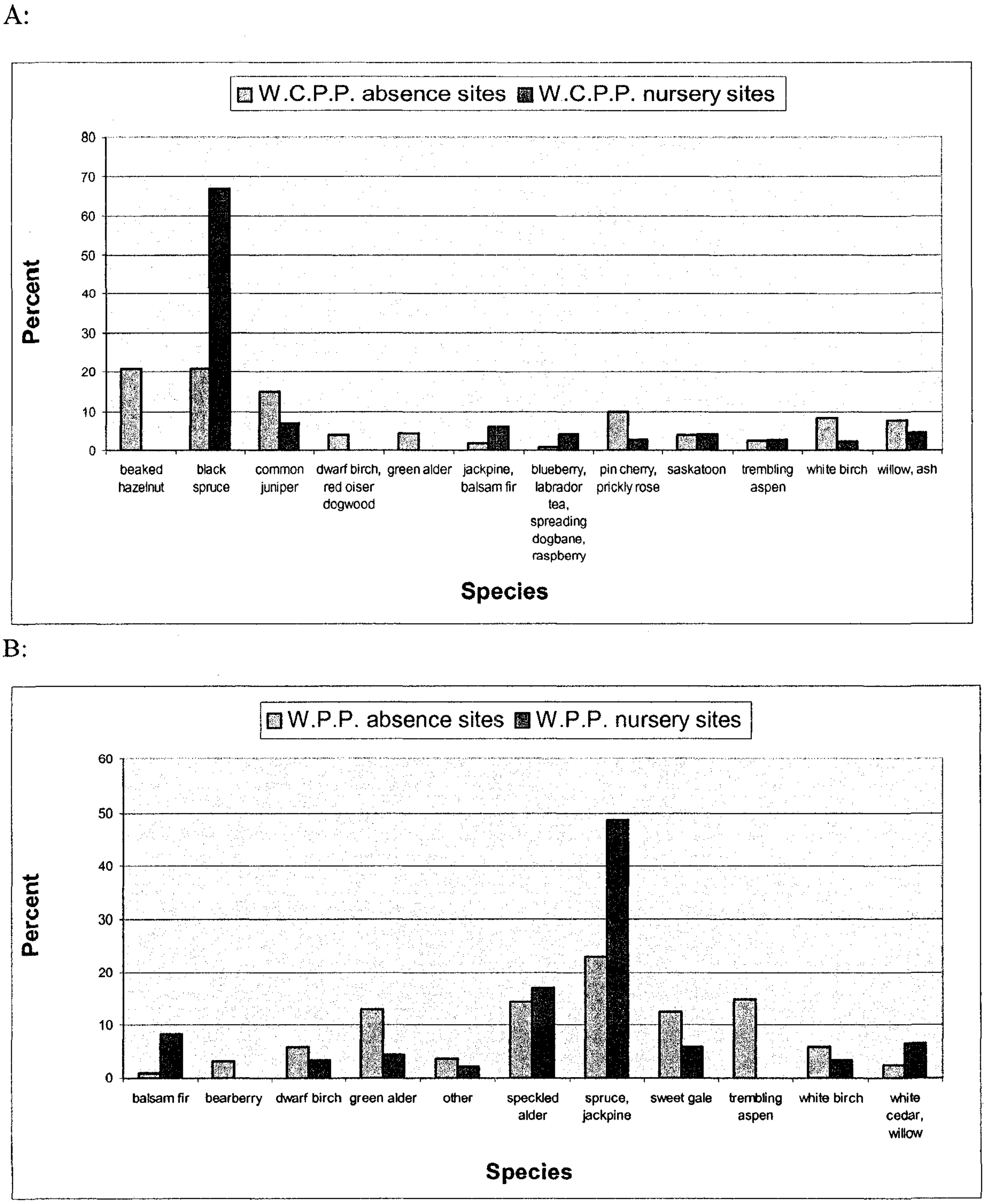


Figure 2.7. Relative abundance of shrub species (%) recorded on transects in each 10m-radius plot in (A) Woodland Caribou Provincial Park absence sites (*n*=495) and nursery sites (*n*=220) and (B) Wabakimi Provincial Park absence sites (*n*=248) and nursery sites (*n*=205). The "other category" in Wabakimi Provincial Park represents saskatoon berry, alder-leaved buckthorn, narrow leaved meadowsweet, bog bilberry, and blueberry. *n* is the total number of individual shrubs recorded on all transects at absence or nursery sites in each park.

In each plot, a nearest neighbour transect was completed for both the overstorey and understorey woody vegetation categories and the percentages are shown in Figure 2.8 (and Appendices 3.8 and 3.9). In comparing the frequency distributions of overstorey species between nursery sites and absence sites in each park, a chi-square test produced a significant result for both Woodland Caribou Provincial Park ($\chi^2 = 65.29$, 3 d.f., $p<0.001$) and Wabakimi Provincial Park ($\chi^2 = 93.62$, 5 d.f., $p<0.001$). In Woodland Caribou Provincial Park, one of the greatest differences occurred in the number of plots with no species of woody vegetation present in the overstorey category at absence sites (20%) versus no species present at nursery site plots (5%). Balsam fir and black spruce were also the species most present in the overstorey at nursery sites (54%), but only 28% of absence sites. In Wabakimi Provincial Park, no species of woody vegetation were present in the overstorey category at 22% of absence sites and 2% of nursery sites. Black spruce was also the species most present in the overstorey category at nursery sites (81%), but only 62% of absence sites.

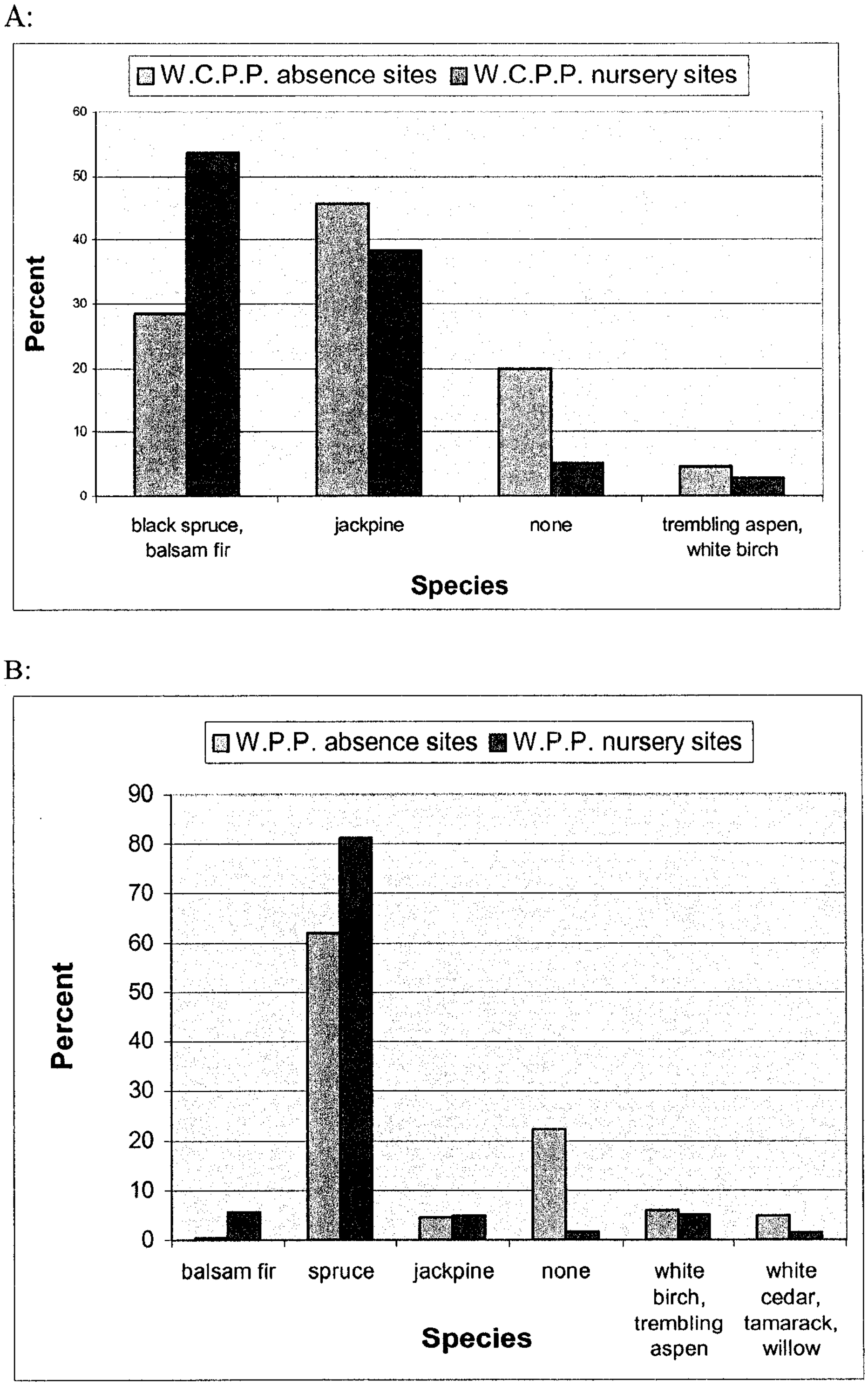


Figure 2.8. Relative abundance of overstorey species recorded by nearest neighbour measurements (%) in each 10m-radius plot at (A) Woodland Caribou Provincial Park absence (*n*=352) and nursery sites (*n*=352) and (B) Wabakimi Provincial Park absence (*n*=336) and nursery sites (*n*=352). *n* is the total number of individual overstorey trees recorded in all quadrants at absence or nursery sites in each park.

In comparing the frequency distributions of understorey species between nursery sites and absence sites in each park, a chi-square test produced a significant result for both Woodland Caribou Provincial Park ($\chi^2 = 95.03$, 5 d.f., $p<0.001$) and Wabakimi Provincial Park ($\chi^2 = 77.92$, 8 d.f., $p<0.001$) (Figure 2.9). In Woodland Caribou Provincial Park, one of the greatest differences occurred in the number of plots with spruce (white and black) in the understorey category at absence sites (39%) versus the nursery site plots (69%). Jack pine was also present in the understorey category density measurements; 1% of nursery sites and 18% of absence sites. In Wabakimi Provincial Park, there were also more nursery sites with spruce as the understorey species (59%) compared to 35% at absence sites. There were also more absence sites with no understorey species present (33%) compared to nursery sites (22%).

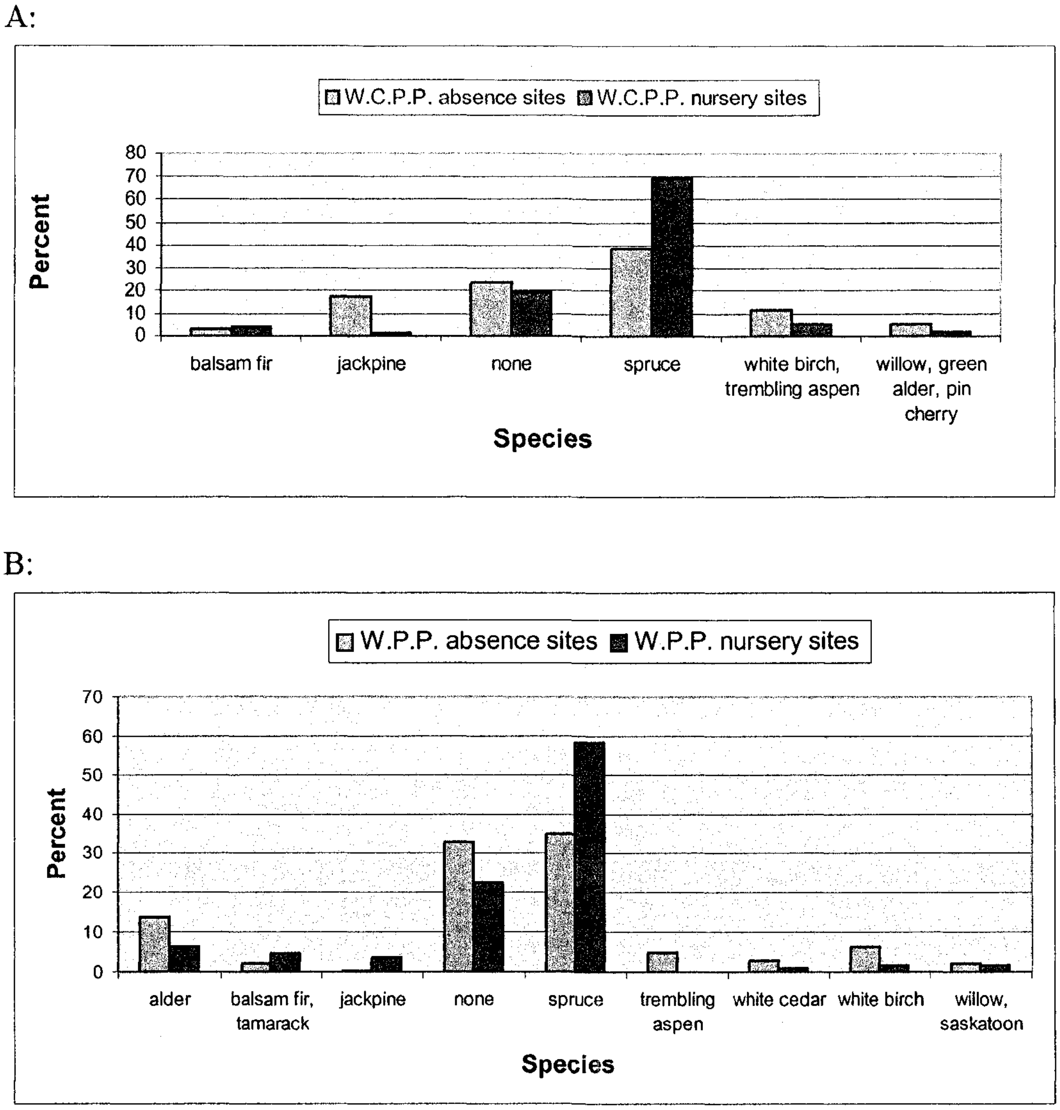


Figure 2.9. Relative abundance of understorey species recorded by nearest neighbour measurements (%) in each 10m-radius plot at (A) Woodland Caribou Provincial Park absence (*n*=352) and nursery sites (*n*=352) and (B) Wabakimi Provincial Park absence (*n*=336) and nursery sites (*n*=352). *n* is the total number of individual understorey trees recorded in all quadrants at absence or nursery sites in each park.

A chi-square test was also used to determine if there was a difference between dominant moss or lichen groundcover at absence sites and nursery sites within each park. Both chi-square tests showed results that were not significant for either Woodland Caribou Provincial Park ($\chi^2 = 0.29$, 1 d.f., p=0.5892) or Wabakimi Provincial Park ($\chi^2 = 0.01$, 1 d.f., p=0.9412) (Figure 2.10). See Appendix 2 for species names of mosses and lichens that occurred at these sites.

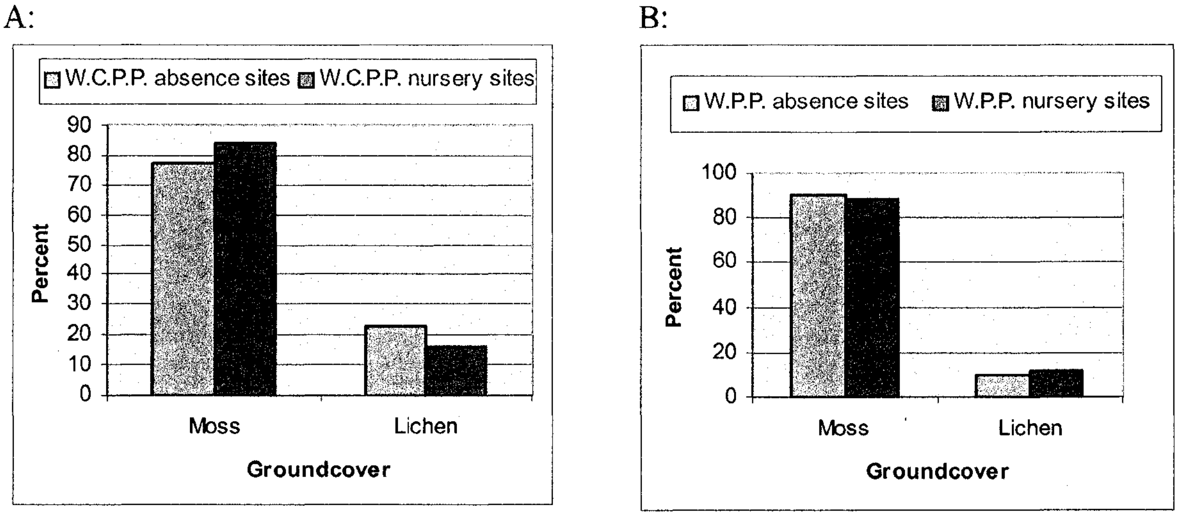
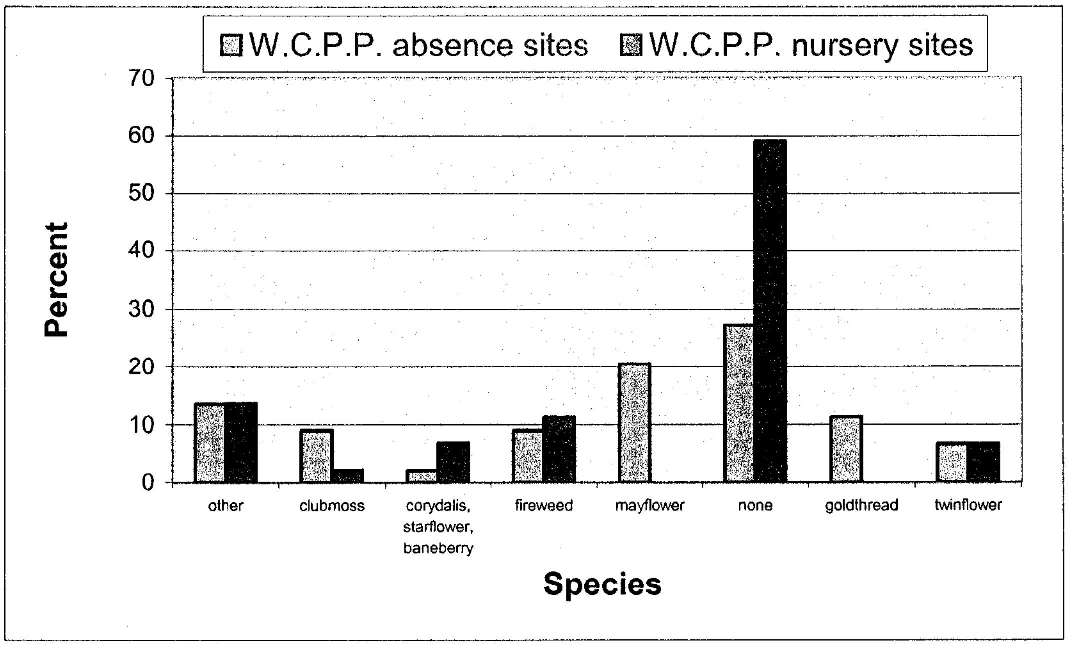


Figure 2.10. Dominant moss or lichen cover (%) in each 10-m radius plot at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44).

A chi-square test was used to determine if there was a difference in dominant herb-graminoid cover between nursery and absence sites within both parks (Appendix 3.9). The chi-square test produced significant results for both Woodland Caribou Provincial Park ($\chi^2 = 22.069$, 7 d.f. p=0.002) and Wabakimi Provincial Park ($\chi^2 = 15.822$, 5 d.f., p=0.007) (Figure 2.11). In Woodland Caribou Provincial Park, the greatest differences occurred where no herb-graminoid species were found at nursery sites (59%) compared to 27% of the absence sites. Mayflower was also dominant at absence sites (21%) but not at nursery sites. In Wabakimi Provincial Park, the greatest differences occurred where no herb-graminoid species were dominant at nursery sites (68%) compared to 43% of absence sites. Bunchberry was also present at absence sites (17%) but not at nursery sites.

A:



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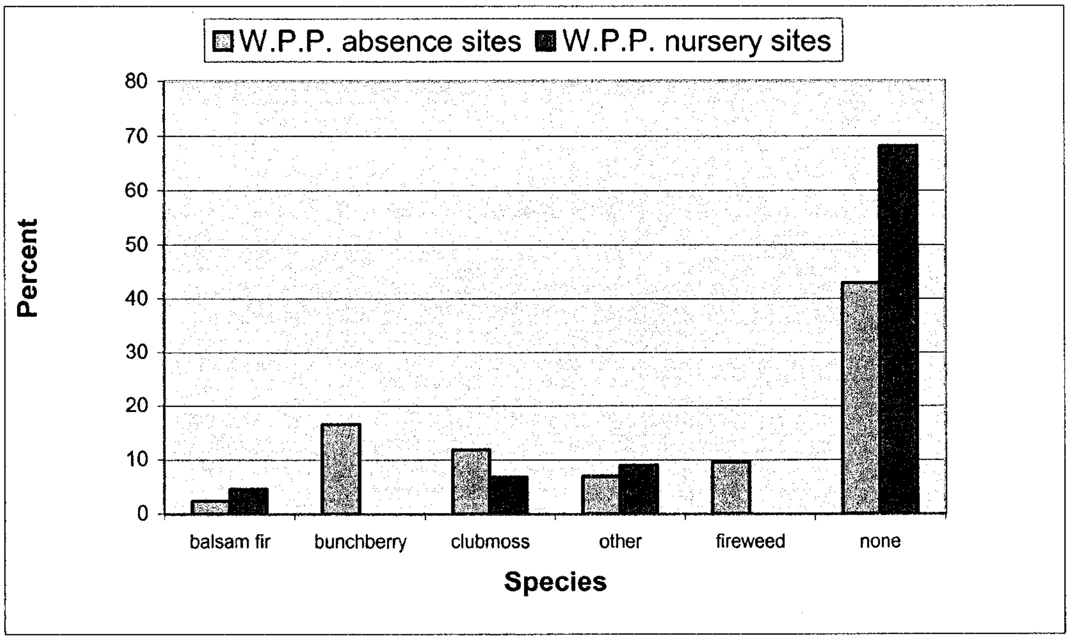


Figure 2.11. Dominant herbs and graminoids (%) in each 10-m radius plot at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44). In Woodland Caribou Provincial Park the "other category" consisted of black fringed bindweed, cottongrass, bunchberry, sedges, sarsaparilla, and prince's pine. In Wabakimi Provincial Park the "other category" consisted of cottongrass, cottontail, horsetail, indian pipe, lady's slipper, sarsaparilla, and northern starflower. Scientific names of plant species are given in Appendix 2.

A chi-square test was used to see if there was a difference between dominant low shrub species at absence sites and nursery sites in each park (Appendix 3.10). Both chi-square tests showed results that were not significant for either Woodland Caribou Provincial Park ($\chi^2 = 10.591$, 6 d.f., $p=0.102$) or Wabakimi Provincial Park ($\chi^2 = 2.898$, 3 d.f., $p=0.408$) (Figure 2.12).

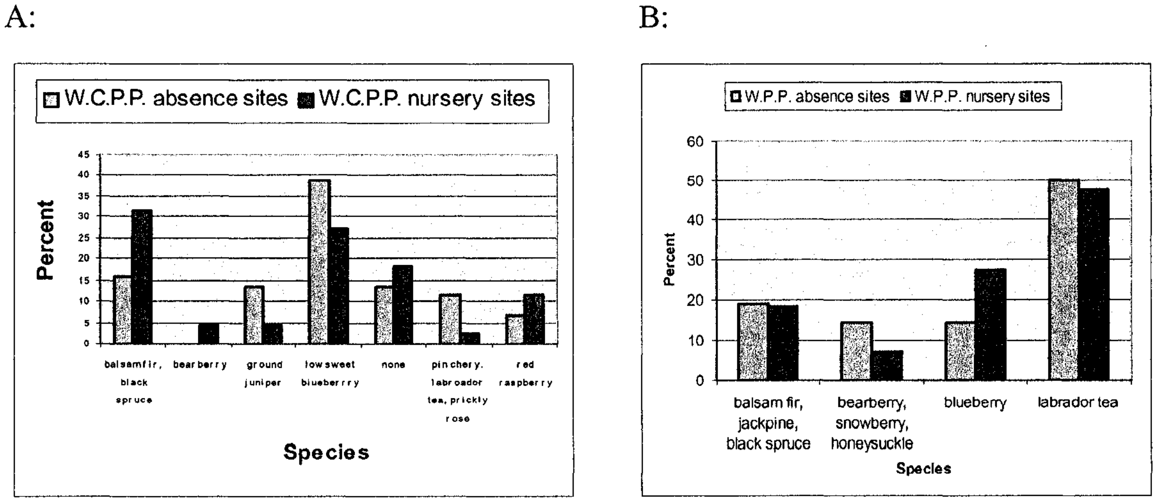
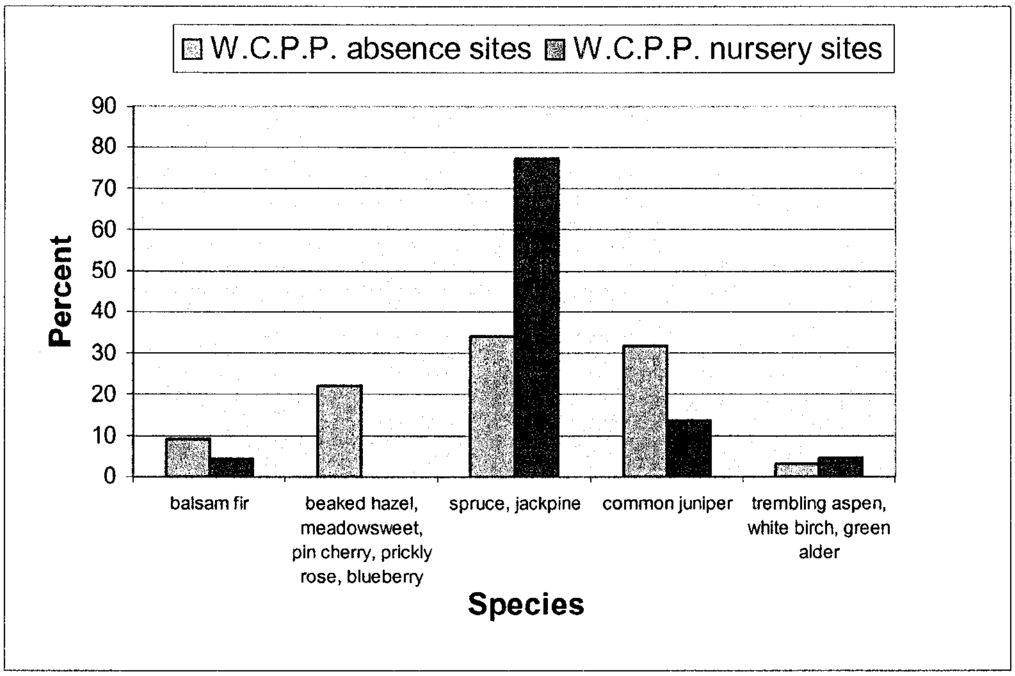


Figure 2.12. Dominant low shrubs and small trees (<0.5m) (%) in each 10-m radius plot at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44).

A chi-square test was used to determine if there was a difference between dominant medium-sized shrub species at absence sites and nursery sites in each park (Figure 2.13; Appendix 3.11). The chi-square tests showed results that were significant for Woodland Caribou Provincial Park ($\chi^2 = 24.519$, 4 d.f., $p<0.001$) and not significant for Wabakimi Provincial Park ($\chi^2 = 3.079$, 2 d.f., $p=0.215$). In Woodland Caribou Provincial Park, one of the greatest differences between nursery and absence sites occurred in the spruce and jack pine category, with this grouping being present at 77% of nursery sites and 34% of the absence sites. The combined category, representing beaked hazel, pin cherry, prickly rose, blueberry, and meadowsweet, was present at 22% of absence sites but not nursery sites.

A:



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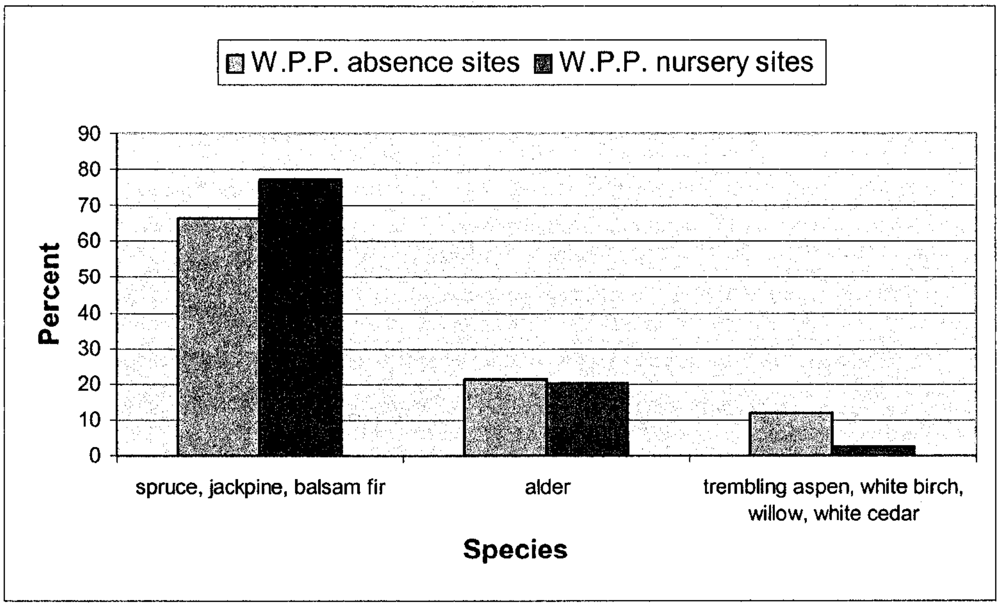

Figure 2.13. Dominant medium shrubs and small trees (0.5-2m) (%) in each 10-m radius plot at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44).

A chi-square test was used to determine if there was a difference between dominant tall shrub species at absence sites and nursery sites in each park (Appendix 3.12). Both chi-square tests showed results that were significant for Woodland Caribou Provincial Park ($\chi^2 = 43.869$, 6 d.f., $p<0.001$) and Wabakimi Provincial Park ($\chi^2 = 10.367$, 4 d.f., $p=0.035$) (Figure 2.14). In Woodland Caribou Provincial Park one of the greatest differences between nursery and absence sites was the occurrence of spruce, which was dominant at 91% of the nursery sites but only 55% of absence sites. In Wabakimi Provincial Park, spruce was dominant at 86% of the nursery plots compared to 62% of the absence plots.

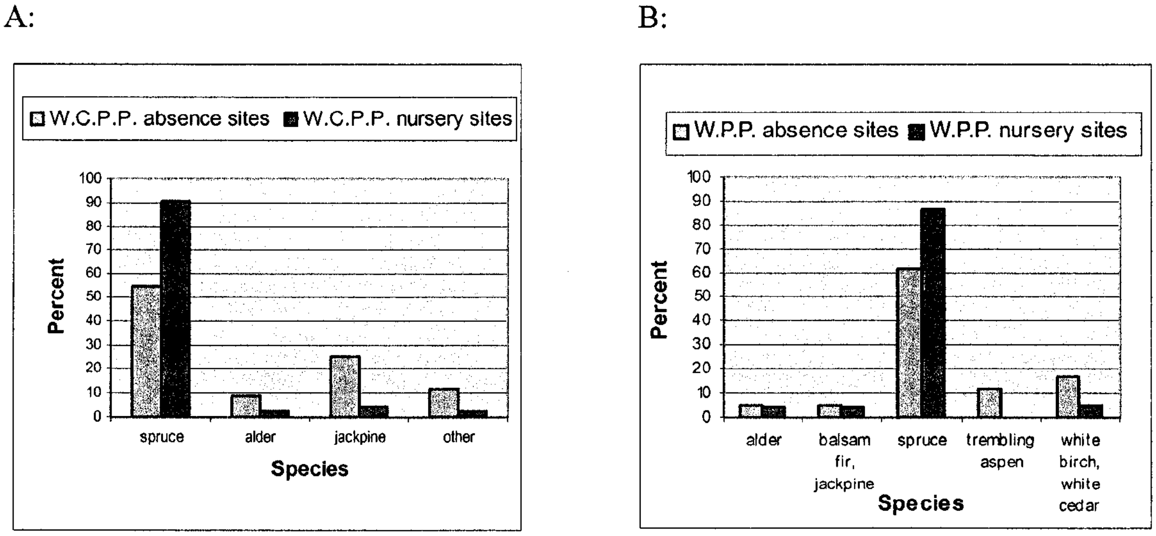

Figure 2.14. Dominant tall shrubs and small trees (2-10m) (%) in each 10m-radius plot at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44). The "other category" in Woodland Caribou Provincial Park consisted of balsam fir, pin cherry, and white birch. Scientific names of plant species are given in Appendix 2.

A chi-square test was used to determine if there was a difference between dominant tree species at absence sites and nursery sites in each park (Appendix 3.13). Chi-square tests showed results that were significant for Woodland Caribou Provincial Park ($\chi^2 = 11.86$, 3 d.f., $p=0.0079$) but were not statistically significant for Wabakimi Provincial Park ($\chi^2 = 6.708$, 3 d.f., $p=0.082$) (Figure 2.15). In Woodland Caribou Provincial Park, one of the greatest differences between nursery and absence sites occurred in the spruce and balsam fir grouping, which was dominant at 50% of nursery sites versus 25% of the absence sites. No dominant tree species were present at 14% of the absence plots but all of the nursery plots had some dominant tree species present.

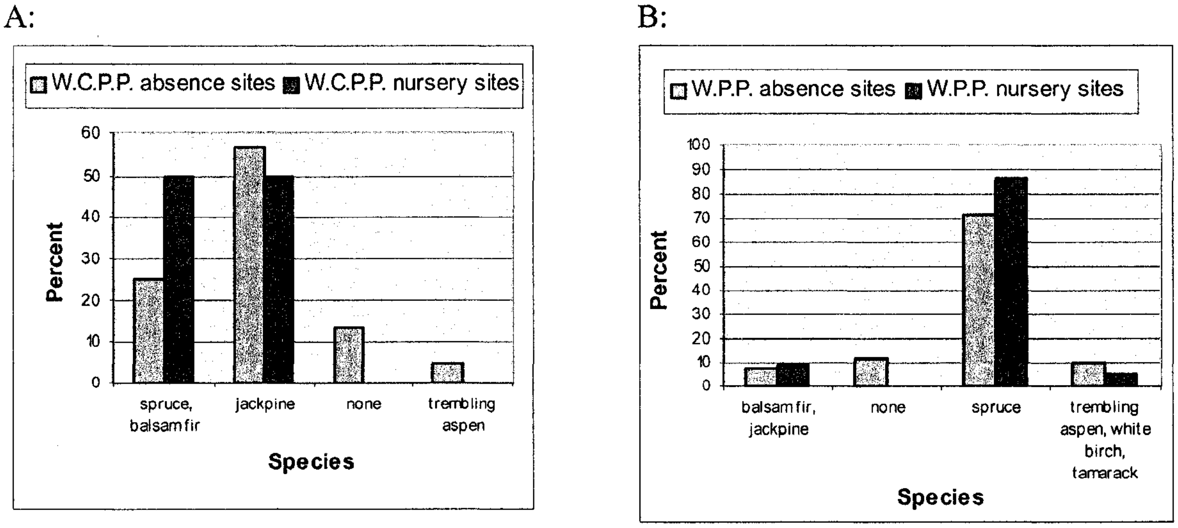

Figure 2.15. Dominant tree species (>10m) (%) in each 10m-radius plot at (A) Woodland Caribou Provincial Park absence (*n*=44) and nursery sites (*n*=44) and (B) Wabakimi Provincial Park absence (*n*=42) and nursery sites (*n*=44).

A chi-square test was used to determine if there was a difference between arboreal lichen class categories (Stevenson et al. 1998) at absence sites and nursery sites in each park (Appendix 3.14). Both chi-square tests showed results that were significant in Woodland Caribou Provincial Park ($\chi^2 = 205.225$, 6 d.f., $p<0.001$) and Wabakimi Provincial Park ($\chi^2 = 97.875$ 6 d.f., $p<0.001$) (Figure 2.16). In Woodland Caribou Provincial Park, there was more arboreal lichen at absence sites and many nursery sites with no arboreal lichen present. In Wabakimi Provincial Park, there was more arboreal lichen at nursery sites and very few sites with no arboreal lichen present compared to absence sites.

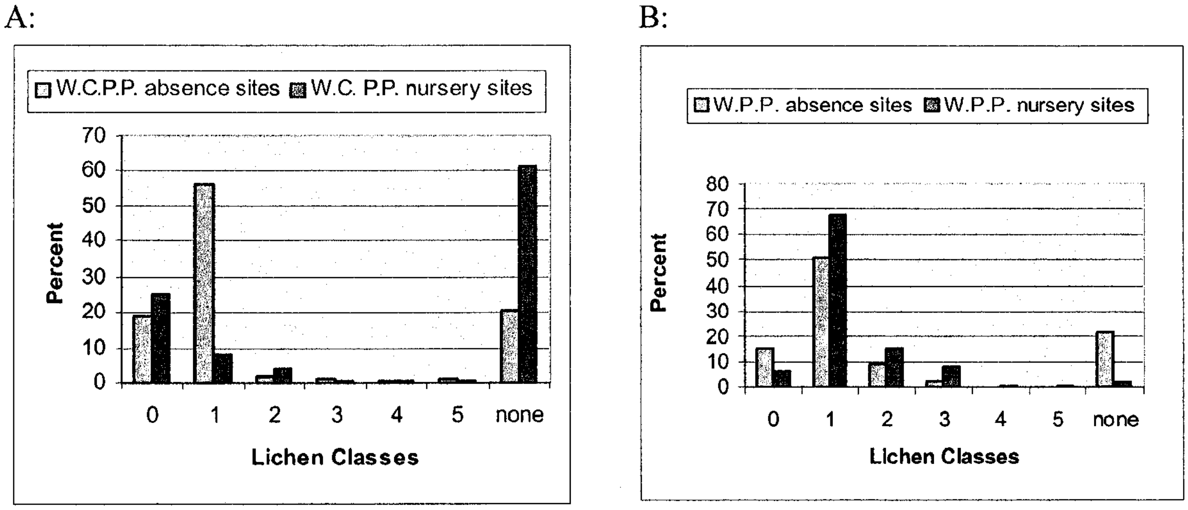

Figure 2.16. Relative abundance of arboreal lichen classes (%) in 10m-radius plots at (A) Woodland Caribou Provincial Park absence (*n*=352) and nursery sites (*n*=352) and (B) Wabakimi Provincial Park absence (*n*=336) and nursery sites (*n*=352). *n* is the total number of individual trees sampled for arboreal lichens at absence or nursery sites in each park. "None" indicates there were no overstorey trees in the plot quadrant for measurement of arboreal lichens.

Interval Scale Data

MANOVA

The MANOVA indicated that there was a significant difference between study sites (F=14.23, d.f.=18, 39, p<0.001) in relation to the habitat variables collected (Table 2.1) and between absence and nursery sites (F=2.04, d.f.=18, 39, p=0.031) for the 4 groups (i.e., Woodland Caribou and Wabakimi nursery and absence sites). The significant differences between study areas indicated that nursery and absence sites should be analyzed separately for each park.

Table 2.1. Means ± standard errors of interval scale variables measured in sample plots at caribou nursery sites and randomly chosen absence sites on lakes in Wabakimi (WPP) and Woodland Caribou Provincial Parks (WCPP), northern Ontario. Variables that showed significant differences in the MANOVA, individual park DFA results used to identify and determine variables most important in distinguishing nursery sites from absence sites, and variables used in the development and evaluation of Resource Selection Functions for calving caribou in each park are indicated by superscripts.

Measurement	WCPP Absence sites (*n*=15)	WCPP Nursery sites (*n*=15)	WPP Absence sites (*n*=15)	WPP Nursery sites (*n*=15)
Slope$^{2\ 3}$ (degrees)	13.4 ± 2.5	18.0 ± 1.2	6.4 ± 1.7	10.6 ± 2.7
Elevation$^{1\ 2}$(m)	364.9 ± 94.2	364.8 ± 94.2	364.5 ± 94.1	360.9 ± 93.2
# Standing Dead Trees^{3}	6.7 ± 1.7	6.9 ± 1.8	4.5 ± 1.2	4.0 ± 1.0
# Stumps	3.1 ± 0.8	3.6 ± 0.9	3.0 ± 0.78	2.7 ± 0.70
Ground Detection Distance$^{1\ 2\ 3\ 5}$ (0-1m)	19.5 ± 5.0	21.7 ± 5.6	28.0 ± 7.2	23.5 ± 6.1
Ground Detection Distance (1-2m)	23.5 ± 6.1	25.9 ± 6.7	30.8 ± 8.0	26.1 ± 6.7
Shrub Density $^{1\ 2\ 5}$ (stems/m^2)	0.39 ± 0.10	0.25 ± 0.07	0.39 ± 0.10	0.22 ± 0.06
Lichen Transect Occurrence$^{1\ 2\ 3\ 6}$(%)	31.1 ± 8.0	38.9 ± 10.0	9.6 ± 2.5	20.0 ± 5.2
Open Groundcover $^{1\ 4\ 6}$ (Rock, Wood, Soil/Litter) (%)	37.01 ± 9.6	18 ± 4.7	38.9 ± 10.0	22.7 ± 5.9
Vegetation Groundcover$^{2\ 4}$ (Moss, Lichen, Herbs, Shrubs, Fungi, Ferns) (%)	75.5 ± 19.5	93.6 ± 24.2	77.9 ± 20.1	83.0 ± 21.4
# downed Trees^{3}	0.75 ± 0.19	0.71 ± 0.18	0.13 ± 0.03	0.13 ± 0.03
Maximum height of downfall (cm)	30.0 ± 7.8	27.8 ± 7.18	34.2 ± 8.8	32.2 ± 8.3
Diameter of downfall $^{1\ 2\ 6}$ (cm)	10.6 ± 2.8	11.2 ± 2.9	10.8 ± 2.8	12.3 ± 3.2
Overstorey Cover$^{1\ 2}$ (%)	19.9 ± 5.1	24.9 ± 6.4	14.3 ± 3.7	22.0 ± 5.7
Understorey Cover ^{1} (%)	7.5 ± 1.9	5.1 ± 1.3	3.0 ± 0.78	5.3 ± 1.4
Dbh (cm)	14.6 ± 3.8	13.8 ± 3.6	14.3 ± 3.7	13.5 ± 3.5
Overstorey Woody Vegetation Density^{1} (stems/m^2)	0.58 ± 0.15	0.73 ± 0.19	0.68 ± 0.18	1.1 ± 0.28
Understorey Woody Vegetation Density$^{2\ 4\ 5}$ (stems/m^2)	0.87 ± 0.23	0.66 ± 0.17	0.41 ± 0.11	0.63 ± 0.16

[1] Variables included in Woodland Caribou Provincial Park models

[2] Variables included in Wabakimi Provincial Park models

[3] Variables that had significant differences between the two parks (MANOVA)

[4] Variables that had significant differences between nursery and absence sites (MANOVA)

[5] Variables marked as important from DFA standardized canonical discriminant functions in Wabakimi Provincial Park

[6] Variables marked as important from DFA standardized canonical discriminant functions in Woodland Caribou Provincial Park

Discriminant Function Analysis

The DFA results for all 4 groups indicated statistically significant classification of 87% of sites. Wilks Lambda indicated that group means differed for the first 2 discriminant functions DF1 ($\chi^2 = 149.61$, 51 d.f., $p<0.001$) and DF2 ($\chi^2 = 52.19$, 32 d.f., $p=0.014$). DF1 explained 81.2 % of the total model variance for park differences and DF2 explained 13.7 % of the total model variance in nursery and absence site differences (Figure 2.17). The habitat variables important in differentiating between parks were primarily the number of downed trees (standardized Canonical Discriminant Functions (CDF) coefficient = 0.952), followed by nearest neighbour measurements of understorey woody vegetation density (CDF = -0.855), 0-1m ground detection distance (CDF = -0.820), and shrub density (CDF = 0.710) (Table 2.2). Woodland Caribou Provincial Park areas fell on the positive side of DF1 in comparison to Wabakimi Provincial Park areas (Figure 2.17). The habitat variables important in separating nursery areas from absence areas in both parks were open groundcover (CDF = 0.833), vegetation groundcover (CDF = 0.793), 0-1m ground detection distance (CDF = 0.779), understorey woody vegetation density (CDF = 0.683), and the diameter of downed trees (CDF = -0.679) (Table 2.2). Absence sites tended to be on the positive end of the DF2 axis in comparison to the nursery sites. The difference between nursery and absence sites in Wabakimi Provincial Park is more apparent than the differences between sites in Woodland Caribou Provincial Park (Figure 2.17).

Figure 2.17. Canonical Discriminant Functions of 17 variables measured at 30 caribou nursery sites and 30 randomly chosen absence sites on lakes in Wabakimi and Woodland Caribou Provincial Parks, northern Ontario. The x-axis (DF1) indicates differences between the parks and the y-axis (DF2) indicates differences between caribou nursery and unused absence sites.

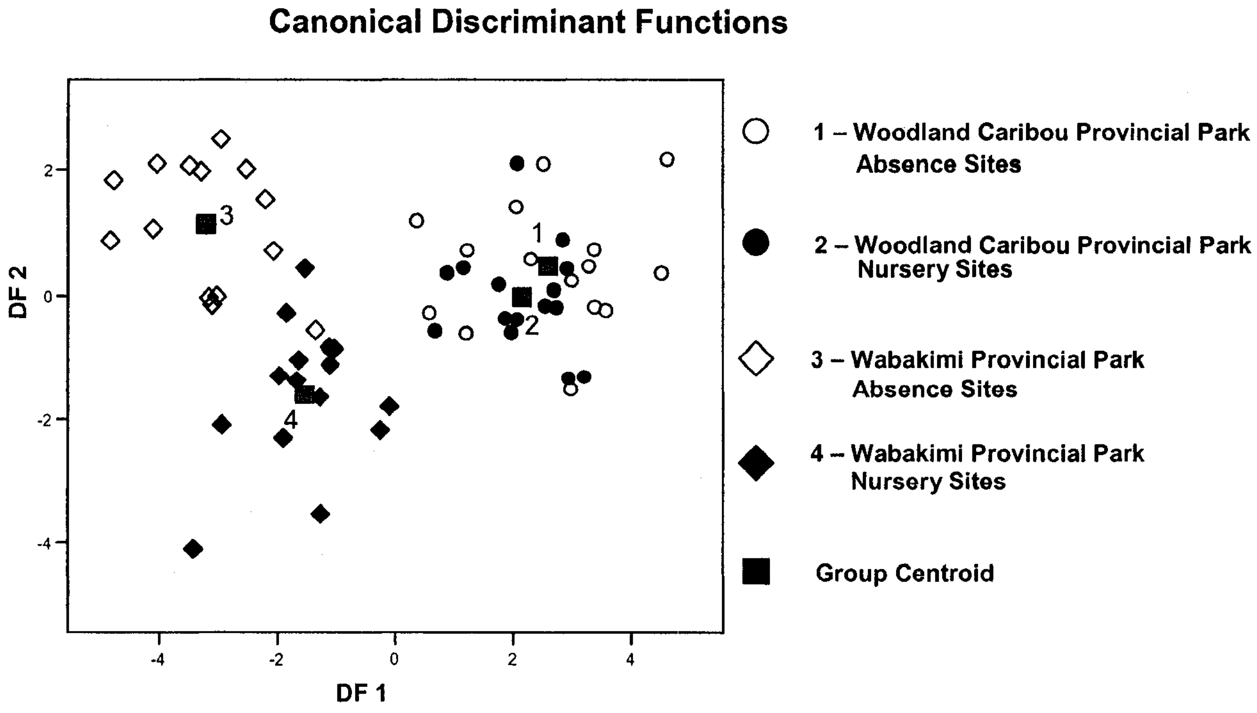

Table 2.2. Standardized Canonical Discriminant Function Coefficients of all 4 groups (Woodland Caribou and Wabakimi Provincial Parks nursery and absence sites). The x-axis (Function 1) represents differences between the parks and the y-axis (Function 2) represents differences between caribou nursery and absence sites.

Measurements	Function1	Function 2
Shrub Density	0.710	-0.165
# Downed Trees	0.952	0.320
Maximum Height of Downfall	-0.100	0.362
Diameter Downfall	-0.080	-0.679
Overstorey Cover	0.402	-0.546
Understorey Cover	-0.088	0.021
dbh	-0.236	0.069
Overstorey Woody Vegetation Density	-0.031	-0.377
Understorey Woody Vegetation Density	-0.855	0.683
Elevation	-0.087	0.155
Slope	-0.068	0.226
Lichen Transect Occurrence	0.331	-0.095
# Standing Dead Trees	0.394	0.233
# Stumps	-0.227	0.104
Ground Detection Distance	-0.820	0.779
Vegetation Groundcover	0.119	0.793
Open Groundcover	0.132	0.833

A separate DFA for each study area was also completed. For Woodland Caribou Provincial Park, nursery and absence sites were classified correctly 100% of the time. The model explained 100% of the variance with a significance value of p=0.036. Wilks Lambda indicated that group means differed for DF1 ($\chi^2 = 28.81$, 17 d.f., p=0.036). The habitat variables that were most important in differentiating between nursery and absence sites were open groundcover (CDF = 1.29), the diameter of downfall (CDF = -0.975), lichen transect occurrence (CDF = -0.890), 0-1m ground detection distance (CDF = -0.699), and overstorey woody vegetation density (CDF = -0.675) (Table 2.3). Absence sites fell on the positive end of the axis differentiating between absence and nursery sites.

Table 2.3. Standardized Canonical Discriminant Function Coefficients of 17 habitat variables measured at nursery and absence sites on lakes in Wabakimi (WPP) and Woodland Caribou (WCPP) Provincial Parks.

Measurements	WCPP	WPP
Shrub Density	0.636	-1.021
# Downed Trees	0.284	-0.449
Maximum Height of Downfall	0.057	0.535
Diameter Downfall	-0.975	-0.956
Overstorey Cover	0.582	-0.710
Understorey Cover	-0.294	0.118
dbh	-0.017	0.213
Overstorey Woody Vegetation Density	-0.675	-0.419
Understorey Woody Vegetation Density	0.419	1.435
Elevation	0.596	0.066
Slope	-0.389	0.598
Lichen Transect Occurrence	-0.890	-0.503
# Standing Dead Trees	0.193	0.153
# Stumps	-0.147	0.910
Ground Detection Distance	-0.699	1.419
Vegetation Groundcover	0.031	0.800
Open Groundcover	1.292	0.663

For Wabakimi Provincial Park, nursery and absence sites were classified correctly 93% of the time. The model explained 100% of the variance with a significance value of p=0.037. Wilks Lambda indicated that group means differed for DF1 ($\chi^2 = 28.73$, 17 d.f., p=0.037). The habitat variables that were most important in differentiating between nursery and absence sites were the understorey woody vegetation density (CDF = 1.435), 0-1m ground detection distance (CDF = 1.419), shrub density (CDF = -0.1.021), diameter of downfall (CDF = -0.956), and vegetation groundcover (CDF = 0.800) (Table 2.3). Absence sites fell on the negative end of the DF1 axis in comparison to nursery sites.

Woodland Caribou Provincial Park Habitat Variable Reduction, Model Selection, Development, and Evaluation

The variables removed by examination of variance inflation factors (VIFs) in hierarchical cluster analysis and condition numbers from principal components analysis were the number of downed trees, height of downfall, dbh, understorey woody vegetation density, 1-2m ground detection distance, number of stumps, vegetation groundcover, and number of standing dead trees. Lichen transect occurrence was retained because the DFA indicated that it was an important variable in the differentiation of absence and nursery sites in Woodland Caribou Provincial Park (Table 2.3). The slope category was strongly related to lichen transect occurrence, shrub density, and ground detection distance in the dendrogram, so it was not included. Ground detection distance at 0-1m and shrub density, as well as overstorey woody vegetation density and overstorey % cover, were kept in the analysis because they were important in differentiating between nursery and absence sites in the DFA.

Stepwise logistic regression of the remaining 9 habitat variables associated with two-thirds of the caribou nursery and absence sites in Woodland Caribou Provincial Park (Table 2.1) resulted in 3 candidate models with statistically significant coefficients ($P<0.01$) (Tables 2.4 and 2.5).

The 1-variable RSF model for calving caribou in Woodland Caribou Provincial Park, based on open groundcover, successfully classified caribou nursery and absence sites for 80% of the test data (Table 2.5). The 2-variable RSF model for calving caribou in Woodland Caribou Provincial Park, based on open groundcover and shrub density, successfully classified caribou nursery and absence sites for 80% of the test data, while the 3-variable model, which also included overstorey canopy cover, had a 60% success rate. The 3-variable model for calving caribou in Woodland Caribou Provincial Park performed better than the 2-variable model based on the logistic regressions and ROC values using two-thirds (n=20) of the nursery and absence site data (Table 2.4), but the 2-variable model also provided good results; an R^2 of 0.85, an 85% correct classification rate, and an area under the ROC curve of 0.98. The 2-variable model also performed exceptionally well in the preceding model development stage, with an area under the ROC curve of 0.98, p<0.001, 95% CI (0.929-1.031), and by adding 1 additional variable the area under the curve only increased 2% to a ROC value of 1.0. In addition, given the small sample size relative to the number of variables in the models, the 3-variable model may overparameterize the data. Thus, I suggest the 2-variable model (Table 2.4) may best represent the RSF of calving caribou in Woodland Caribou Provincial Park.

Table 2.4. Candidate Resource Selection Function (RSFs) models resulting from stepwise logistic regression of 9 variables associated with two-thirds (*n*=20) of the caribou nursery and randomly chosen absence sites sampled in Woodland Caribou Provincial Park and their evaluation by Akaike Information Criterion for small sample size (AIC_c) and Receiver Operating Characteristic curves (ROCs).

Model	Variables in Model	-2log likelihood	Nagelkerke R Square	% Correct	AICc	AICc Evidence Ratio	Area Under ROC Curve
1	Open Groundcover	16.878	0.56	65	41.256	>10	0.85
2	Open Groundcover, Shrub Density	7.597	0.85	85	25.861	>10	0.98
3	Open Groudcover, Shrub Density, Overstorey Cover	2.45E-06	1.00	100	14.286	1	1.00

Table 2.5. Predictive probabilities (i.e., proportions of sites correctly or incorrectly classified) of candidate Resource Selection Function (RSFs) models (Table 2.4) based on one-third (*n*=10) of the data from caribou nursery and randomly chosen absence sites sampled in Woodland Caribou Provincial Park.

Model	Variables in Model	Percent Correctly Predicted Absence	Percent False Positives Absence	Percent Correctly Predicted Presence	Percent False Positives Presence
1	Open Groundcover	80	20	80	20
2	Open Groundcover, Shrub Density	80	20	80	20
3	Open Groundcover, Shrub Density, Overstorey Cover	60	40	60	40

Wabakimi Provincial Park Habitat Variable Reduction, Model Selection, Development, and Evaluation

Following examination of VIFs, linkages, and condition numbers, the variables used to develop resource selection functions (RSFs) were lichen transect occurrence, vegetation groundcover, diameter of downfall, overstorey cover, understorey woody vegetation density, elevation, and slope. Shrub density and ground detection distance at 0-1m were included in the model as well, because both were indicated as important in the DFA.

Stepwise logistic regression of the remaining 9 habitat variables associated with two-thirds of the caribou nursery and absence sites in Wabakimi Provincial Park (Table 2.1) resulted in 3 candidate models with statistically significant coefficients ($P<0.01$) (Tables 2.6 and 2.7).

The 1-variable RSF model for calving caribou in Wabakimi Provincial Park, based on density of understorey woody vegetation, successfully classified caribou nursery and absence sites for 60% of the test data (Table 2.7). The 2-variable RSF model for calving caribou in Wabakimi Provincial Park, based on density of understorey woody vegetation and ground detection distance at 0-1m, successfully classified caribou nursery and absence sites for 80% of the test data, while the 3-variable model, which also included vegetation groundcover, had a 60% success rate. Although the 3-variable model performed better than the 2-variable model based on the logistic regressions and ROC values using two-thirds (n=20) of the nursery and absence site data (Table 2.6), the 2-variable model had an R^2 of 0.74, a 90% correct classification rate, and an area under the ROC curve of 0.96. The 2-variable model also performed exceptionally well in the preceding model development stage, with an area under the ROC curve of 0.96, p=0.001, 95 % CI (0.883-1.037), and by adding 1 additional variable (groundcover vegetation) the area under the ROC curve increased by only 4% to a ROC value of 1.0 (Table 2.6). As with the Woodland Caribou Provincial Park models, given the small sample size relative to the number of variables in the models, the 3-variable model may overparameterize the data. Thus, I suggest the 2-variable model (Table 2.6) may best represent the RSF of calving caribou in Wabakimi Provincial Park.

Table 2.6. Candidate Resource Selection Function (RSFs) models resulting from stepwise logistic regression of 9 variables associated with two-thirds (*n*=20) of the caribou nursery and randomly chosen absence sites sampled in Wabakimi Provincial Park and their evaluation by Akaike Information Criterion for small sample size (AIC_c) and Receiver Operating Characteristic curves (ROCs).

Model	Variables in Model	-2log likelihood	Nagelkerke R Square	% Correct	AICc	AICc Evidence Ratio	Area Under ROC Curve
1	Understorey Woody Vegetation Density	20.777	0.39	75	49.055	>10	0.80
2	Understorey Woody Vegetation Density, Ground Detection Distance (0-1m)	11.389	0.74	90	33.444	>10	0.96
3	Understorey Woody Vegetation Density, Ground Detection Distance (0-1m), Vegetation Groundcover	1.52E-06	1.00	100	14.286	1	1.00

Table 2.7. Predictive probabilities (i.e., proportions of sites correctly or incorrectly classified) of candidate Resource Selection Function (RSFs) models (Table 2.6) based on one-third (n=10) of the data from caribou nursery and randomly chosen absence sites sampled in Wabakimi Provincial Park.

	Variables in Model	Percent Correctly Predicted Absence	Percent False Positives Absence	Percent Correctly Predicted Presence	Percent False Positives Presence
1	Understorey Woody Vegetation Density	60	40	60	40
2	Understorey Woody Vegetation Density, Ground Detection Distance (0-1m)	80	20	80	20
3	Understorey Woody Vegetation Density, Ground Detection Distance (0-1m), Vegetation Groundcover	60	40	60	40

Discussion

In Woodland Caribou Provincial Park the slope, lichen occurrence, and number of standing and downed trees were higher, while ground detection distances at 0-1m were lower, than absence and nursery sites in Wabakimi Provincial Park (Table 2.1). These small-scale differences between the parks are likely the result of large-scale geographic variation in weather, topography, soil productivity, and dominant vegetation across the 2 different ecoregions in which they are situated (Hills 1959, Crins and Uhlig 2000); Woodland Caribou Provincial Park falls in more of a "boreal prairie" area being on the east Manitoba border and Wabakimi Provincial Park falls in more of a "true boreal" region in north-central Ontario). Although not statistically different, the density of overstorey trees and canopy cover were higher at nursery sites than unused absence sites in both Woodland Caribou and Wabakimi Provincial Parks, suggesting selection of nursery sites in older-growth forests of both ecoregions.

Many of the characteristics associated with caribou nursery sites in Wabakimi and Woodland Caribou Provincial Parks, particularly those associated with older-growth forests and identified for inclusion in 2-variable RSFs, were related to forage abundance and possible predator avoidance strategies. In Wabakimi Provincial Park, density of understorey woody vegetation and ground detection distance at 0-1m were the 2 most important variables differentiating between nursery sites and randomly chosen absence sites. The density of understorey woody vegetation was higher at nursery sites than absence sites (Table 2.1), although unused absence sites were generally in shrub rich areas while nursery sites were in old growth areas of spruce (Figures 2.7, 2.9, and 2.15). Due to differences in deciduous versus coniferous growth forms, particularly foliage density, ground detection distances at 0-1m were higher at absence sites than nursery sites in Wabakimi Provincial Park. Nursery sites were predominantly in the V34 or V32 FEC types, dominated by black spruce and jack pine, whereas absence sites were mainly found in the mixedwood categories in both parks, with the exception of V30 in Woodland Caribou Provincial Park (Figure 2.3). Deciduous tree species such as white birch and trembling aspen were noted more often at absence sites than nursery sites. In both parks, nursery sites had higher densities of mature trees and lower shrub densities than unused absence sites, providing potentially greater sensory detection of approaching predators. As well, higher vegetative groundcover, including greater lichen abundance, was found at nursery sites compared to absence sites in the 2 parks. All of these characteristics suggest female caribou in both parks were selecting nursery sites that may reduce predation risk while providing abundant forage (Gustine et al. 2006). These results are consistent with Stuart-Smith et al. (1997) and Lantin et al. (2003) who found spruce dominated stands to be associated with caribou calf presence in Québec, Saskatchewan, and Alberta. Use of conifer forests for calving may provide reduced risk of predation due to lower moose and, hence, wolf densities (Ferguson and Elkie 2004).

Lent (1974) described the "hiding" and "following" responses of ungulate neonates as anti-predator strategies and Fitzgibbon (1990) described the tactics used by woodland caribou to be those of a "follower". In dense vegetation, a caribou calf may drop down out of sight and take a prone position, keeping the head low to the ground and remaining motionless if spotted by a predator (Fitzgibbon 1990). Upon closer approach by a predator, the caribou cow may take flight and the calf follows closely, rather than attempting to remain hidden in the vegetation as is the typical hiding behaviour of other ungulates such as white-tailed deer (*Odocoileus virginianus*) (Lesage et al. 2002). Caribou nursery site selection and response to predators is thus more similar to that of moose (*Alces alces*). Bowyer et al. (1999) identified greater forage, a southeasterly aspect, and better visibility as being the key variables at Alaskan moose birth sites. Although I did not find any relationship between aspect and nursery site selection, greater forage availability and visibility were also important to caribou as previous studies have found for other ungulate calving sites (Bowyer et al. 2001). Food in the summer months for caribou often consists of forbs, shrubs, fungi, grasses, and sedges (Darby and Pruitt 1984), but lichens, even though they have lower nutritional value, may also comprise a high proportion of their diet (Ahti and Hepburn 1967). As vegetative ground cover, including greater lichen abundance, was found at nursery sites compared to absence sites in the 2 parks, it does not appear that caribou necessarily trade off forage availability for greater concealment cover, but they may be willing to accept lower forage quality (i.e., lichens rather than other summer foods) in exchange for a reduction in predation risk.

Bergerud (1985) and Ferguson et al. (1988) suggested woodland caribou maternal cows should take actions to reduce the success rates of wolves and bears in encountering, detecting, and capturing calves by reducing movement and using shorelines with slopes, especially on islands, such as those in Pukaskwa National Park and Neys Provincial Park. Although not statistically significant, the higher slopes at caribou nursery sites than absence sites in both Wabakimi and Woodland Caribou Provincial Parks are consistent with this strategy. The higher slope at nursery sites may help caribou detect oncoming predators more easily and facilitate escape. Similarly, Wilton and Garner (1991) found that moose calving sites were most often situated at high points and on knolls, on islands, and Addison et al. (1990) determined these were usually within 200m of water. These locations may minimize encounters with mobile predators as they will require more energy to get to islands and slopes will further increase their searching time for females with calves (Bergerud 1985).

This study provides a preliminary basis for identifying caribou nursery sites both outside and within protected area boundaries across northern Ontario. A logical next step for this work is the development of a first generation spatial model from the predictors established in this study. This model can then be validated and field tested to determine the utility of the model as a management tool for further application in both parks and Forest Management Units north of the southern limit of contiguous range occupancy for woodland caribou in northern Ontario (Figure 1). Although logistically challenging, future studies should attempt to identify a larger number of nursery sites for assessment, but I do not suggest that all variables I initially collected be measured. Rather, the 12 variables used for development of models in both parks (Table 2.1), particularly those related to overstorey and understorey cover and woody vegetation density, groundcover, especially lichen abundance, shrub density, slope, and ground detection distance at 0-1m, may provide a more suitable starting point. As remote sensing information improves, it may be possible to correlate these habitat variables with satellite spectral data to decrease the logistic/financial problems associated with the identification of caribou nursery sites in remote locations, thereby improving their protection in future management policies and legislation. Ultimately, future studies need to relate caribou fitness to nursery site selection at multiple spatial scales.

Chapter 3. Landscape Characteristics of Woodland Caribou Nursery Sites in Northern Ontario

Introduction

Understanding space-use patterns of highly mobile animals relative to the hierarchy of limiting factors that affect individual fitness is required to conserve animals such as woodland caribou (Allen and Starr 1982, Ferguson and Elkie 2005). Habitat selection can be examined on both a coarse and fine scale (Holling 1992), and these scales of selection are important for wide-ranging animals such as woodland caribou that have evolved space-use strategies to minimize predation, as discussed in earlier chapters.

As discussed earlier in this thesis, calving sites often include shorelines and islands in large lakes, which are thought to reduce predation risk. Ferguson and Elkie (2005) found that females that were first radio-collared in either winter or summer were both as likely to be found on lakes or islands to calve in the following summer and that there was no difference in the probability of female caribou using shoreline sites on lakes or islands to calve relative to latitude. Ferguson and Elkie (2005) also found that male and female caribou used habitat differently in the summer. Females used habitat on medium-sized islands (10 – 100ha) compared to male locations, which were less likely to be found on lakes and generally in areas with less water. The overall mean island size used by females was smaller than available (30ha versus 200ha). Ferguson and Elkie (2005) also found that female caribou secondarily used fens for calving and that there was no significant difference between the use of treed or open fens.

Wabakimi Provincial Park in northern Ontario has a concentration of large lakes with convoluted shorelines and numerous islands that may offer many actual and potential calving sites and summer habitat (Timmermann 1998). Bergerud (1989) reported that Cumming (1982) had found no summer use of islands less than 9.9ha in size on one particular lake but did find summer use on islands less than 9.9ha in size on 2 other lakes in Wabakimi Provincial Park. Cumming (1982) found that simply walking across islands provided a very good means of determining summer use by resident caribou. Cumming (unpublished report) found that woodland caribou in Wabakimi Provincial Park were widely dispersed in the summer, possibly as an anti-predator technique. Islands were used more than mainland shorelines for calving (Cumming, unpublished report).

Some studies have shown the use of islands by caribou to avoid bears and wolves (Bergerud and Butler 1984, Cumming and Beange 1987). Cumming and Beange (1987) reported use of beaches and conifer-covered islands on Lake Nipigon and on 1 lake in Wabakimi Provincial Park. They found that the islands in use were from 0.5 to 1,550ha in size (from a total range of 0.3 to 7,190ha), although they did oversample islands between 10 and 25ha and undersample very small and very large islands. Both caribou and moose seemed to prefer islands 25-75ha in size and avoided those less than 5ha in size. Caribou sign showed more clumping of island use than would be expected by chance; however, measurements of all islands (those islands used and those not used) showed a more uniform spacing than that expected by chance. It appeared that the caribou chose islands clustered together but evenly spaced apart, which could be another escape strategy because caribou are good swimmers and could retreat to a neighbouring island fairly quickly if a predator was encountered.

Human activities within caribou range, which do not necessarily destroy habitat, may still result in a functional loss of usable space because of disturbance and the resulting displacement of caribou (Webster 1997). Relatively isolated areas caribou live in, such as parks, may make them more responsive to human disturbance, eliciting a high stress response (Webster 1997). Ungulate response to human-related harassment may result in anything from a slight increase in vigilance to panicked flight, with equally variable consequences for the animal (Jakimchuk 1980, Schideler et al 1986). Caribou and other ungulates perceive humans as predators and because of this, pedestrian approaches elicit greater cardiac and behavioural responses than mechanical stimuli (Eckstein et al. 1979, MacArthur et al. 1982, Freddy et al. 1986, Simpson 1987, Anderson et al. 1996). Documented cases of ungulate response to humans on foot primarily concern active avoidance and a corresponding increase in energy expenditure (Richens and Lavigne 1978, Eckstein et al. 1979, Ferguson and Keith 1982, Freddy et al. 1986). Freddy et al. (1986) found that deer ran longer and further when disturbed by people on foot in comparison to snowmobiles. Two possible reasons to explain this response are the relatively silent approach and sudden appearance of pedestrians (Webster 1997). The closer a stimulus is to an ungulate before triggering a flight response, the longer the flight distance and time for heart rate to return to normal (Anderson et al. 1996). Subtle noises that caribou are unable to pinpoint are more likely to be associated with predators than steady state noises from mechanical stimuli (Jakimchuk 1980). Kuck et al. (1985) concluded that elk responded more strongly to direct human harassment than to simulated mine noises (100 decibels). The disturbed cow-calf pairs tended to use random selections of habitats, used larger areas, moved greater distances, and more readily abandoned the calf rearing area. This abandonment of a calving ground is unusual for elk, as they show strong fidelity to calving grounds, similar to caribou.

A study by Nellemann et al. (2000) examined winter foraging behaviour and distances to one tourist resort of reindeer (*R. t. tarandus)* in Rondane National Park in Norway. Caribou cow-calf pairs, apparently sensitive to disturbance, located themselves 15-25km from the resort as compared to males and yearlings who were 5-10km from the resort. Avoidance in the 0-5km distances to a resort reflected an approximate critical tolerance distance to cabins, independent of human activity. This displacement most likely resulted in an underuse of areas close to resorts and an overuse of undisturbed areas. Vegetation data did suggest that overgrazing may be occurring as a result of redistribution of caribou away from the tourist resort (Nellemann et al. 2000), which could have long-term consequences for the population.

Disturbance from human activity in Woodland Caribou and Wabakimi Provincial Parks may occur in a number a ways; from campsites, shorelunch areas, motor boats, aircraft, and fishing outposts. Webster (1997) examined the effects of human-related harassment on woodland caribou in British Columbia and defined "harassment" as a specific human activity resulting in the altering of an animal's behaviour that could potentially increase energy expenditure or risk of injury. Geist (1975) states that during harassment, regulatory systems require additional energy that would normally be allocated to growth, maintenance, or reproduction and the excitation temporally doubles the energy required for maintenance by increasing metabolism about 25%. Repeated harassment could therefore result in reduced growth rates, poor body condition, and decreased reproductive rates that may in turn increase caribou adult and calf mortality (Webster 1997). Caribou are most sensitive to harassment and additional stress during the calving period, and may suffer the most serious consequence if displaced at that time (Webster 1997).

The objective of this chapter is to describe landscape scale characteristics of woodland caribou nursery sites on lake habitat used by cow-calf pairs in Wabakimi and Woodland Caribou Provincial Parks. Based on previous studies, I hypothesized that calving caribou in both parks would select nursery sites primarily on islands that consist of a cluster of land features within short distances in order to escape predators and human disturbance. Comparisons are made between nursery and absence sites and random points in each park. Landscape characteristics are theorized to reflect some of the predator avoidance strategies discussed earlier. These landscape characteristics may be helpful in future studies to evaluate predictors of potential calving and/or nursery areas.

Methods

All absence and nursery sites identified over the 3 years of study in both parks were used in this investigation. There were a total of 870 absence sites and 94 nursery sites initially identified from surveys in Woodland Caribou Provincial Park and a total of 164 absence sites and 39 nursery sites initially identified from surveys in Wabakimi Provincial Park. See survey methodology in Chapter 2 for details of site identification.

GIS Analysis

Geographic co-ordinates of all sites were brought into the ArcMap 8.3 Geographic Information System (GIS) and assigned to landcover classes in Landcover 2000. Landcover 2000 (Spectranalysis 2004) is a remotely sensed coverage that was produced from satellite imagery collected during 1999-2002 to produce a data set composed of 25m-grid cells, each classified into 1 of 27 different landcover classes consisting of vegetation types (such as forest, wetlands, and agricultural crops or pasture) and categories of non-vegetated surface areas (such as water bodies, bedrock outcrops, or settlements). To compare the availability of landcover classes in areas that were searched for evidence of caribou nursery activity to the availability of these classes at the landscape scale within each park, buffered areas were delineated along the shorelines of lakes and islands that were surveyed. The buffered areas included the first 100m of mainland shoreline, all islands less than 500m either in length or width, as well as the first 100m of shoreline on all islands over 500m in length or width. Random points were then created within the buffered areas of each park with a Random Point Generator (Version 13; Jenness 2005). Initially, the number of random points generated was equal to 5 times the number of absence and nursery sites identified in each park. For each park, I compared the frequency distributions of random points among Landcover 2000 categories in buffered areas to the distribution of classified 25m-grid cells in buffered areas. If the random points in buffered areas did not represent the frequency distribution of available Landcover 2000 categories based on 25m-grid cells in the buffers, then more random points were added until there was no statistically significant difference (chi-square) between landcover classes represented by random points in buffered areas and 25m-grid cells within buffered areas. In the end, there were 7,935 random points within buffered areas in Woodland Caribou Provincial Park and 3,886 random points within buffered areas in Wabakimi Provincial Park.

To determine the landscape feature types used by calving caribou in addition to islands and the mainland, I selected all peninsulas on the mainland and islands larger than 10ha in size within the surveyed areas of each park. A peninsula was defined as a landmass that projected from the shore with ≥ 1 length to 1 width of base ratio. The minimum 1:1 ratio ensured that the landmass was a definite visual protrusion on the shorelines of the mainland and islands. Peninsulas were then subdivided into size categories. The "small" category for peninsulas included those peninsulas 0.1-5ha in size while the "large peninsula" category was anything larger than 5ha. Two scales were used to delineate the peninsulas in Woodland Caribou and Wabakimi Provincial Parks; 1:10,000 and 1:24,000, creating 2 datasets for peninsulas in both parks. Simply stated, the 1:10,000 scale had more detailed features and the 1:24,000 had less detailed features.

A Nearest Feature Tool (Jenness 2001) in ArcView 3.2 was used to examine minimum distances from initial points (nursery sites, absence sites, and random points within buffered areas) to the edge of the closest landscape feature (i.e., island, peninsula, or mainland) (Figure 3.1). If the distance was larger than 1km radius from an initial point, the distance was not used because I assumed that landscape features within a 1km radius of nursery sites are most important to cow-calf pairs during the nursery period and Ferguson and Elkie (2004) found that caribou did not move more than approximately 1km a day during the summer season. The closest land edge feature had a unique ID in the GIS attribute table, so I was able to identify individual mainland peninsulas (small and large), island peninsulas (small and large), islands, and mainland as unique feature types. Minimum distances were measured 3 times from each initial point, whether it was a random point within the buffered areas, nursery, or absence site, to establish the first 3 minimum escape distances and 3 closest feature types. The distance to the first feature and the average of the first 3 distances from each point or site were used in the analyses.

Measurements and analyses were performed at both scales (1:10,000 and 1:24,000) of delineation in each park. However, I have reported only the "broad" scale (1:10,000) results since there were no significant differences in findings using the 2 scales.

To examine the potential effects of human activity on calving caribou, the closest distance, to a maximum of 35km, was measured from nursery, absence, and random points within the buffered areas to the closest fishing outpost in each park, regardless of whether the outpost occurred on the same lake as the nursery and absence sites. The study lakes were much smaller in size in Woodland Caribou Provincial Park in comparison to Wabakimi Provincial Park, necessitating a maximum distance of 35km for comparing the closest fishing outpost between parks. This restriction left 7,907 random points within buffered areas, 93 nursery, and 870 absence measurements in Woodland Caribou Provincial Park and 3,880 random points within buffered areas, 39 nursery, and 164 absence measurements in Wabakimi Provincial Park. I did not consider intensity of use of each fly-in outpost in this study.

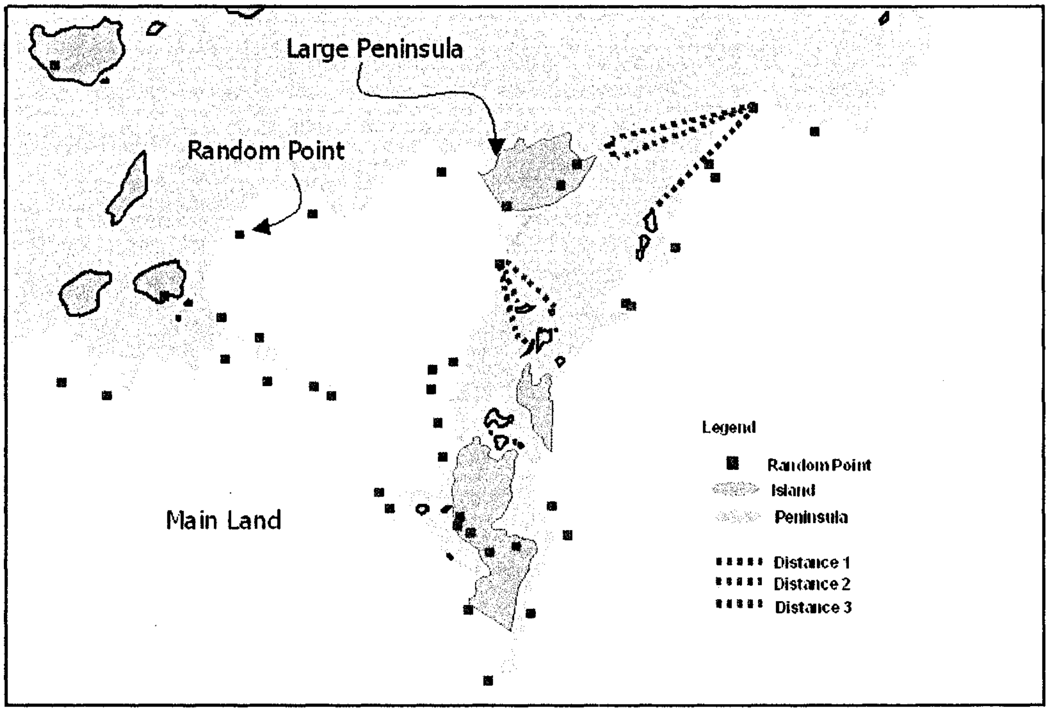

Figure 3.1. Examples of minimum escape distance measurements from random points in buffered survey areas to closest land features using the Nearest Feature Tool (Jenness 2001) in ArcView 3.2 GIS.

Statistical Analysis

Nominal Scale Data

All Landcover 2000 measurements produced nominal data that were compiled into frequency distributions. I compared the frequency distributions among Landcover 2000 categories of random points within buffered areas, absence sites, and nursery sites using a chi-square statistical analysis. Points that fell in the water, cuts, regenerating depletion, clouds, and "other" (undefined) categories were not included. This removal left 6,002 random, 24 nursery, and 189 absence sites in Woodland Caribou Provincial Park and 2,650 random, 19 nursery, and 74 absence sites in Wabakimi Provincial Park. Nursery and absence sites were mostly reduced due to these sites falling on land but being misclassified as water due to their close proximity to water; each grid cell (i.e., pixel) was 25m by 25m and a site that fell 15m from the water's edge was most likely classified as water. Fen and bog categories were grouped together. According to Field (2005), all expected counts should be >1 and no more than 20% of the expected counts should be <5 when dealing with larger chi-square tables. Burns, fens/bogs, and bedrock categories were used in the chi-square tests as long as they did not violate these restrictions. Nominal data occurring with expected frequencies <2 were combined into a single category (Zar 1999).

A chi-square test was also used to compare the frequency of landscape feature types used by calving caribou at nursery sites with absence sites and random points within the buffered areas in each park. The same rule of thumb regarding expected counts (Field 2005) was used in these chi-square tests as for the preceding comparisons of landcover classes.

Interval Scale Data

I tested the assumption of normality of all interval scale data. Log, square root, and arcsine transformations were performed when these data were not normally distributed. All tests were completed using the Statistical Package for the Social Sciences (Version 14.0, SPSS Inc., Chicago, Illinois).

The average of the first 3 closest distances and the first closest feature distance alone were compared among absence, nursery, and random points within the buffered areas in separate t-tests; mean distances from nursery and absences sites were compared to the mean distance from random points in each park with 1-sample t-tests and comparisons between nursery and absence sites were made with 2-sample t-tests.

Distances from all nursery, absence, and random points within the buffered areas to fly-in outpost camps were examined using a non-parametric Kolmogorov-Smirnov test of normality and Levene's test for homogeneity of variance. The data violated both of these assumptions required for ANOVA, even after data transformation, so I chose a non-parametric Kruskal-Wallis test to analyze the untransformed fly-in outpost distance data, followed by a Mann-Whitney U test to compare each pair of conditions in a non-parametric post hoc procedure: nursery versus random sites, nursery versus absence sites, and absence versus random sites, with the effect size for each comparison as outlined by Field (2005).

Results

General Landscape Characteristics

Wabakimi Provincial Park

In Wabakimi Provincial Park, the average size of lakes was 32.2ha (range ± s.d.; 0.01-11,049.7 ± 357.4ha) with an average perimeter of 3,079.3m (8.1– 747,062.1 ± 21,742.1m). The average size of the 10 lakes used for analysis in Wabakimi Provincial Park was 4,822ha (188.1 – 11,049.7 ± 5,580.1ha) with an average perimeter of 133,564m (17,356.8 – 747,062.1 ± 105,883.2m). The average island size in the entire park was 4.0ha (0.01-7,518.5 ± 102.0ha) with an average perimeter of 392.9m (17.2 – 80,708.0± 1,646.2m). The average size of islands on lakes with nursery activity was 8.2ha (0.01 – 7,518.5 ± 167.5) with an average perimeter of 590.6m (33.8 – 80,708.0 ± 4,453.3). The average island size in the study lakes was 7.0ha (0.01-7,518.5 ± 147.8ha) with an average perimeter of 561.2m (33.7 – 80,708.0 ± 3,962.3m). The average large peninsula size both on islands and the mainland in the 10 lakes used for analysis in Wabakimi Provincial Park was 21.5ha (5.3-158.4 ± 21.0ha), with an average perimeter of 2,334m (1,058.1–8,732.7 ± 1,180.1m), while the average small peninsula size both on islands and the mainland was 1.1ha (0.1-14.9 ± 1.3ha) , with an average perimeter of 457m (134.9-2,583.8 ± 261.7ha).

Woodland Caribou Provincial Park

In Woodland Caribou Provincial Park, the average size of lakes was 39.3ha (0.02 – 3,160.8 ± 198.2ha) with an average perimeter of 3,851.0m (82.5 – 231,537.0 ± 10,683.4m). The average size of the 83 lakes used for analysis in Woodland Caribou Provincial Park was 487.6ha (3.4 – 3,160.8 ± 812.3ha), with an average perimeter of 26,898.9m (1,054.9-231,537.0 ± 32,933.5m). The average island size in the entire Woodland Caribou Provincial Park was 2.2ha (0.01-219.0 ± 10.4ha) with an average perimeter of 445.9m (27.4-12,035.8 ± 792.0m). The average size of islands on lakes with nursery activity was 4.6ha (0.01 – 218.0 ± 16.0) with an average perimeter of 709.5m (31.8 – 8,076.2 ± 1,052.5). The average island size in the study lakes was 4.4ha (0.01 – 218.0 ± 17.0ha) with an average perimeter of 670.2m (31.8 – 12,008.3 ± 1,121.4m). The average large peninsula size in the 83 lakes used for analysis in Woodland Caribou Provincial Park was 24.1ha (5.2-225.6 ± 28.7ha) with an average perimeter of 2,496m (957.0-13,396.4 ± 1,673.4m), while the average small peninsula size was 1.2ha (0.1-4.9 ± 1.1ha) with an average perimeter of 478m (133.5-1,378.7 ± 219.5m).

Nominal Scale Data

Appendix 4 provides tabular data of the frequencies and percentages of all nominal scale data used in Chapter 3.

Landcover Classes

Woodland Caribou Provincial Park

The random points generated in the buffered areas around islands and along shorelines of lakes studied in Woodland Caribou Provincial Park were a representative sample of the landcover classes available in the park (Figure 3.2A; $\chi^2 = 1.984$, 6 d.f., $p = 0.921$). The random points in buffered areas were also distributed similarly to absence sites among landcover classes (Figure 3.2B; $\chi^2 = 5.298$, 4 d.f., $p = 0.258$). Thus, the random points in buffered areas represented the availability of landcover types in both the park and at absence sites for comparisons with landcover types selected by caribou as nursery sites.

There was a significant difference in the distributions of random points and nursery sites among landcover classes (Figure 3.2C; $\chi^2 = 6.476$, 2 d.f., $p = 0.039$). There were a higher percentage of nursery sites (63%) than random points (42%) in the coniferous landcover category and a higher percentage of random points (16%) than nursery sites (0%) in the deciduous category. There were also more nursery sites (63%) in the coniferous landcover category than absence sites (35%), which were more common in the deciduous (18%) and sparse-mixed (48%) landcover classes than nursery sites (0% and 38%, respectively) (Figure 3.2D; $\chi^2 = 8.991$, 2 d.f., $p = 0.01$).

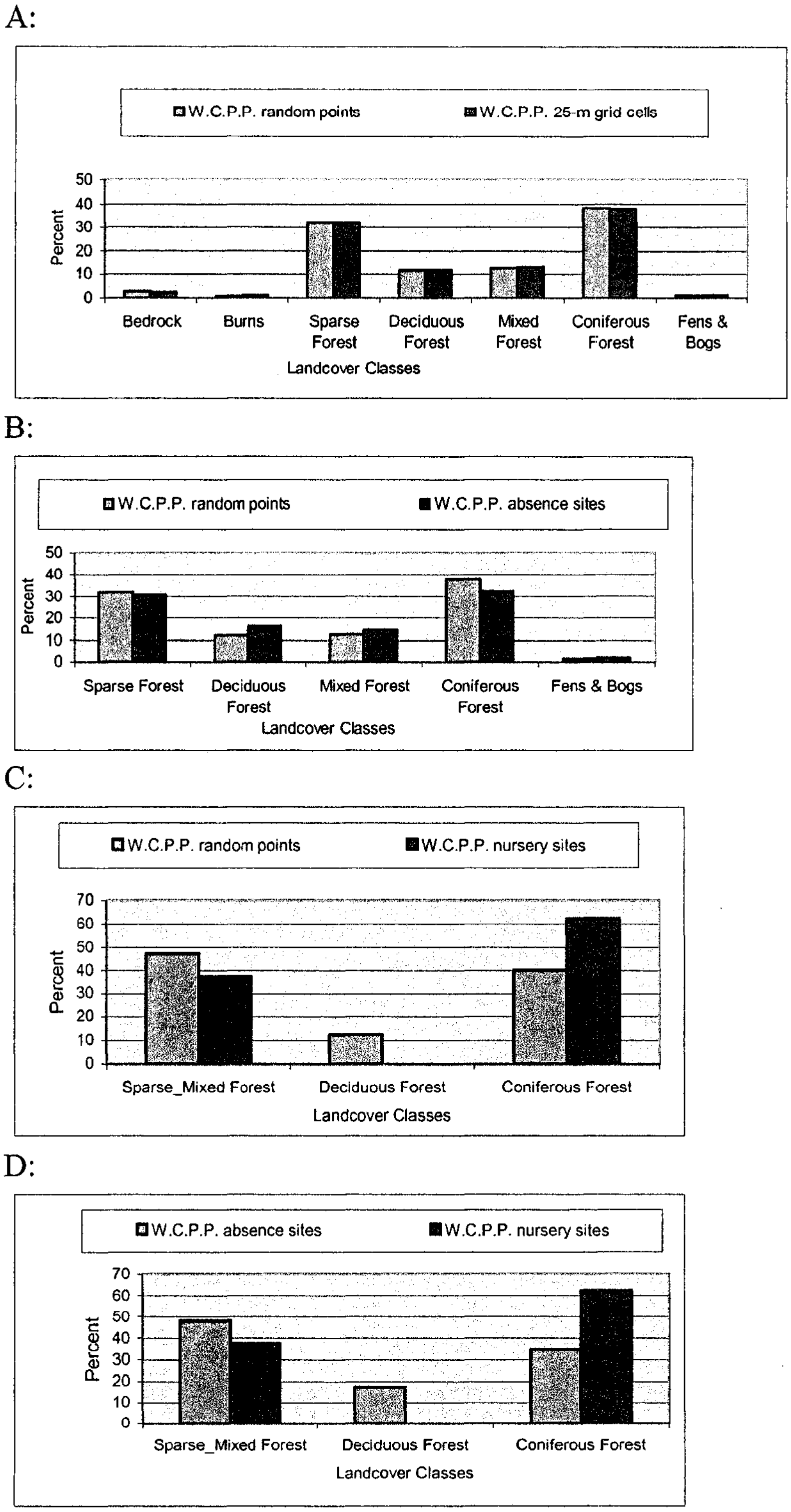

Figure 3.2. Proportions of 25-m grid cells, random points, absence sites, and nursery sites classified by landcover types in Woodland Caribou Provincial Park: (A) random points within buffered areas (*n*=6,002) vs. 25-m grid cells in buffered areas (*n* pixels =262,408); (B) random points (*n*=5,783) vs. absence sites (*n*=182); (C) random points (*n*=5,706) vs. nursery sites (*n*=24); and (D) absence sites (*n*=179) vs. nursery sites (*n*=24).

Wabakimi Provincial Park

The random points generated in the buffered areas in Wabakimi Provincial Park were a representative sample of the landcover classes available in the park (Figure 3.3A; $\chi^2 = 6.179$, 6 d.f., $p = 0.289$). Absence sites were distributed similarly to what was randomly found on the landscape among landcover classes (Figure 3.3B; $\chi^2 = 3.521$, 4 d.f., $p = 0.475$). Therefore, the random points in buffered areas represented the availability of landcover types in both the park and at absence sites for comparisons with landcover types at caribou nursery sites.

There was a not significant difference in the distributions of random points and nursery sites among landcover classes (Figure 3.3C; $\chi^2 = 1.087$, 2 d.f., $p = 0.581$) or nursery and absence sites (Figure 3.3D; $\chi^2 = 1.540$, 1 d.f., $p = 0.163$).

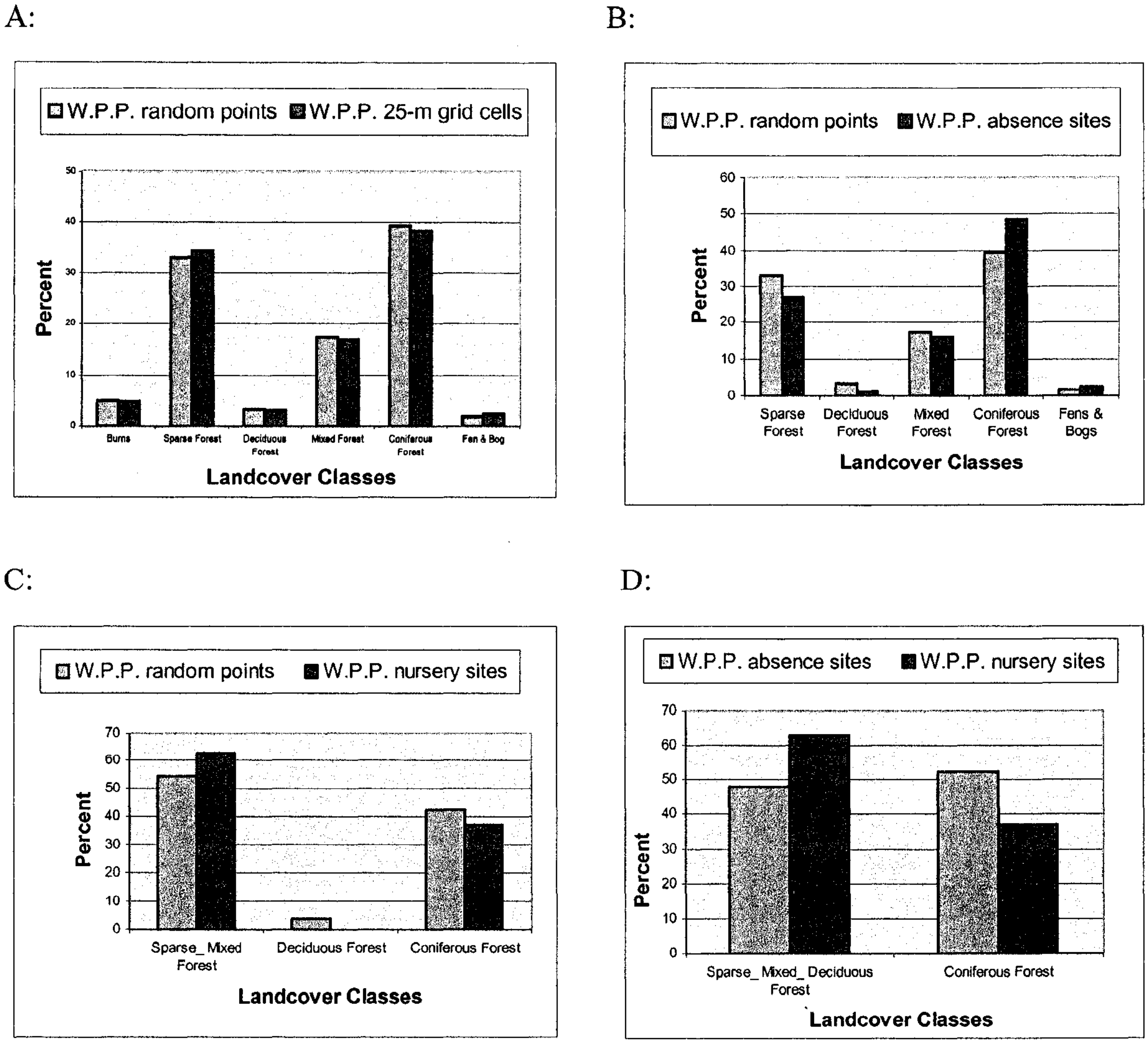

Figure 3.3. Proportions of 25-m grid cells, random points, absence sites, and nursery sites classified by landcover types in Wabakimi Provincial Park: (A) random points within buffered areas (*n*=2,650) vs. 25-m grid cells in buffered areas (*n* pixels =167,491); (B) random points (*n*=2,518) vs. absence sites (*n*=71); (C) random points (*n*=2,469) vs. nursery sites (*n*=19); and (D) absence sites (*n*=68) vs. nursery sites (*n*=19).

Feature Analysis

Initial Point (Random points, Nursery, and Absence sites) Feature Type Analysis

Woodland Caribou Provincial Park

The absence sites were not distributed among landscape feature types similarly to what was randomly found on the landscape (Figure 3.4A; $\chi^2 = 793.596$, 3 d.f., $p < 0.001$) in Woodland Caribou Provincial Park. There were more absence sites on islands and less on the mainland in comparison to the random points. Therefore, the absence sites did not represent the availability of landscape feature types at random for comparison to nursery sites, although there was a significant difference between landscape feature types at absence and nursery sites (Figure 3.4C; $\chi^2 = 22.420$, 3 d.f., $p < 0.001$).

In Woodland Caribou Provincial Park, nursery sites were found more often on islands (77%) than expected from the random availability of islands on the landscape (11%) (Figure 3.4B; $\chi^2 = 362.783$, 2 d.f., $p < 0.001$). Nursery sites were also found more often on small peninsulas on the mainland and islands (11%) relative to their availability on the landscape (3%). Nursery sites in this analysis occurred much less on the mainland (12%) than expected from the numbers of random points classified as mainland (86%).

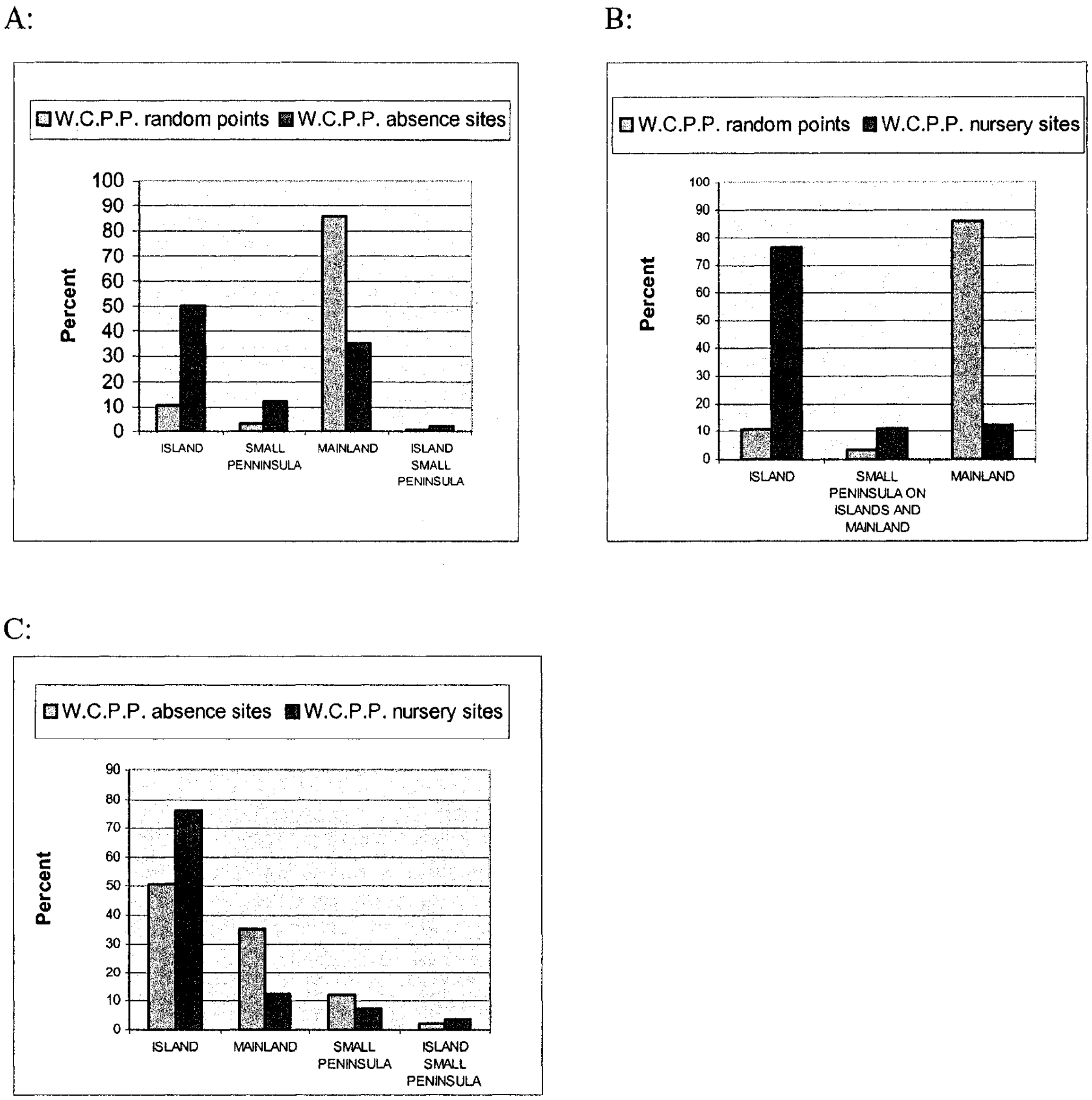

Figure 3.4. Proportions of random points, absence sites, and nursery sites classified by landscape feature types in Woodland Caribou Provincial Park: (A) random points (*n*=6,380) vs. absence sites (*n*=486); (B) random points (*n*=6,380) vs. nursery sites (*n*=81); and (C) absence sites (*n*=486) vs. nursery sites (*n*=81).

Wabakimi Provincial Park

The absence sites were not distributed among landscape feature types similarly to what was randomly found on the landscape (Figure 3.5A; $\chi^2 = 16.763$, 2 d.f., $p < 0.001$). Therefore, the absence sites did not represent the availability of landscape feature types at random for comparison to nursery sites, although there was a significant difference between landscape feature types at absence and nursery sites (Figure 3.5C; $\chi^2 = 57.573$, 2 d.f., $p < 0.001$).

In Wabakimi Provincial Park, nursery sites were also found more often on islands (59%) than expected from the random availability of islands on the landscape (23%) (Figure 3.5B; $\chi^2 = 57.573$, 2 d.f., $p < 0.001$). Nursery sites were again found more often on small peninsulas on islands and the mainland (19%) relative to their availability on the landscape (4%). Similar to Woodland Caribou Provincial Park, nursery sites in Wabakimi Provincial Park occurred much less on the mainland (22%) than expected from the numbers of random points classified as mainland (73%).

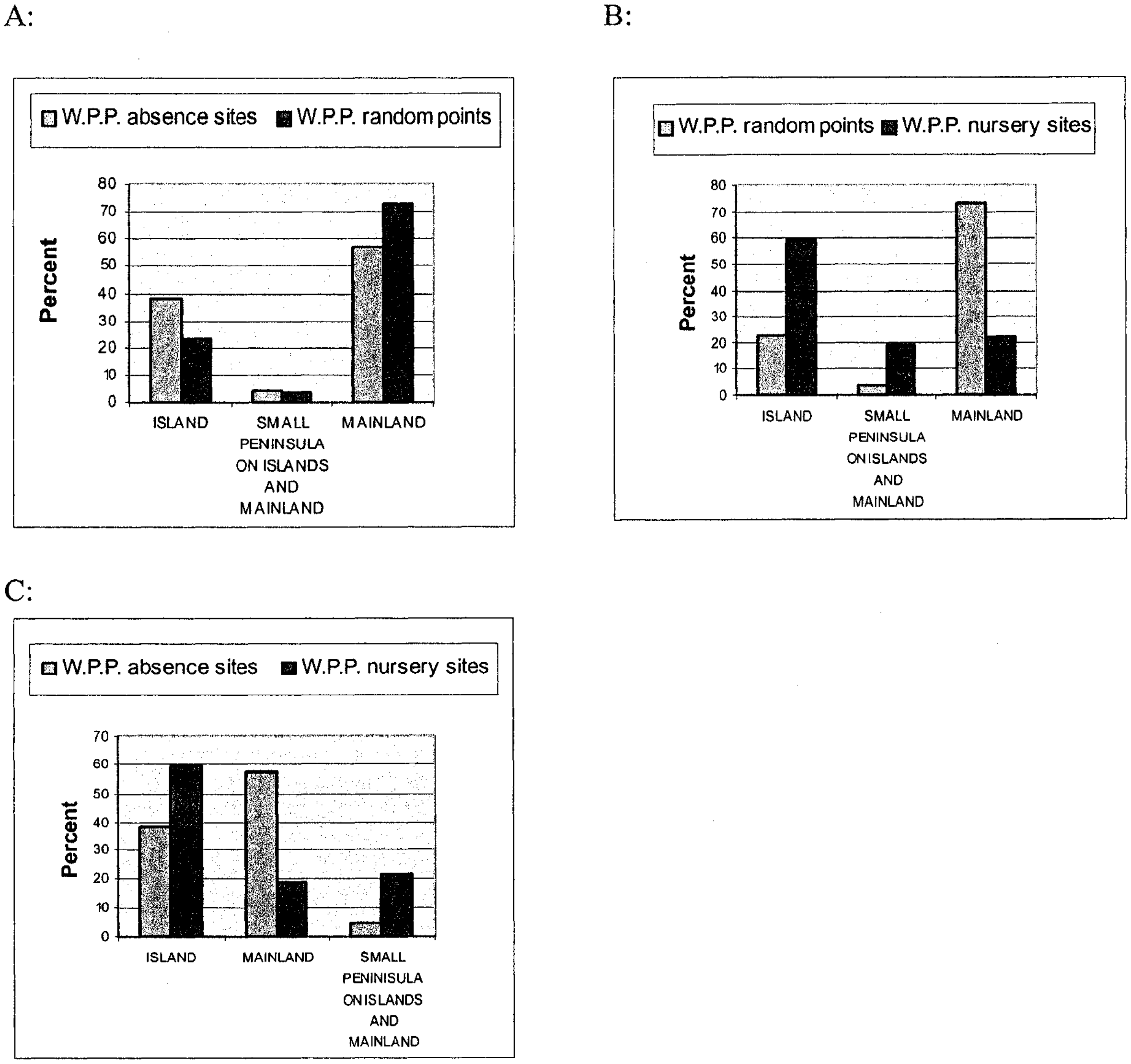

Figure 3.5. Proportions of random points, absence sites, and nursery sites classified by landscape feature types in Wabakimi Provincial Park: (A) random points (*n*=3,360) vs. absence sites (*n*=131); (B) random points (*n*=3,360) vs. nursery sites (*n*=32); and (C) absence sites (*n*=131) vs. nursery sites (*n*=32).

First Closest Feature from Initial Points (Random Points, Nursery, and Absence Sites) Analysis

Woodland Caribou Provincial Park

The first closest features to absence sites were not distributed among landscape feature types similarly to what was randomly found on the landscape (Figure 3.6A; $\chi^2 = 464.110$, 3 d.f., $p < 0.001$). Therefore, the first closest features to absence sites did not represent the availability of landscape feature types at random for comparison to first closest features to nursery sites, although there was a significant difference between the first closest features to absence and nursery sites (Figure 3.6C; ($\chi^2 = 16.074$, 3 d.f., $p < 0.001$).

In Woodland Caribou Provincial Park, nursery sites were often found near islands (48%) when examining the first feature from the initial nursery site as compared to the islands that were randomly available (37%) on the landscape (Figure 3.6B; $\chi^2 = 48.849$, 2 d.f., $p < 0.001$). Nursery sites in this analysis also showed a high proportion near the mainland (36%) as compared to 15% of random points near the mainland.

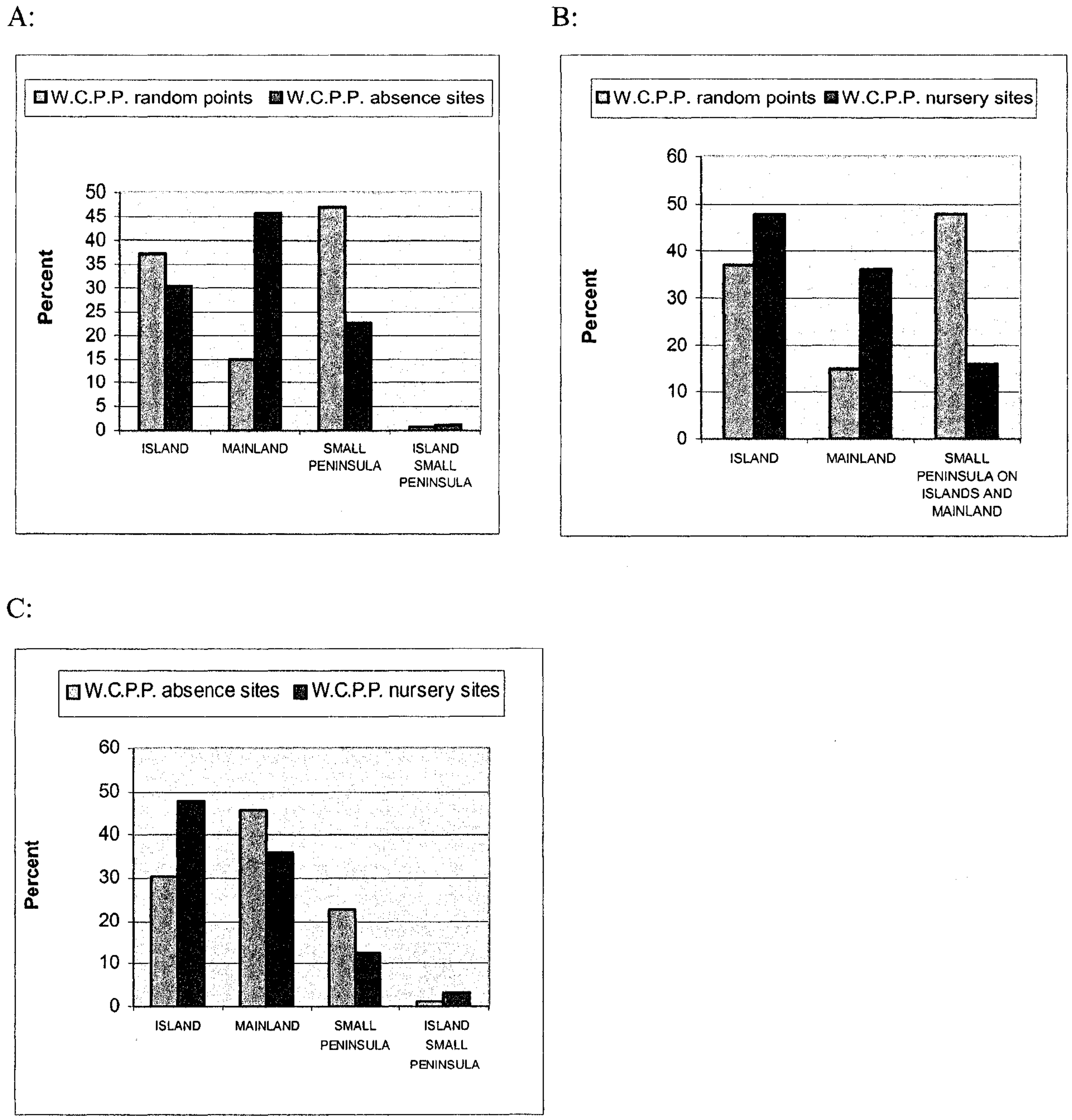

Figure 3.6. Proportions of random points, absence sites, and nursery sites classified by closest landscape feature types in Woodland Caribou Provincial Park: (A) random points (*n*=5,214) vs. absence sites (*n*=837); (B) random points (*n*=5,214) vs. nursery sites (*n*=94); and (C) absence sites (*n*=837) vs. nursery sites (*n*=94).

Wabakimi Provincial Park

The first closest features to absence sites were not distributed among landscape feature types similarly to what was randomly found on the landscape (Figure 3.7A; $\chi^2 = 96.912$, 3 d.f., $p < 0.001$). Therefore, the first closest features to absence sites did not represent the availability of landscape feature types at random for comparison to first closest features to nursery sites. There was no significant difference between the first closest features to absence and nursery sites (Figure 3.7C; $\chi^2 = 2.859$, 3 d.f., $p = 0.414$). Sites near peninsulas, as I have defined them, do not seem to be utilized in proportion to their availability in Wabakimi Provincial Park.

In Wabakimi Provincial Park, nursery sites were often found near islands (59%) when examining the first feature from the initial nursery site as compared to the islands that were randomly available (53%) on the landscape (Figure 3.7B; $\chi^2 = 28.412$, 2 d.f., $p < 0.001$). Nursery sites in this analysis also showed a high proportion near the mainland (21%) as compared to 4% of random points near the mainland.

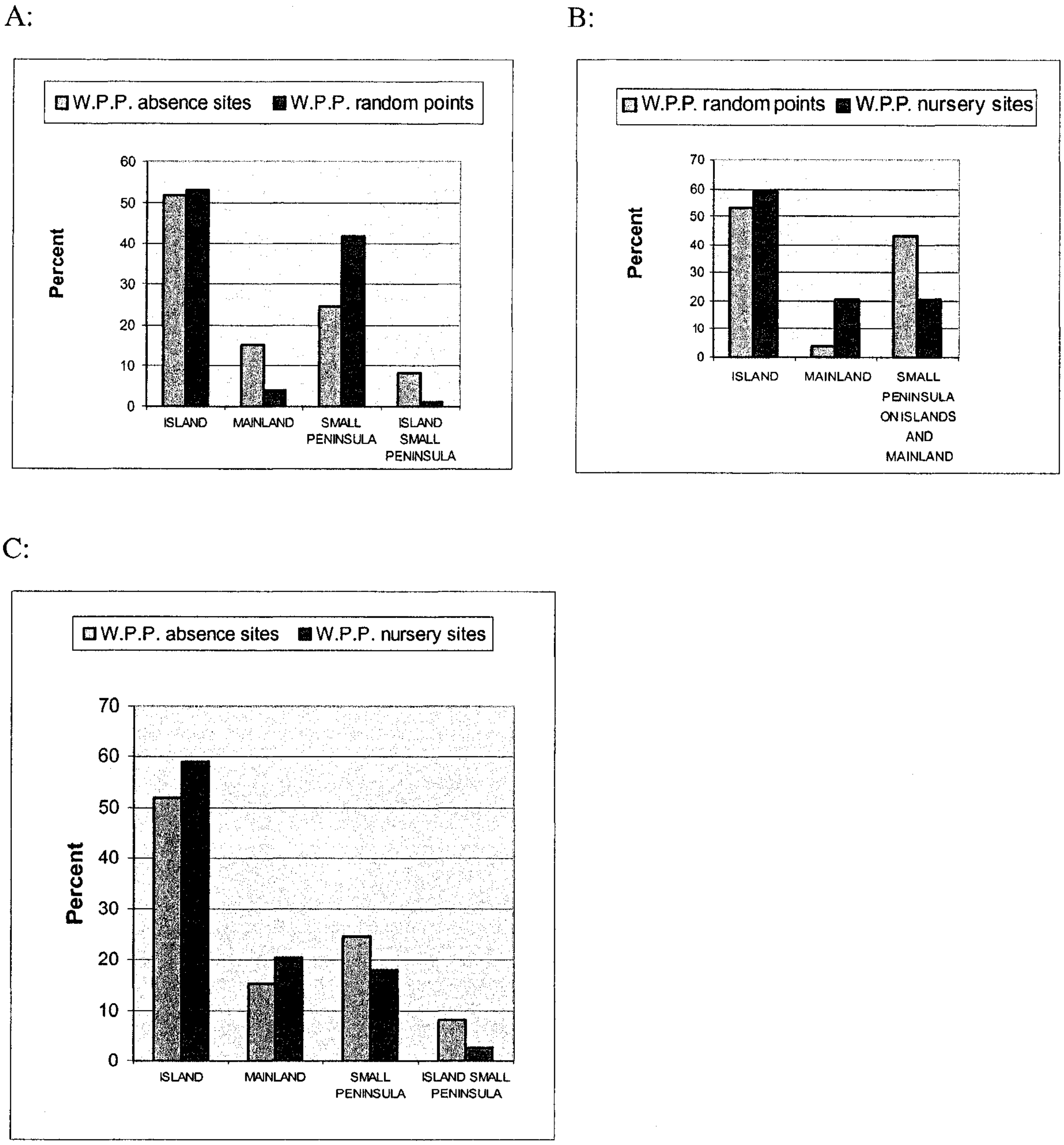

Figure 3.7. Proportions of random points, absence sites, and nursery sites classified by closest landscape feature types in Wabakimi Provincial Park: (A) random points (*n*=1,972) vs. absence sites (*n*=158); (B) random points (*n*=1,972) vs. nursery sites (*n*=39); and (C) absence sites (*n*=158) vs. nursery sites (*n*=39).

Minimum Escape Distances

Woodland Caribou Provincial Park

A 1-sample t-test showed there was a significantly smaller first minimum distance to a feature from absence sites in comparison to the mean distance from random points (t = -28.397, d.f. = 836, p < 0.001; Figure 3.8). A 1-sample t-test also showed a significantly smaller first minimum distance to a feature from nursery sites in comparison to the mean distance from random points (t = -10.120, d.f. = 93, p < 0.001). A 2-sample t-test showed there was no significant difference in the mean first minimum distances to a feature when comparing nursery and absence sites (t = - 1.0, d.f. = 929, p = 0.319).

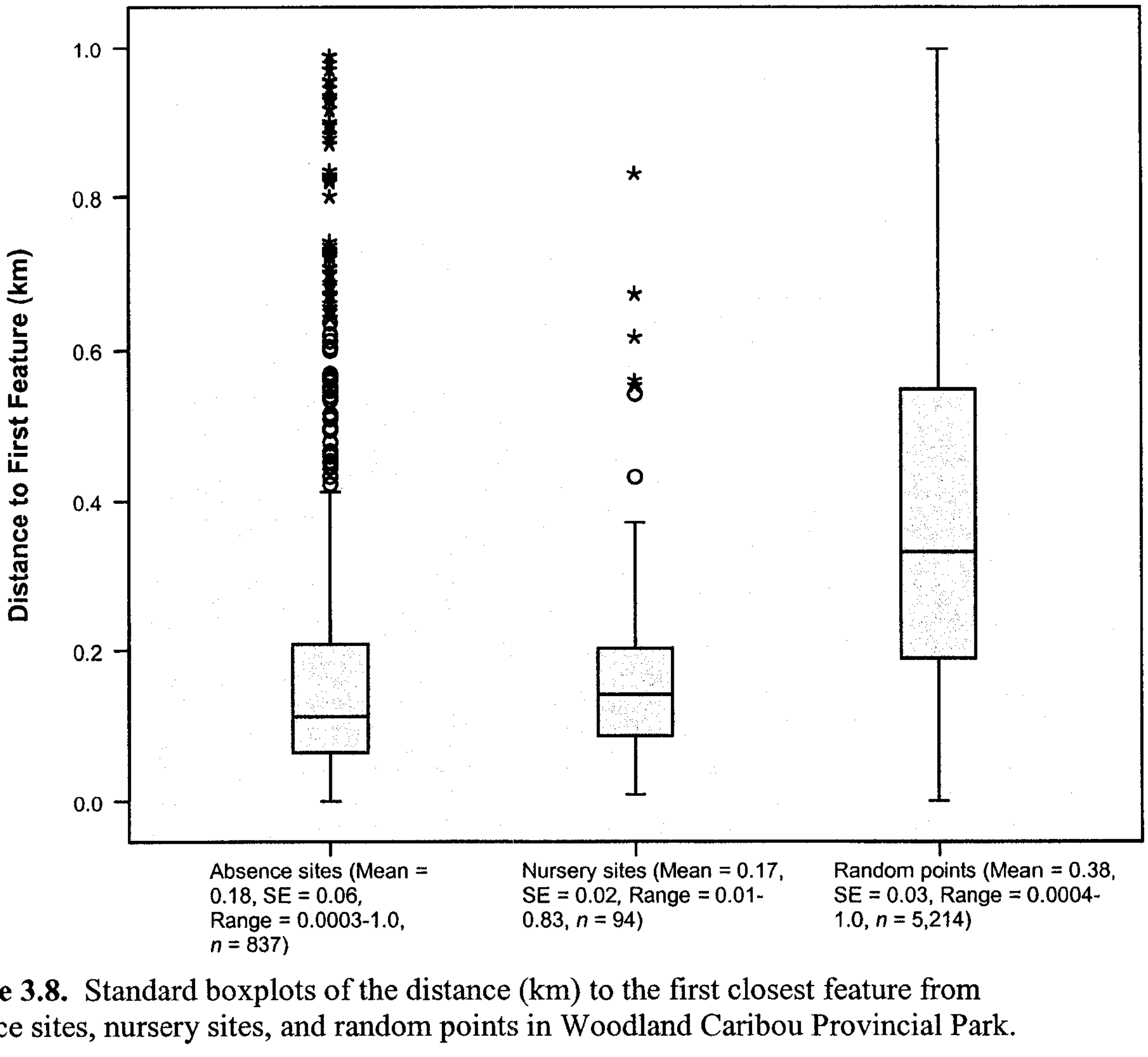

Figure 3.8. Standard boxplots of the distance (km) to the first closest feature from absence sites, nursery sites, and random points in Woodland Caribou Provincial Park.

A 1-sample t-test showed there was a significantly smaller average minimum distance to the first three nearest features from absence sites in comparison to the mean distance from random points (t = -9.018, d.f. =649, p < 0.001; Figure 3.9). A 1-sample t-test also showed a significantly smaller average minimum distance to the first 3 nearest features from nursery sites in comparison to the mean distance from random points (t = -4.867, d.f. =88, p < 0.001). A 2-sample t-test showed there was not a significantly smaller average minimum distance to the first 3 nearest features from nursery sites than absence sites (t = 1.82, d.f. = 737, p = 0.07).

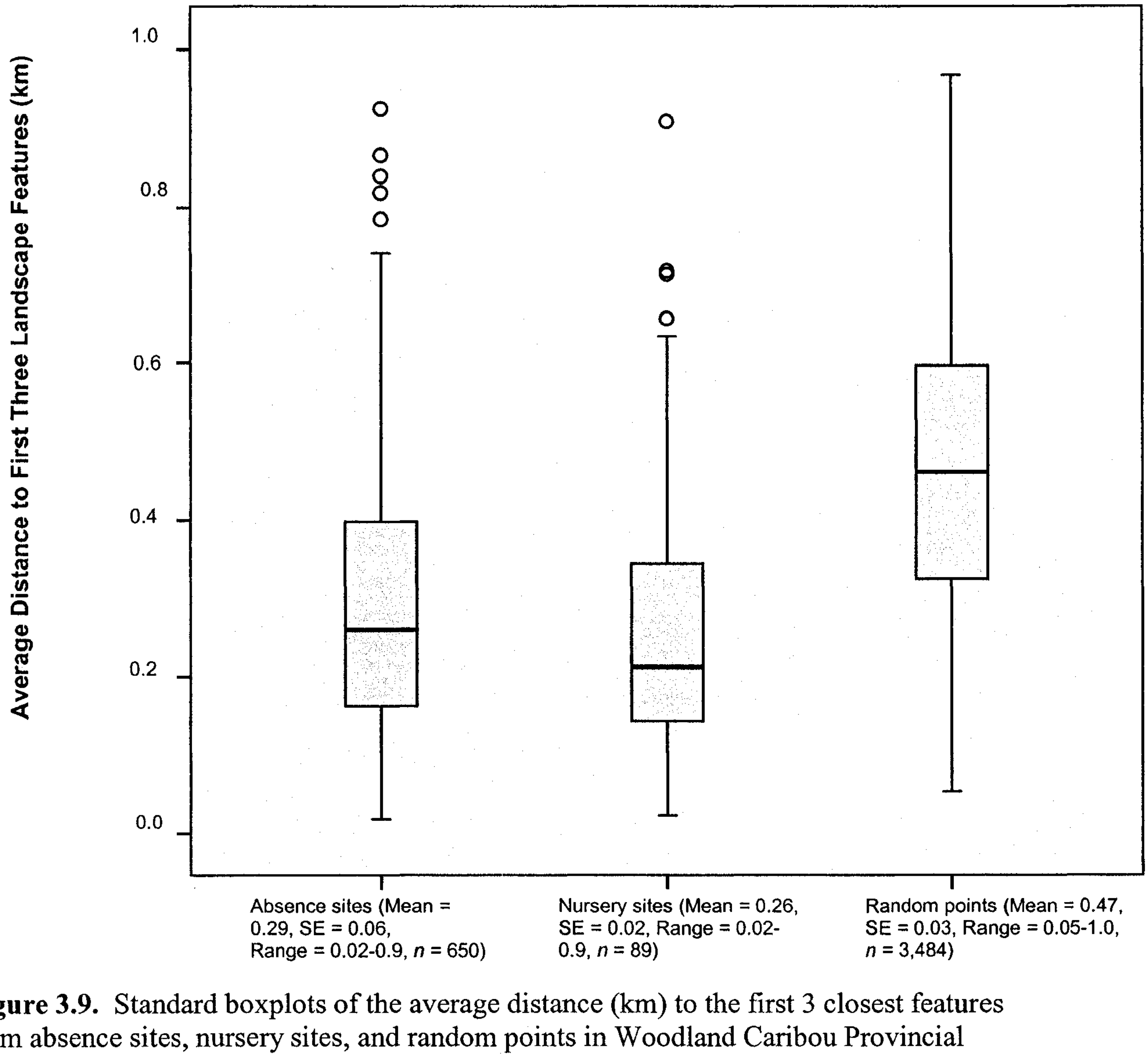

Figure 3.9. Standard boxplots of the average distance (km) to the first 3 closest features from absence sites, nursery sites, and random points in Woodland Caribou Provincial Park.

Wabakimi Provincial Park

A 1-sample t-test showed there was a significantly smaller first minimum distance to a feature from absence sites in comparison to the mean distance from random points (t = -4.386, d.f. = 157, p < 0.001; Figure 3.10). A 1-sample t-test also showed a significantly smaller first minimum distance to a feature from nursery sites in comparison to the mean distance from random points (t = -3.140, d.f. = 38, p = 0.003). A 2-sample t-test showed there was no significant difference in the mean first minimum distances to a feature when comparing nursery and absence sites (t = - 0.27, d.f. = 92, p = 0.79).

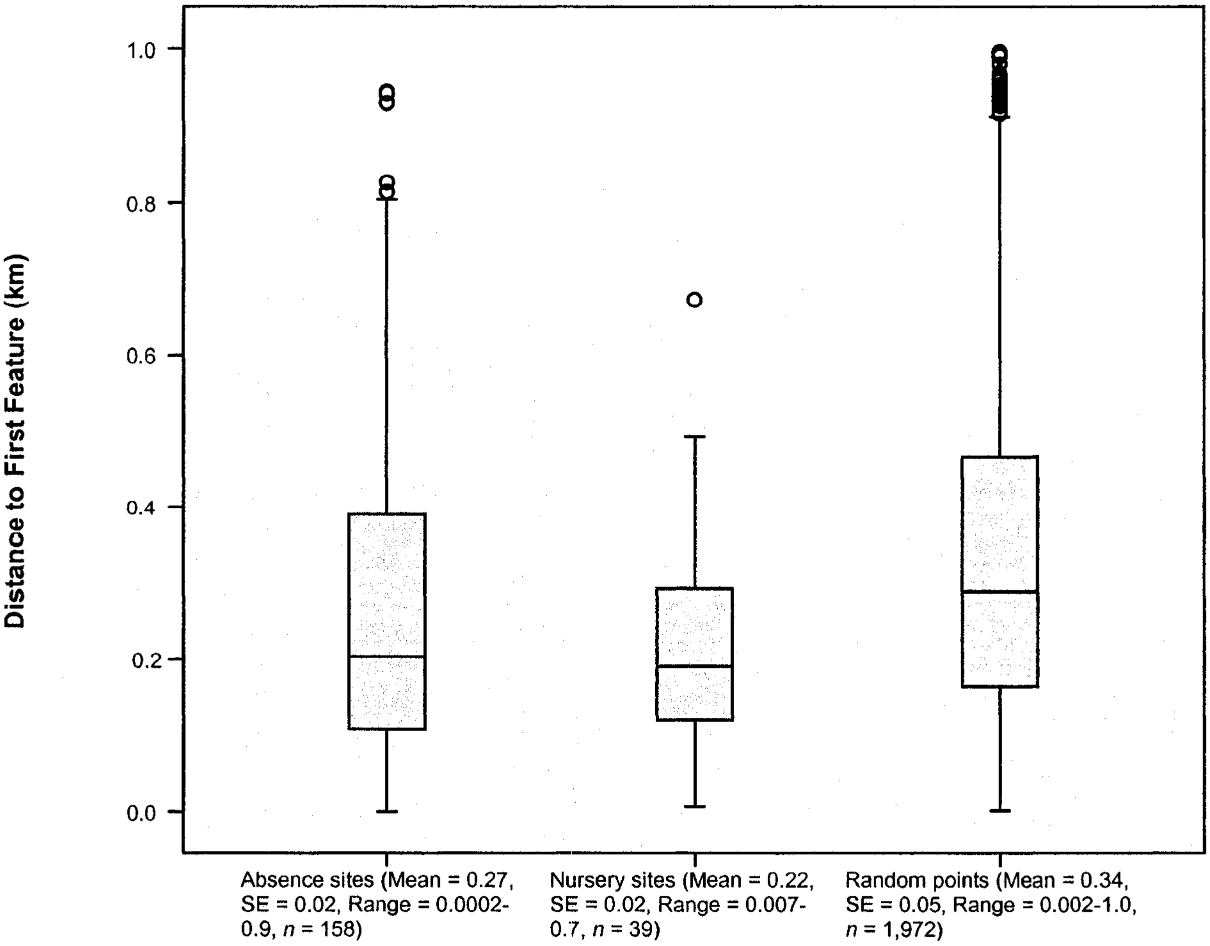

Figure 3.10. Standard boxplots of the distance (km) to the first closest feature from absence sites, nursery sites, and random points in Wabakimi Provincial Park.

A 1-sample t-test showed there was no significant average minimum distance to the first three nearest features from absence sites in comparison to the mean distance from random points (t = 0.905, d.f. = 126 , p = 0.367; Figure 3.11). Nor was there a significant average minimum distance to the first 3 nearest features from nursery sites in comparison to the mean distance from random points (t = -0.158, d.f. =38 , p = 0.875). A 2-sample t-test showed there was no significant difference in the average minimum distances to the first 3 nearest features when comparing nursery and absence sites (t = 0.57, d.f. = 164, p = 0.57).

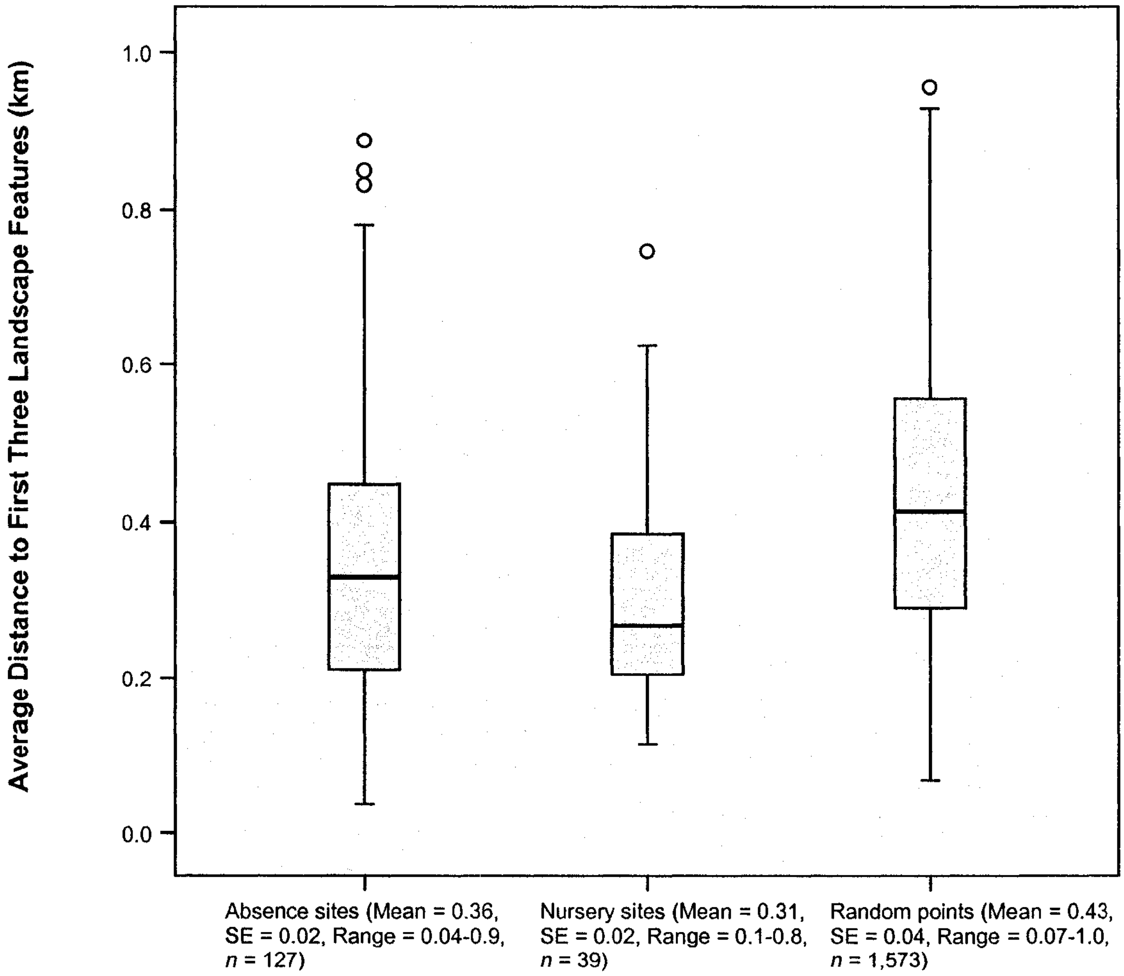

Figure 3.11. Standard boxplots of the average distance (km) to the first 3 closest features from absence sites, nursery sites, and random points in Wabakimi Provincial Park.

Fly-in outpost Analysis

In Woodland Caribou Provincial Park, the distance from random points, absence sites, and nursery sites to the closest fly-in outpost were not significantly different (H (2) = 4.38, p = 0.112) (Figure 3.12).

In Wabakimi Provincial Park, random points, absence sites, and nursery sites were significantly different distances from the closest fly-in outpost (Figure 3.13) (H (2) = 10.99, p = 0.004). Mann-Whitney tests were used to follow up this finding. To ensure that Type 1 errors did not occur in this test, Bonferroni correction was used and resulted in a 0.0167 level of significance (i.e., 0.05 divided into the 3 tests: random versus nursery, nursery versus absence, and absence versus random). It appeared that nursery sites and random points (U = 53541, p = 0.002, r = - 0.050) and nursery and absence sites (U = 2190, p = 0.002, r = - 0.215) were significantly different distances from the closest fly-in outpost. According to Field's (2005) definitions of effects in this test, the nursery and random site comparison represents a very small effect because r is close to 0. On the other hand, nursery and absence site comparisons represent a medium effect and a fairly substantive finding. The random and absence comparison did not show a significant difference in distance from the closest fly-in outpost (U = 303938, p = 0.332, r = -0. 0153). I concluded from these results that nursery sites ($\bar{x}$ = 9,059m) were further from the closest fly-in outpost than either random points ($\bar{x}$ = 5,715m) or absence sites ($\bar{x}$ = 6,315m).

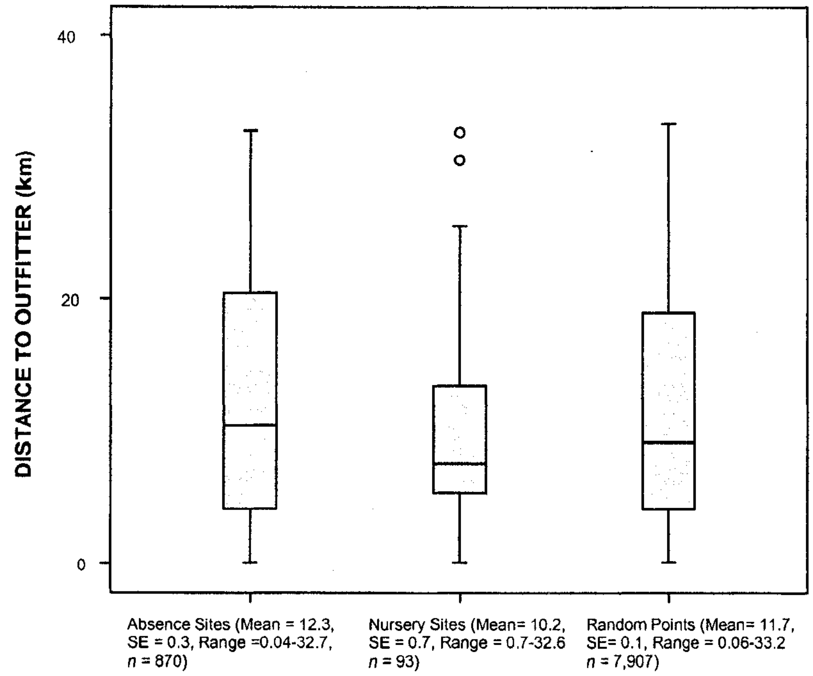

Figure 3.12. Standard boxplots of the distance (km) to the closest fly-in outpost from absence sites, nursery sites, and random points in Woodland Caribou Provincial Park.

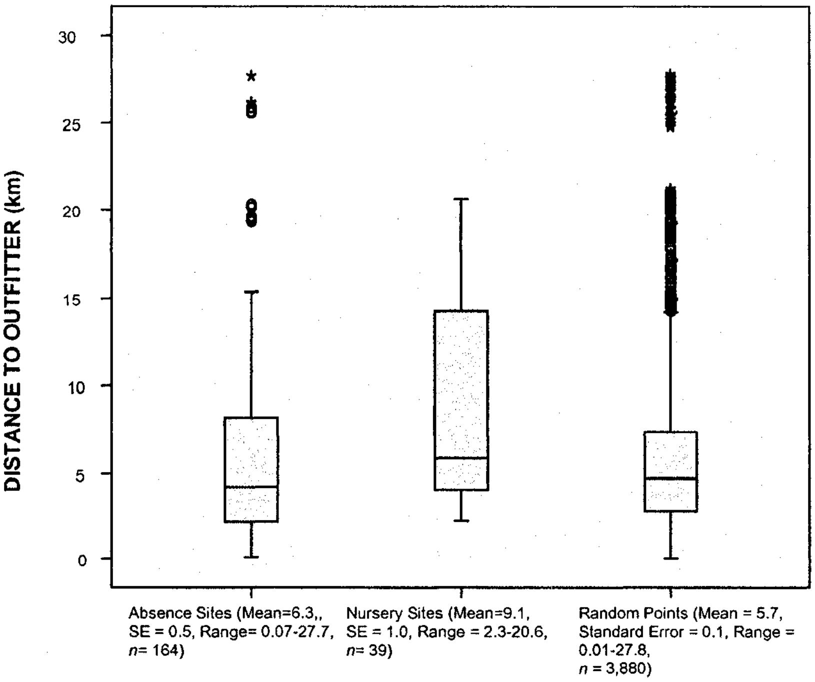

Figure 3.13. Standard boxplots of the distance (km) to the closest fly-in outpost from absence sites, nursery sites, and random points in Wabakimi Provincial Park.

Discussion

My study indicates that caribou in both Wabakimi and Woodland Caribou Provincial Parks use the larger of available islands for nursery activity (means of 8.2ha vs. 4.0ha and 4.6ha vs. 2.2ha, respectively). These results are within the range reported by Cumming and Beange (1987) who found female caribou used islands in the summer that were from 0.5 to 1,550ha in size on Lake Nipigon and on 1 lake in Wabakimi Provincial Park. However, their study found female caribou usually avoided islands less than 5ha in size whereas, in Woodland Caribou Provincial Park, I found that females used islands that had a mean of 4.6ha. My results are in better agreement with Ferguson and Elkie (2005) who found that females used medium-sized islands 10-100ha (mean of 30ha to 200ha available on the landscape) compared to male locations.

In Woodland Caribou Provincial Park, it appears that nursery sites were in the coniferous landcover type when compared to landcover classes at absence sites and random points on the landscape. In Wabakimi Provincial Park, it appears that nursery sites were used in proportion to landcover classes available on the landscape. Ferguson and Elkie (2004) also found that their sample of caribou (consisting mostly of females) did not use more coniferous forest than available from May to July. In both parks, caribou selected nursery sites that minimized escape distances with islands as both the first choice for the actual nursery activity and islands or the mainland as an escape feature from predators.

In this study, I found that nursery sites were all significantly closer to land features as compared to the random points in buffered areas on the landscape in both parks. Generally, the closest feature from the nursery sites on islands was not another island but usually the mainland. In Woodland Caribou Provincial Park, nursery sites were on average 208m closer to the mainland and 201m closer to all land features than the average of the first 3 closest feature distances to random points on the landscape. In Wabakimi Provincial Park, nursery sites were 117m closer to the mainland and 118m closer to the nearest land features than the average of the first 3 closest feature distances to random points on the landscape.

The fly-in outpost analysis had significant findings in Wabakimi Provincial Park, but not in Woodland Caribou Provincial Park. Wabakimi Provincial Park nursery sites (9,059m) were over 2,700m further from the closest fly-in outpost than the mean distance from the absence sites (6,315m) or random points (5,715m). The mean distance from the closest fly-in outpost to nursery sites in Woodland Caribou Provincial Park was about 10,000m. Although not statistically different from absence sites or random points, the mean distance from the closest fly-in outpost to nursery sites in Woodland Caribou Provincial Park is thus remarkably similar to that in Wabakimi Provincial Park, but slightly less than found in the resort disturbance study by Vistnes (1999) in Norway (15-25km). This may suggest a critical threshold, although more research needs to be done to look at the effects of intensity of activity at particular fly-in outposts on caribou nursery site selection. The next logical step for this work would be the development of a spatial model for land managers to assist with Parks and Forest Management Unit planning.

In summary, calving caribou did select areas that were primarily on smaller islands that consist of a cluster of land features within a short distance. These clusters may facilitate escape from predators by acting as retreats surrounded by water. Islands also allow the calving caribou to detect approaching predators more readily and escape more easily than mainland sites.

General Summary

Current laboratory methods were not successful in extracting DNA from summer-collected faecal samples to examine site fidelity of calving female caribou. The same procedures, however, have proven to be successful when used with winter-collected faeces (Morrill et al. 2005). Nonetheless, nursery sites were used repeatedly throughout the study years based on cow-calf sign such as pellets, beds, and tracks (Morrill et al. 2005).

Vegetation characteristics that were important in the selection of caribou nursery sites in Woodland Caribou Provincial Park were groundcover vegetation and shrub density. In Wabakimi Provincial Park understorey vegetation density and horizontal sightability were critical in distinguishing nursery from absence sites. Generally, female caribou in both parks selected nursery sites with greater slope, lower shrub density, but thicker groundcover vegetation, and higher overstorey cover than shoreline sites that were not used. Comparison of vegetation showed significant differences between nursery and absence sites for both parks in V-types, shrub and tree species, arboreal lichen classes, and herb/graminoid species. At the landscape scale, there were trends towards nursery sites with minimum escape distances of less than 220m occurring where landscape features were clustered and nursery sites were selected most often on islands and, secondarily, on both large and small peninsulas.

Further studies are required to examine the scale at which site fidelity is occurring in both parks. It is possible that caribou change calving sites each year to avoid predators that have become accustomed to their pattern of site selection (Welch et al. 2000). Mortality of moose offspring was found to influence the repeated use of moose calving sites (Testa et al. 2000, Welch 2000). Bowyer et al. (1999) hypothesized that unpredictable behaviour by maternal female moose in Alaska was a key anti-predator strategy. The use of coniferous classes for nursery sites in proportion to their availability in Wabakimi Provincial Park may indicate a trade-off between more suitable foraging and selection of a landscape with anti-predator features.

One innovative way to monitor the health of caribou populations is by monitoring pregnancy hormone rates (Vors 2006). Studies should continue to collect genetic samples along with hormone analysis of female samples to detect any possible effects of disturbance on caribou fecundity in both of these parks. These types of analysis could also lead to critical, ecological threshold studies.

Further studies should also focus on ecological thresholds for both recreational and forestry activities within and outside park boundaries. Huggett (2005) stated that it is extremely difficult to identify an abrupt ecological threshold break point even with good quality data. He stated that there needs to be the development of statistically rigorous methods to identify thresholds (Huggett 2005). Huggett (2005) also suggests that there are potentially a wide range of different threshold responses to the same disturbance or land use changes that ecological processes can exhibit. Bennett and Radford (2003) suggest that the confounding effect of multiple variables interacting to produce a complex threshold response makes it difficult to identify a single casual factor. Nonetheless, given the threatened status of woodland caribou, these studies need to be attempted.

To avoid assumptions related to suitability in site attribute studies, such as used sites being suitable and unused sites being unsuitable, North and Reynolds (1996) proposed that instead of comparing used with unused sites, the used sites should be categorized by their intensity of use and compared this way with unused sites. Thus, further studies in these parks should attempt to also quantify intensity of use of caribou nursery sites.

The selection of caribou calving sites is most likely related to many factors such as past experiences, individual behaviour patterns, age, and predator avoidance strategies. At both the site-specific and landscape scales, it is clearly shown that caribou are seeking nursery areas with predator-avoidance features, such as islands. These islands act as landforms of seclusion, increased visibility, and reduce the risk of encountering a predator. Seclusion is an important predator-avoidance tactic that allows control of social interactions and the forming of strong bonds between cow and calf (Lent 1974).

Seclusion provided by these islands is important in both parks during caribou calving and nursery periods and should be protected.

Female caribou behaved differently in each park, which is not surprising since the 2 landscapes differ. As discussed earlier, these differences between parks are likely the result of large-scale geographic variation in weather, topography, soil productivity, and dominant vegetation across the 2 different ecoregions in which they are situated (Crins 2000). Caribou movements and habitat selection must be well understood in each area and across the broader landscape with the appreciation that their behaviours and patterns will change or shift over time, and management must factor these differences appropriately.

Management Implications

In Ontario, forest management guidelines for the conservation of woodland caribou give special consideration to calving areas by providing a 1,000m buffer around calving sites (Racey et al. 1999), when they can be identified. Given the potential for disturbance from attempting to directly observe parturition in calving caribou and the difficulties in distinguishing calving sites from postpartum nursery areas, protection should also be extended to nursery sites in general. Moreover, as industrial (i.e., forestry, mining, etc.) activities generally increase the number of roads around parks and protected areas, allowing easy access for predators, roads need to be limited in number and use. A comprehensive road development strategy adjacent to parks and protected areas would also mitigate further impacts of habitat fragmentation on woodland caribou. The impact of recreational use on calving caribou within parks and protected areas also needs to be minimized. Travel and recreational use of lakes or portions of lakes, particularly near nursery sites that are reused by female caribou, should be restricted at least during the calving period. Site fidelity is an important feature for gauging the effects of human activity on animal movement (White and Garrott 1990). If animals do retreat from safer island habitat to mainland habitat that lacks predator avoidance features, this could be problematic, especially if female calves return there to calve when they reach adulthood (Webster 1997).

Calving and nursery sites in previously unstudied areas should be identified using some of the techniques discussed here, such as the habitat characteristics on the ground in Chapter 2 and GIS-based approaches in Chapter 3, as indicators of calving or nursery use. This research should be ongoing and use an adaptive management approach (Holling 1978, Nyberg 1998). First generation spatial models should be developed from the predictor variables established in this study. This would enable the broad identification of areas that are likely to provide forest-dwelling woodland caribou calving and nursery areas north of the southern limit of contiguous range occupancy for woodland caribou in Ontario (Figure 1). These first generation spatial models should be further tested and validated. Following testing, second generation models should be developed and applied to Parks and Forest Management Units and the implications to tourism and the forestry industry should be discussed as new policies are advanced.

Habitat shifts do occur with regard to caribou and continued monitoring will ensure that management can adapt to these changes. Large nature reserve zones should be considered in areas with high use by female caribou for calving and nursery activity and have sufficient buffers to protect these areas from recreational use and industrial activity. In areas with higher recreational use there should be a mandatory user number reporting system for all fly-in outposts and lodges. Motorboats should be limited and, if allowed, limited in noise and speed. Assigned shore-lunch areas should be given to each fly-in outpost. Assigned camping areas should also be considered, especially during the critical calving and nursery period from May to August. Travel on selected lakes or areas of lakes should be prohibited during this sensitive period. To minimize stress by human disturbance, users, while in the backcountry, should stay a distance from caribou that does not disturb or alarm them. Further facility development on or near caribou habitats designated as calving and/or nursery areas should be prevented. More studies should inventory and monitor fen habitat as well; Ontario Parks' research has found high use in remote fens in Wabakimi Provincial Park (Morrill et al. 2005). Most importantly, education of park users must be enhanced with regard to caribou and their lifecycle.

Canada has only recently acquired (2002) national endangered species legislation (i.e., Species at Risk Legislation). Soon after, Ontario proposed a new provincial Species at Risk Legislative Review in 2006, which included recommendations for a new Endangered Species Act for Ontario. The new Endangered Species Act (Bill 184) was passed in Ontario on May 16, 2007. In Ontario, this act includes threatened species such as woodland caribou. It is yet to be seen whether such legislation can be used to actively recover species in parks. Within national and provincial parks, a new emphasis on "ecological integrity" strives to put protection of flora and fauna ahead of human uses (Canada National Parks Act 2000, Provincial Parks and Conservation Reserves Act 2006). Possible caribou calving and nursery sites should be identified and adequate protection must be provided to ensure the persistence of the species.

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Appendix 1

Laboratory Methods for DNA extraction

(Ball and Wilson 2004)

The pellets were received and stored on ice for genetic analysis.

DNA extraction from faecal pellets was preformed utilizing a pellet wash modified from Flagstad et al. (1999). This procedure isolates epithelial cells from the mucosal outer layer of the pellet, increasing the amount of DNA to be extracted while at the same time reducing the amount of inhibitor, which is released from digested plant material. All faecal samples were removed from the storage vials and washed in order to isolate mucosal cells, which cover the outside of the faecal pellet through intestinal sloughing. Pellets were washed in 1ml of 0.1 M Phosphate Buffered Solution (PBS) contained in a 50ml falcon tube. No less than 4 pellets were washed at any given time, which was dependent on the pellet size. Pellets were gently swirled in the PBS for 5 minutes, with care taken not to break the pellet. After washing, the PBS buffer was removed and placed into a 1.5 ml eppendorf tube. An equal volume of 1x lysis buffer was added to the wash solution, which did not exceed 250 µl. 125 units of proteinase K was added to each sample and then all were incubated at 70 C for 2 hours. All samples were extracted using the DNeasy tissue extraction kit and protocol issued by Qiagen. However, in order to concentrate the DNA from each of the samples, elutions were formed using a volume of 30 µl. All eluted samples were stored frozen.

MtDNA Control Region Amplification

To determine successful extraction of caribou DNA, the control region of the mitochondrial DNA (mtDNA) was amplified (460 bp). To assess the effect of inhibitors that may be present in the eluted samples, mtDNA amplification was also performed using a 1/10 dilution to reduce any inhibitory effect. PCR amplification of the mtDNA control region was done in a 25 µl volume containing the following components: 1x PCR buffer; 2.0mM MgCl; 0.4µg/ml of bovine serum albumen; 0.2µM of each mtDNA control region primer H00068 and L15693 (Hundertmark et al. 2002); 0.2µM of each dinucleotide triphosphate (A, T, C, G); 1 unit of Taq polymerase (Invitrogen) and 2 µl of DNA template. The thermocycling protocol consisted of 95°C for 10 min, then 35 cycles of 94°C for 30 sec, 50°C for 30 sec and 72°C for 30 sec, then a final extension time of 65°C for 15 minutes.

MtDNA Product Screening

MtDNA control region amplified product for each sample was loaded onto a 1.5% agarose gel stained with ethidium bromide (EtBr). EtBr is a fluorescent stain that attaches to double stranded DNA, enabling a researcher to view amplification product under UV illumination. The amplified product was electrophoresed through the agarose gel at 150 volts for 1 hour. Samples showing positive amplification were chosen for nuclear microsatellite amplification.

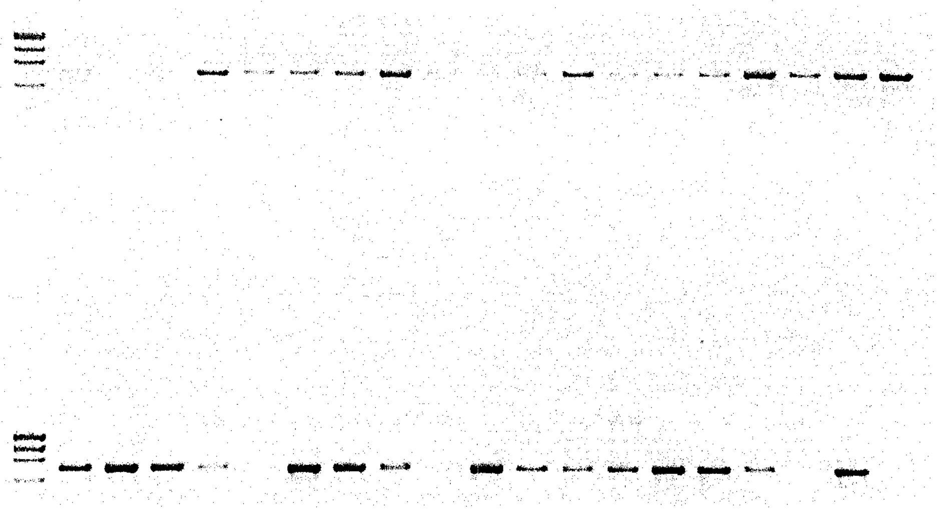

Figure 1.1. Amplification of mtDNA control region using agarose gel stained with ethidium bromide for a subset of caribou faecal samples collected in the summer of 2004.

Microsatellite Amplification

All samples having positive mtDNA amplification were tested to determine if there was enough genomic DNA available to be amplified using nuclear microsatellite markers. In faecal samples, DNA degradation is a common occurrence, thus the microsatellite loci chosen for amplification were of small, less than 200 base pairs (bp) in length. By doing so, the effects of degradation may not be so apparent, as smaller fragments of DNA may still be intact for amplification (Taberlet et al. 1999).

Currently, 5 microsatellite markers have been optimized to amplify caribou DNA (RT9, RT6, BM4513, Map 2C, and RT30). To test successful amplification of nuclear DNA each of the samples collected was amplified separately in a 20 µl volume containing the following components: 1x PCR buffer; 2.0mM MgCl; 0.4µg/ml of bovine serum albumin; 0.3µM of each of both the forward and reverse primers (Wilson et al. 1997); 0.2µM of each dinucleotide triphosphate; 1 unit of Taq polymerase (Invitrogen) and 2 µl of DNA template. The thermocycling protocol for this PCR reaction consisted of 94°C for 5 min, then 49 cycles of 94°C for 30 sec, 56°C for 30 sec and 72°C for 30 sec, then a final extension time of 60°C for 45 minutes.

Microsatellite Genotyping Using the AB1377

All samples exhibiting successful microsatellite amplification through agarose electrophoresis were submitted for genotyping using an automated fluorescent unit, ABI 377. Spectropherograms were produced for each of the samples showing the allelic pattern for each of the amplified loci. From these spectropherograms, alleles were defined based upon size (base pairs). These were recorded for each individual sample and from this information sample individuality could be determined through differences in the allele assignments among individuals.

Mitochondrial DNA Control Region Sequencing and Analysis

Once the individuality of each sample was confirmed through genotyping, those samples were selected for sequencing of the mtDNA control region. All samples were cleaned using QiaQuick PCR cleanup kit (Qiagen) to remove bi-products from PCR, which may inhibit the sequencing reaction. All samples were sequenced and those having an overall score of at least 92 were then imported into sequence analyzing software (BIOedit) for alignments and comparison. Sequence haplotypes were derived for each sample using a neighbour joining analysis, which grouped samples according to sequence differences. Each sample was then given a numerical haplotype designation according to the results and the frequencies of the different haplotypes were then derived within each region and compared.

Appendix 2

Glossary of vegetation species measures in sample plots.

Dominant Mosses and Lichens

Common Name	**Scientific Name**
Big Red Stem	*Pleurozium schreberi*
Electric Eels	*Dicranum polysetum*
Girgensohn's Peat Moss	*Sphagnum girgensohnii*
Green Reindeer Lichen	*Cladina mitis*
Grey Reindeer Lichen	*Cladina rangiferina*
Juniper Hair-cap	*Polytrichum juniperinum*
Knight's Plume	*Ptilium crista-castrensis*
Northern Reindeer Lichen	*Cladina stellaris*
Stair-step Moss	*Hylocomium splendens*
Woolly Coral	*Stereocaulon tomentosum*

Dominant Herbaceous Vegetation

Common Name	**Scientific Name**
Baneberry	*Actaea rubra*
Bunchberry	*Cornus canadensis*
Canada Mayflower	*Maianthemum canadense*
Cottongrass*	*Eriophorum* spp.
Fireweed	*Epilobium angustofolium*
Fringed Black Bindweed	*Polygonum cilinode*
Goldthread	*Coptis trifolia*
Ground-Pine	*Lycopodium obscurum*
Indian Pipe	*Monotropa uniflora*
Blueflag	*Iris Versicolour*
Northern Starflower	*Trientalis borealis*
Pale Corydalis	*Corydalis sempervirens*
Pink Lady's Slipper	*Cypripedium acaule*
Pink Pyrola	*Pyrola asarifolia*
Prince's Pine	*Chimaphila umbellata*
Large Round-leaved Orchid	*Platanthera orbiculata*
Sarsaparilla	*Aralia nudicaulis*
Sedge*	*Carex* spp.
Spreading Dogbane	*Apocynum androsaemifolium*
Stiff Clubmoss	*Lycopodium annotinum*
Swamp Horsetail	*Equisetum fluviatile*
Twinflower	*Linnaea borealis*
Woodland Horsetail	*Equisetum sylvaticum*

Woody Vegetation from Shrub Transects and Dominant Species chi-square tests

Common Name	**Scientific Name**
Alder-leaved Buckthorn	*Rhamnus alnifolia*
Ash*	*Fraxinus* spp.
Balsam Fir	*Abies balsamea*
Beaked Hazel	*Corylus cornuta*
Bearberry	*Arctostaphylos uva-ursi*
Black Spruce	*Picea mariana*
Bog Bilberry	*Vaccinium uliginosum*
Bush Honeysuckle	*Diervilla lonicera*
Common Juniper	*Juniperus communis*
Dwarf Birch	*Betula pumila*
Dwarf Raspberry	*Rubus pubescens*
Green Alder	*Alnus viridis (crispa)*
Jack Pine	*Pinus banksiana*
Labrador Tea	*Ledum groenlandicum*
Low Sweet Blueberry	*Vaccinium angustifolium*
Narrow-leafed Meadow Sweet	*Spiraea alba*
Pin Cherry	*Prunus pensylvanica*
Prickly Wild Rose	*Rosa acicularis*
Red-oiser Dogwood	*Cornus stolonifera*
Saskatoon	*Amelanchier alnifolia*
Snowberry	*Gaultheria hispidula*
Speckled Alder	*Alnus rugosa*
Sweet Gale	*Myrica gale*
Tamarack	*Larix laricina*
Trembling Aspen	*Populus tremuloides*
Velvet-Leaved Blueberry	*Vaccinium myrtilloides*
White Birch	*Betula papyrifera*
White Cedar	*Thuja occidentalis*
White Spruce	*Picea glauca*
Wild Red Raspberry	*Rubus idaeus*
Willow*	*Salix* spp

*Not identified to species

Appendix 3

Tabular data of all frequency distributions of nominal data recorded in sample plots (Chapter 2).

3.1: Frequency Table of V-types (Sims et al. 1989; Appendix 5)

V-Type	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
4	0	0.0	0	0.0	1	2.4	1	2.3
5	0	0.0	0	0.0	2	4.8	0	0.0
11	0	0.0	0	0.0	1	2.4	0	0.0
16	0	0.0	1	2.3	0	0.0	0	0.0
17	3	6.8	0	0.0	0	0.0	0	0.0
18	3	6.8	0	0.0	1	2.4	0	0.0
19	3	6.8	0	0.0	1	2.4	0	0.0
20	0	0.0	3	6.8	9	21.4	7	15.9
22	0	0.0	0	0.0	2	4.8	0	0.0
23	0	0.0	0	0.0	1	2.4	1	2.3
25	0	0.0	0	0.0	9	21.4	4	9.1
28	0	0.0	1	2.3	0	0.0	0	0.0
29	0	0.0	1	2.3	0	0.0	0	0.0
30	26	59.1	18	40.9	5	11.9	8	18.2
31	0	0.0	0	0.0	2	4.8	0	0.0
32	6	13.7	20	45.4	2	4.8	3	6.8
33	3	6.8	0	0.0	4	9.5	4	9.1
34	0	0.0	0	0.0	0	0.0	12	27.3
35	0	0.0	0	0.0	1	2.4	3	6.8
36	0	0.0	0	0.0	0	0.0	1	2.3
37	0	0.0	0	0.0	1	2.4	0	0.0

3.2: Frequency Table of Ecosite Types (Racey et al. 1996; Appendix 7)

ES-Type	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
12	42	95.5	43	97.7	34	81.0	38	86.4
13	0	0.0	1	2.3	1	2.3	2	4.8
14	0	0.0	0	0.0	2	4.8	0	0.0
16	2	4.5	0	0.0	0	0.0	0	0.0
22	0	0.0	0	0.0	1	2.4	0	0.0
26	0	0.0	0	0.0	0	0.0	2	4.5
27	0	0.0	0	0.0	0	0.0	1	2.3
31	0	0.0	0	0.0	3	7.1	1	2.3
36	0	0.0	0	0.0	1	2.4	0	0.0

3.3: Frequency Table for Soil Types (Sims et al. 1989; Appendix 6)

S-Type	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
S1	0	0.0	0	0.0	4	9.5	1	2.3
S4	0	0.0	0	0.0	0	0.0	1	2.3
S6	0	0.0	0	0.0	0	0.0	3	7.0
S10	0	0.0	0	0.0	1	2.4	1	2.3
SS1	19	43.2	9	20.5	2	4.8	0	0.0
SS2	15	34.1	27	61.4	6	14.3	8	18.2
SS3	8	18.2	5	11.4	24	57.1	28	65.1
SS5	2	4.5	1	2.3	3	7.1	2	4.6
SS7	0	0.0	2	4.5	0	0.0	0	0.0
SS8	0	0.0	0	0.0	1	2.4	0	0.0
S12S	0	0.0	0	0.0	1	2.4	0	0.0

3.4: Frequency Table of Aspect

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Aspect	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
None	4	9.1	10	22.7	19	45.1	17	38.6
N	5	11.3	2	4.6	6	14.3	4	9.1
E	7	15.9	3	6.8	2	4.8	0	0.0
S	3	6.8	0	0.0	1	2.4	5	11.4
W	2	4.6	6	13.6	2	4.8	0	0.0
NW	7	15.9	9	20.5	1	2.4	4	9.1
SE	9	20.5	4	9.1	0	0.0	1	2.3
SW	3	6.8	5	11.4	6	14.3	6	13.6
NE	4	9.1	5	11.4	5	11.9	7	15.9

3.5: Frequency Table of overstorey species (from nearest neighbour measurements)

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
balsam fir	1	0.3	9	2.6	1	0.3	20	5.7
black spruce	99	28.1	180	51.1	208	61.9	277	78.7
jack pine	160	45.5	135	38.4	15	4.5	17	4.8
none	70	9.9	18	5.1	75	22.3	6	1.7
tamarack	0	0.0	0	0.0	3	0.9	2	0.6
trembling aspen	14	4.0	5	1.4	3	0.9	0	0.0
white birch	8	2.3	5	1.4	17	5.1	18	5.1
white cedar	0	0.0	0	0.0	12	3.6	3	0.9
white spruce	0	0.0	0	0.0	1	0.3	9	2.6
willow spp.	0	0.0	0	0.0	1	0.3	0	0.0

3.6: Frequency Table of understorey species (from nearest neighbour)

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
balsam fir	11	3.1	13	3.7	4	1.2	16	4.6
black spruce	132	37.5	242	68.8	118	35.1	196	55.7
green alder	6	1.7	0	0.0	9	2.7	22	6.3
jack pine	62	17.6	5	1.4	1	0.3	13	3.7
none	84	23.9	68	19.3	110	32.7	79	22.4
pin cherry	2	0.6	0	0.0	0	0.0	0	0.0
saskatoon berry	0	0.0	0	0.0	1	0.3	0	0.0
speckled alder	0	0.0	0	0.0	37	11.0	0	0.0
tamarack	0	0.0	0	0.0	3	0.9	0	0.0
trembling aspen	7	2.0	1	0.3	16	4.8	0	0.0
white birch	34	9.7	17	4.8	21	6.3	6	1.7
white cedar	0	0.0	0	0.0	10	3.0	4	1.1
white spruce	4	1.1	0	0.0	0	0.0	10	2.8
willow spp.	10	2.8	6	1.7	6	1.8	6	1.7

3.7: Frequency Table of Shrub Species (from shrub transect)

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
alder-leaved buckthorn	0	0.0	0	0.0	1	0.4	1	0.5
ash spp.	4	0.8	0	0.0	0	0.0	0	0.0
balsam fir	4	0.8	3	1.4	2	0.9	17	8.3
beaked hazel	103	20.8	0	0.0	0	0.0	0	0.0
bearberry	0	0.0	0	0.0	8	3.2	0	0.0
black spruce	103	20.8	147	66.8	51	20.6	98	47.8
bog bilberry	0	0.0	0	0.0	3	1.3	0	0.0
common juniper	73	14.8	15	6.8	0	0.0	0	0.0
dwarf birch	10	2.0	0	0.0	15	6.0	7	3.4
green alder	22	4.4	0	0.0	32	12.9	9	4.4
jack pine	5	1.0	10	4.6	6	2.4	0	0.0
labrador tea	0	0.0	2	0.9	0	0.0	0	0.0
low sweet blueberry	1	0.2	2	0.9	0	0.0	0	0.0
narrow-leaved meadowsweet	0	0.0	0	0.0	1	0.4	0	0.0
pin cherry	39	7.9	6	2.7	0	0.0	0	0.0
prickly wild rose	11	2.2	0	0.0	0	0.0	0	0.0
red-osier dogwood	10	2.0	0	0.0	0	0.0	0	0.0
saskatoon berry	20	4.0	9	4.1	4	1.6	1	0.5
speckled alder	0	0.0	0	0.0	36	14.5	35	17.7
spreading dogbane	1	0.2	0	0.0	0	0.0	0	0.0
sweet gale	0	0.0	0	0.0	31	12.5	12	6.1
trembling aspen	12	2.4	6	2.7	37	14.9	0	0.0
white birch	41	8.3	5	2.3	15	6.0	7	3.5
white cedar	0	0.0	0	0.0	1	0.4	8	4.0
white spruce	0	0.0	0	0.0	0	0.0	2	1.0
wild red raspberry	2	0.4	5	2.3	0	0.0	0	0.0
willow spp.	34	6.9	10	4.6	5	2.0	5	2.4
velvet-leaf blueberry	0	0.0	0	0.0	0	0.0	3	1.5

3.8: Frequency Table of Dominant Moss or Lichen Cover

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Groundcover	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
moss	34	77.2	37	84.1	38	90.5	39	88.6
lichen	10	22.8	7	15.9	4	9.5	5	11.4

3.9: Frequency Table of Dominant Herbs and Graminoid Species

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
balsam fir	0	0.0	0	0.0	1	2.4	2	4.5
baneberry	0	0.0	1	2.3	0	0.0	0	0.0
bindweed	0	0.0	2	4.5	0	0.0	0	0.0
bunchberry	2	4.5	1	2.3	7	16.6	0	0.0
clubmoss	4	9.1	1	2.3	5	11.8	3	6.8
cordydalis	1	2.3	1	2.3	0	0.0	0	0.0
cottongrass	0	0.0	0	0.0	1	2.4	0	0.0
cottontail	0	0.0	0	0.0	0	0.0	1	2.3
fireweed	4	9.1	5	11.4	4	9.5	0	0.0
goldthread	5	11.4	0	0.0	0	0.0	0	0.0
horsetail	0	0.0	0	0.0	1	2.4	0	0.0
indian pipe	0	0.0	0	0.0	1	2.4	5	11.4
lady's slipper	0	0.0	0	0.0	1	2.4	2	4.5
northern starflower	0	0.0	1	2.3	1	2.4	1	2.3
none	12	27.3	26	59.1	18	42.9	30	68.2
mayflower	9	20.5	0	0.0	0	0.0	0	0.0
prince's pine	2	4.5	1	2.3	0	0.0	0	0.0
sedge spp.	0	0.0	2	4.5	0	0.0	0	0.0
sweet gale	0	0.0	0	0.0	1	2.4	0	0.0
twinflower	3	6.8	3	6.7	0	0.0	0	0.0

3.10: Frequency Table of Dominant Low Shrub Species

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
balsam fir	0	0.0	1	2.3	0	0.0	4	9.1
bearberry	0	0.0	2	4.5	4	9.5	3	6.8
black spruce	7	15.9	13	29.5	6	14.3	4	9.1
blueberry	17	38.6	12	27.3	6	14.3	12	27.3
common juniper	6	13.6	2	4.5	0	0.0	0	0.0
honeysuckle	0	0.0	0	0.0	1	2.4	0	0.0
jack pine	0	0.0	0	0.0	2	4.7	0	0.0
labrador tea	0	0.0	1	2.3	21	50.0	21	47.7
pin cherry	1	2.3	0	0.0	0	0.0	0	0.0
prickly rose	4	9.2	0	0.0	0	0.0	0	0.0
raspberry	3	6.8	5	11.4	0	0.0	0	0.0
snowberry	0	0.0	0	0.0	1	2.4	0	0.0
none	6	13.6	8	18.2	1	2.4	0	0.0

3.11: Frequency Table of Dominant Medium Shrub Species

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
alder	3	6.8	0	0.0	9	21.4	9	20.4
balsam fir	4	9.1	2	4.5	0	0.0	1	2.3
beaked hazel	2	4.5	0	0.0	0	0.0	0	0.0
blueberry	2	4.5	0	0.0	0	0.0	0	0.0
common juniper	14	31.8	6	13.6	0	0.0	0	0.0
jack pine	0	0.0	1	2.3	1	2.4	0	0.0
meadowsweet	1	2.3	0	0.0	0	0.0	0	0.0
pin cherry	2	4.5	0	0.0	0	0.0	0	0.0
prickly rose	1	2.3	0	0.0	0	0.0	0	0.0
spruce	15	34.0	33	75.0	27	64.2	33	75.0
trembling aspen	0	0.0	1	2.3	2	4.8	0	0.0
white birch	0	0.0	1	2.3	1	2.4	0	0.0
white cedar	0	0.0	0	0.0	1	2.4	1	2.3
willow spp.	0	0.0	0	0.0	1	2.4	0	0.0

3.12: Frequency Table of Dominant Tall Shrub Species

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
alder	4	9.0	1	2.3	2	4.8	2	4.5
balsam fir	2	4.6	1	2.3	0	0.0	2	4.5
jack pine	11	25.0	2	4.6	2	4.8	0	0.0
pin cherry	1	2.3	0	0.0	0	0.0	0	0.0
spruce	24	54.5	40	90.8	26	61.8	38	86.4
trembling aspen	0	0.0	0	0.0	5	11.9	0	0.0
white birch	2	4.6	0	0.0	5	11.9	1	2.3
white cedar	0	0.0	0	0.0	2	4.8	1	2.3

3.13: Frequency Table of Dominant Tree Species

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP.Nursery Sites	
Species	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
balsam fir	0	0.0	1	2.3	0	0.0	3	6.8
jack pine	25	56.8	22	50.0	3	7.1	1	2.3
none	6	13.6	0	0.0	5	11.9	0	0.0
spruce	11	25.0	21	47.7	30	71.4	38	86.3
tamarack	0	0.0	0	0.0	1	2.4	1	2.3
trembling aspen	2	4.6	0	0.0	2	4.8	0	0.0
white birch	0	0.0	0	0.0	1	2.4	1	2.3

3.14: Frequency Table of Lichen Classes

	WCPP Absence Sites		WCPP Nursery Sites		WPP Absence Sites		WPP Nursery Sites	
Lichen Classes	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
0	67	19.0	89	25.3	52	15.5	22	6.3
1	196	55.7	28	8.0	171	50.9	239	67.9
2	7	2.0	14	4.0	31	9.2	54	15.3
3	3	0.9	1	0.3	8	2.4	28	8.0
4	1	0.3	1	0.3	0	0.0	1	0.3
5	5	1.4	2	0.6	0	0.0	1	0.3
none	73	20.7	217	61.5	74	22.0	7	2.0

Appendix 4

Tabular data of all frequency distributions of nominal data in landscape analyses (Chapter 3)

4.1: Frequency Table of Landcover Classes in Woodland Caribou Provincial Park

	WCPP Absence Sites		WCPP Nursery Sites		WCPP Random Sites		WCPP Buffered Areas	
Landcover Classes	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Bedrock	NA		NA		159	2.7	6842	2.6
Burns	NA		NA		60	0.9	3003	1.1
Coniferous Forest	62	34.0	15	62.5	2290	38.2	99292	37.8
Deciduous Forest	31	17.0	0	0.0	718	12.0	30951	11.8
Fen_Bog	3	1.7	NA		77	1.3	3418	1.3
Mixed Forest	28	15.4	4	16.7	761	12.7	34193	13.0
Sparse Forest	58	31.9	5	20.8	1937	32.2	84709	32.3

4.2: Frequency Table of Landcover Classes in Wabakimi Provincial Park

	WPP Absence Sites		WPP Nursery Sites		WPP Random Sites		WPP Buffered Areas	
Landcover Classes	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Bedrock	NA		NA		NA		NA	
Burns	NA		NA		132	5.0	8028	4.8
Coniferous Forest	36	50.7	7	36.8	1043	39.4	64109	38.3
Deciduous Forest	1	1.4	0	0.0	88	3.3	5272	3.1
Fen_Bog	2	2.8	0	0.0	49	1.8	3981	2.4
Mixed Forest	12	16.9	1	5.3	462	17.4	28377	16.9
Sparse Forest	20	28.2	11	57.9	876	33.1	57724	34.5

4.3: Frequency Table of Initial Points in Woodland Caribou Provincial Park

	WCPP Absence Sites		WCPP Nursery Sites		WCPP Random Sites	
Feature	Frequency	Percent	Frequency	Percent	Frequency	Percent
Island	245	50.4	62	76.5	689	10.8
Mainland	172	35.4	10	12.4	5481	85.9
Small Peninsula	59	12.1	6	7.4	175	2.7
Island Small Peninsula	10	2.1	3	3.7	35	0.6

4.4: Frequency Table of Initial Points in Wabakimi Provincial Park

	WPP Absence Sites		WPP Nursery Sites		WPP Random Sites	
Feature	Frequency	Percent	Frequency	Percent	Frequency	Percent
Island	50	38.2	19	59.4	776	23.1
Mainland	75	57.3	6	18.8	2459	73.2
Small Peninsula	5	3.8	5	15.6	92	2.7
Island Small Peninsula	1	0.7	2	6.2	33	1.0

4.5: Frequency Table of First Closest Feature from Initial Points in Woodland Caribou Provincial Park

	WCPP Absence Sites		WCPP Nursery Sites		WCPP Random Sites	
Feature	Frequency	Percent	Frequency	Percent	Frequency	Percent
Island	254	30.3	45	47.9	1936	37.1
Mainland	383	45.8	34	36.2	780	15.0
Small Peninsula	190	22.7	12	12.7	2454	47.1
Island Small Peninsula	10	1.2	3	3.2	44	0.8

4.6: Frequency Table of First Closest Feature from Initial Points in Wabakimi Provincial Park

	WPP Absence Sites		WPP Nursery Sites		WPP Random Sites	
Feature	Frequency	Percent	Frequency	Percent	Frequency	Percent
Island	82	51.9	23	59.0	1047	53.1
Mainland	24	15.2	8	20.5	80	15.1
Small Peninsula	39	24.7	7	17.9	825	24.6
Island Small Peninsula	13	8.2	1	2.6	20	8.2

Appendix 5

Vegetation type Classification Categories
(from Sims et al. 1989)

V1: Balsam poplar hardwood and mixedwood
V2: Black ash hardwood and mixedwood
V3: Other hardwoods and mixedwoods
V4: White birch hardwood and mixedwood
V5: Aspen hardwood
V6: Trembling aspen (white birch) – balsam fir/mountain maple
V7: Trembling aspen – balsam fir / balsam fir shrub
V8: Trembling aspen (white birch) / mountain maple
V9: Trembling aspen mixedwood
V10: Trembling aspen – black spruce – jack pine / low shrub
V11: Trembling aspen – conifer / blueberry / feathermoss
V12: White pine mixedwood
V13: Red pine mixedwood
V14: Balsam fir mixedwood
V15: White spruce mixedwood
V16: Balsam fir – white spruce mixedwood / feathermoss
V17: Jack pine mixedwood / shrub rich
V18: Jack pine mixedwood / feathermoss
V19: Black spruce mixedwood / herb rich
V20: Black spruce mixedwood / feathermoss
V21: Cedar (incl. mixedwood) / mountain maple
V22: Cedar (incl. mixedwood) / speckled alder / sphagnum
V23: Tamarack (black spruce) / speckled alder / Labrador tea
V24: White spruce – balsam fir / shrub rich
V25: White spruce – balsam fir / feathermoss
V26: White pine conifer
V27: Red pine conifer
V28: Jack pine / low shrub
V29: Jack pine / ericaceous shrub / feathermoss
V30: Jack pine / black spruce / blueberry / lichen
V31: Black spruce – jack pine / tall shrub / feathermoss
V32: Jack pine – black spruce / ericaceous shrub / feathermoss
V33: Black spruce / feathermoss
V34: Black spruce / labrador tea / feathermoss (sphagnum)
V35: Black spruce / speckled alder / sphagnum
V36: Black spruce / bunchberry / sphagnum (feathermoss)
V37: Black spruce / ericaceous shrub / sphagnum
V38: Black spruce / leatherleaf / sphagnum

Appendix 6

Soil type Classification Categories
(from Sims et al. 1989)

S1: Dry / coarse sandy
S2: Fresh / fine sandy
S3: Fresh / coarse loamy
S4: Fresh / silty – silt loamy
S5: Fresh / fine loamy
S6: Fresh / clayey
S7: Moist / sandy
S8: Moist / coarse loamy
S9: Moist / silty – silt loamy
S10: Moist / fine loamy - clayey
S11: Moist / peaty phase
S12F: Wet / organic (feathermoss)
S12S: Wet / organic (sphagnum)
SS1: Discontinuous organic mat on bedrock
SS2: Extremely shallow soil on bedrock
SS3: Very shallow soil on bedrock
SS4: Very shallow soil on boulder pavement
SS5: Shallow – moderately deep / sandy
SS6: Shallow – moderately deep / coarse loamy
SS7: Shallow – moderately deep / silty – fine loamy - clayey
SS8: Shallow – moderately deep / mottles-gley
SS9: Shallow-moderately deep / organic-peaty phase

Appendix 7

Ecosite type Classification Categories
(from Racey et al. 1996)

ES11: Red pine – white pine–jack pine: very shallow soil
ES12: Black spruce – jack pine: very shallow soil
ES13: Jack pine – conifer: dry–moderately fresh, sandy soil
ES14: Pine – spruce mixedwood: sandy soil
ES15: Red pine – white pine: sandy soil
ES16: Hardwood –fir–spruce mixedwood: sandy soil
ES17: White cedar: fresh –moist, coarse–fine loamy soil
ES18: Red pine–white pine: fresh, coarse loamy soil
ES19: Hardwood–fir–spruce mixedwood: fresh, sandy-coarse loamy soil
ES20: Spruce-pine / feathermoss: fresh, sandy-coarse loamy soil
ES21: Fir-spruce mixedwood: fresh, coarse loamy soil
ES22: Spruce-pine / ledum / feathermoss: moist, sandy-coarse loamy soil
ES23: Hardwood-fir-spruce mixedwood: moist, sandy-coarse loamy soil
ES24: Red pine-white pine: fresh, fine loamy soil
ES25: Pine-spruce / feathermoss: fresh, silty soil
ES26: Spruce-pine / feathermoss: fresh, fine loamy-clayey soil
ES27: Fir-spruce mixedwood: fresh, silty-fine loamy soil
ES28: Hardwood-fir-spruce mixedwood: fresh, silty loamy
ES29: Hardwood-fir-spruce mixedwood: fresh, fine loamy-clayey soil
ES30: Black ash hardwood: fresh, silty-clayey soil
ES31: Spruce-pine / feathermoss: moist, silty-clayey soil
ES32: Fir-spruce mixedwood: moist, silty-clayey soil
ES33: Hardwood-fir-spruce mixedwood: moist, silty-clayey soil
ES34: Treed bog: black spruce / sphagnum: organic soil
ES35: Poor swamp: black spruce: organic soil
ES36: Intermediate swamp: black spruce (tamarack): organic soil
ES37: Rich swamp: cedar (other conifer): organic soil
ES38: Rich swamp: black ash (other hardwood): organic-mineral rich
ES39: Open bog: ericaceous shrub / sphagnum: organic soil
ES40: Treed fen: tamarack-black spruce / sphagnum:organic soil
ES41: Open poor fen: ericaceous shrub-sedge / sphagnum: organic soil
ES42: Open moderately rich fen: ericaceous shrub / sedge: organic soil
ES43: Open extremely rich fen: ericaceous shrub / brown moss: organic soil
ES44: Thicket swamp: organic-mineral soil
ES45: Shore fen: organic soil
ES46: Meadow marsh: organic-mineral soil
ES47: Sheltered marsh: emergent: sedimentary peat substrate
ES48: Exposed marsh: emergent mineral substrate
ES49: Open water marsh:submergent / floating-leaved:sedimentary peat substrate
ES50: Open water marsh: submergent: mineral substrate