

**HABITAT USE BY
WHITE-WINGED SCOTERS (*MELANITTA FUSCA*)
AND SURF SCOTERS (*MELANITTA PERSPICILLATA*)
IN THE MACKENZIE DELTA REGION,
NORTHWEST TERRITORIES**

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By

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ABSTRACT

Apparent long-term declines of white-winged and surf scoter (*Melanitta fusca* and *M. perspicillata*) populations in the northern boreal forest have raised concern for these sea duck species. Reasons for population declines are not well understood but some evidence suggests that factors associated with events on the breeding grounds may be responsible. Breeding ground changes could adversely affect abiotic or biotic characteristics of upland or wetland habitats or key food sources for breeding females or ducklings, which in turn may lower productivity or recruitment. Like most boreal-nesting ducks, virtually nothing is known about wetland habitat preferences of scoters. Determining habitat features that scoters need to breed successfully, and how habitat changes in the boreal forest affect scoters, is an important step in understanding their ecology and developing conservation initiatives. Thus, my overall goal was to look for evidence of habitat selection in scoters at two spatial scales by characterizing biotic and abiotic features of areas used by scoter pairs and broods, and comparing these features with those of areas not used by scoters. Habitat characteristics and scoter use of wetlands in recently burned forest was also contrasted with unburned forest to determine whether habitat change caused by fire could affect patterns of habitat use by scoters.

I used remote sensing data as a tool to delineate coarse-scale patterns of habitat use by scoter pairs and broods. Results indicate that although scoters may not settle on wetlands in areas dominated by burned vegetation two years following the fire, three years after the fire I found no difference in scoter pair or brood use between wetlands in burned and unburned upland. I found that surf and white-winged scoter pairs often co-occurred on wetlands. I was unable to find any evidence to support the prediction that scoters prefer wetlands with irregular shorelines that might enhance pair isolation and offer greater protection to ducklings from severe winds and wave action.

Based on fine-scale wetland habitat characteristics, scoter pairs and broods used wetlands with more abundant food, a finding that is consistent with many

other waterfowl studies. However, unlike some previous waterfowl studies, I did not find a consistent correlation between total phosphorus levels and amphipod abundance or wetland use by scoters. Very high total nitrogen to total phosphorus ratios in sampled wetlands lead me to speculate that wetlands in my study area may be phosphorus limited. I did not detect a difference in fine-scale features of wetlands surrounded by burned versus unburned vegetation. This study of scoters in the northern boreal forest was among the first to determine why scoters use specific wetlands or areas and not others.

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DEDICATION

To the Gwich'in Elders and hunters who first introduced me to "black ducks".

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CHAPTER 1: GENERAL INTRODUCTION

1.1 INTRODUCTION

One of the most important traits an animal has is the ability to distinguish between and select among different habitats because this determines the resources available to individuals within a population (Holt 1987). Depending on the habitat occupied, individuals will be exposed to certain abiotic and biotic factors (Martin 1992, Petit and Petit 1996, Williams et al. 2002) that can directly influence each individual's chance of survival and reproductive success (Greene and Stamps 2001). At a population level, these factors affect the primary processes that contribute to changes in the population over time (Williams et al. 2002). Thus, researching factors that influence habitat selection is essential to understanding the dynamics and ecology of populations and to developing conservation initiatives (Caughley 1994, Petit and Petit 1996).

Habitat selection occurs when an environment is used disproportionately to its availability (Johnson 1980). The choice of one site over another in which to live may result from adaptive behavioural responses favoring abiotic and biotic features that increase the chance of survival or reproductive success (Hutto 1985, Greene and Stamps 2001). Therefore, there are two aspects to habitat selection that are necessary to understand the adaptive significance of disproportionate use: choice and fitness (Jones 2001). Habitat selection is a hierarchical process of behavioural responses that range from choices being made at the macro scale to the micro scale (Johnson 1980). For avian species, these range from choosing habitats that make up a species' geographic range to an individual's choice of nest site. At every spatial scale, the effect of certain biotic and abiotic factors on reproduction and survival has contributed to habitat choice. Researchers studying the process of breeding

habitat selection must be able to demonstrate how observed patterns of habitat use reflect choice, and how differences in habitat features affect breeding success (Van Horne 1983, Martin 1992, Jones 2001).

In field studies it may be difficult to quantify these two components. First, a species may perceive its environment at a scale that doesn't reflect the quantitative methods used in a study (MacFaden and Capen 2002). Second, it may be difficult to demonstrate that individuals have a full range of habitats to choose from when assessing fitness consequences in those habitats (Martin 1998). Third, biologically important habitat features might not even be measured (Martin 1992) by a researcher due to lack of sufficient *a priori* information to choose appropriate variables to study, or for logistical reasons. A good first step towards understanding why species select particular habitats and what habitat features are required for successful reproduction and survival may be to examine patterns of habitat use or how features of used habitats differ from features of available habitats. However, this is not adequate on its own because used habitat may not necessarily be optimal habitat if individuals are in some way prevented from occupying or identifying optimal sites (Van Horne 1983, Pulliam 1988, Martin 1992, Jones 2001). As optimal breeding habitat is that which provides the resources necessary to reproduce successfully, features of used habitats should also be compared to habitat features in areas that support successful breeding (Clark and Shutler 1999).

Factors commonly thought to influence habitat selection by waterfowl include vegetation composition, food availability (Martin 1987, Sjöberg et al. 2000), density of predators and competitors (Martin 1993, Petit and Petit 1996), conspecific attraction (Stamps 1988, Pöysä 1998), and philopatry to natal areas or areas in which breeding was previously successful (Greenwood 1980). However, very little is known about habitat selection in boreal-nesting waterfowl species. White-winged and surf scoters (*Melanitta fusca* and *M. perspicillata*, respectively) are two boreal-nesting ducks that are among the least studied species of waterfowl in North America (Bellrose 1980). An apparent long-term decline in their continental population has raised concern about underlying causes and the long-

term viability of these sea duck species (SDJV Prospectus). Annual waterfowl breeding population surveys indicate that combined white-winged and surf scoter populations from northern Alberta, British Columbia, and the Northwest Territories may have declined by as much as 75% since the 1970s (Figure 1.1) (Can. Wildl. Serv., Prairie and Northern Region Sea Duck Team 2000). This is of particular concern because these same population surveys indicate that most of the combined scoter population breeds in the northern boreal forest between Great Slave Lake and the Arctic Ocean (Bellrose 1980).

Population trends of scoters mirror those of several other duck species, scaup (*Aythya affinis* and *A. marila*) in particular, that breed in the boreal region. These patterns also emerge from long-term data obtained from U.S. Fish and Wildlife Service waterfowl breeding population surveys (S. Slattery, Ducks Unlimited Canada [DUC], pers. comm.). These duck species all share breeding habitat in the boreal forest: upland areas for nesting and wetlands for feeding and for raising offspring, whereas most have different wintering areas, thus contributing to a general hypothesis that reasons for the decline are linked to this region. This has increased the impetus to learn more about waterfowl breeding in the boreal forest.

Although several different factors could be contributing to scoter population decline (Brown and Brown 1981, Kehoe et al. 1989, Kehoe et al. 1994), one hypothesis suggests that conditions in the boreal forest may have changed and this has adversely affected the ability of these species to breed successfully in this region. Scoter low offspring survival and recruitment and life history attributes such as long life-span, delayed first breeding, and low breeding propensity may accentuate their sensitivity to habitat alteration and disturbance (Brown and Brown 1981, Brown and Fredrickson 1989, Kehoe et al. 1989, Brown and Fredrickson 1997, Kremenz et al. 1997, Savard et al. 1998, Traylor 2003). To date, the northern boreal forest has not been subject to the same level of fragmentation, degradation, and habitat loss as the southern boreal (i.e. due to natural gas exploration and forestry) or prairie-parkland (i.e. due to agricultural practices) regions of Canada.

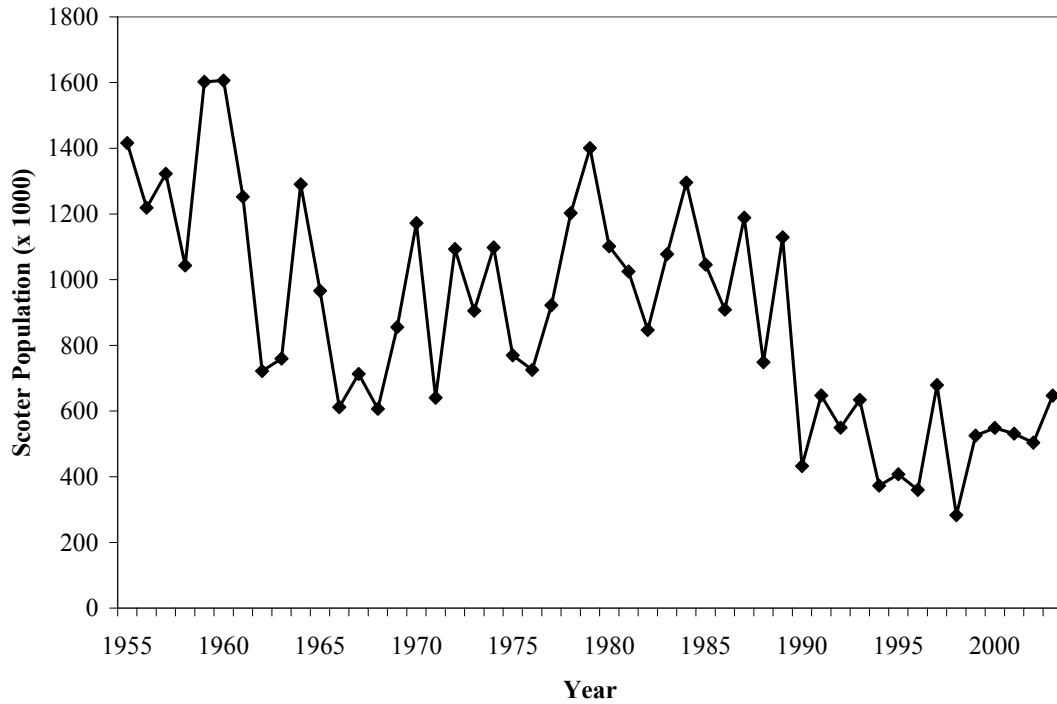


Figure 1.1. Combined scoter population during 1955 to 2003 for all strata in Northern Alberta, British Columbia, and the Northwest Territories from annual U. S. Fish and Wildlife Service breeding waterfowl surveys (U. S. Fish and Wildlife Service unpubl. data).

One possibility is that habitat changes in the northern boreal forest may be linked to climate warming and its unstudied effects on hydrology, forest fire frequency, and subsequently on upland and wetland systems and habitat. This study begins to document habitat associations of scoter breeding in the northern boreal forest.

1.2 ORGANIZATION OF THESIS

Major objectives of this study were to characterize biotic and abiotic features of wetlands not used by these species with features of wetlands that were used by pairs and broods. I also compared features and patterns of scoter habitat use on burned and unburned areas to begin to document basic information on possible impacts of fire on wetlands across the northern boreal forest. In Chapter 2, I use satellite imagery and aerial survey data to characterize coarse-scale features of available wetlands and compare them to those used by breeding pairs and/or broods. I assess whether forest fire affects the abundance of pairs and broods at a broad spatial scale. I also challenge the assumption that breeding pair density is a suitable index of breeding success by comparing the density of pairs and broods at two different spatial scales. Chapter 3 investigates scoter pair and brood habitat associations at the wetland level by examining fine-scale biotic and abiotic features. I also compare these features between burned and unburned wetlands to assess impacts of forest fire and its effects on scoter abundance and distribution. My final chapter (Chapter 4) is a synthesis of my major findings, a discussion of my limitations and assumptions, and provides suggestions for future work. In Appendix A, I test major assumptions and limitations of detection probability and how results from my study must take this into account. Appendix B includes supplemental earth cover classification data for Chapter 2.

CHAPTER 2: COARSE-SCALE HABITAT SELECTION BY WHITE-WINGED AND SURF SCOTERS IN THE MACKENZIE DELTA REGION

2.1 INTRODUCTION

Very little is known about patterns of habitat use by white-winged and surf scoters during the breeding season. Although annual surveys indicate that most of the combined scoter population breeds in the northern boreal forest between Great Slave Lake and the Arctic Ocean (Bellrose 1980), few studies have been conducted in this core portion of their breeding range. The lack of work on breeding waterfowl in the northern boreal forest is most likely due to the vastness and inaccessibility of the region. However, apparent long-term declines in scoter and other waterfowl populations breeding in northern Alberta, British Columbia, and the Northwest Territories (Canadian Wildlife Service, Prairie and Northern Region Sea Duck Team 2000; S. Slattery, Ducks Unlimited Canada [DUC], pers. comm.) have heightened attention to the need for research in this region. Although these populations could decrease as a result of multiple factors, one breeding season hypothesis proposes that quality of terrestrial and aquatic systems in this region have deteriorated. For instance, climatic change impacts on hydrology, forest fire frequency, and land cover could affect aquatic food resources and vegetation and upland nesting habitat. Unfortunately, we have little reliable information about impacts of these processes on distribution and success of breeding waterfowl.

Knowledge about habitat use and breeding biology of scoters originates from only a few studies of relatively small, isolated populations breeding in colonies on islands in large lakes: white-winged scoters in the Prairie Parkland of Canada (Vermeer 1969, Brown and Brown 1981, Brown and Fredrickson 1986, Kehoe 1986, Brown and Fredrickson 1989, Traylor 2003) and in Finland

(Koskimies and Routamo 1953, Hilden 1964) and surf scoters in forested areas of Québec (Savard and Lamothe 1991, Reed et al. 1994, Decarie et al. 1995).

Although these studies describe characteristics of wetlands, nest sites, and foraging areas used by scoters, only Traylor (2003) compares used with available, randomly selected habitats (Jones 2001), making any robust inferences regarding the process of habitat selection. No study has investigated whether habitat selection by scoters influences reproductive success in the core portion of their breeding range. As part of this process, it is critical to identify “optimal” habitats (ie. where scoters breed *successfully vs unsuccessfully*) rather than just delineate “used” habitats (Morrison and Hall 2001).

This study begins to fill this deficiency by determining coarse-scale habitat associations of breeding scoters. Habitat selection is a hierarchical process, ranging from first-order selection of a geographic range to fourth-order selection of nest or foraging sites (Johnson 1980). My main objective was to use Landsat imagery to characterize features of available wetlands and compare them to those used by breeding pairs and/or broods, enabling me to evaluate second-order habitat selection patterns. Apart from the logical idea that more scoters could potentially settle on larger wetlands, I was interested in determining if specific features of wetlands and adjacent uplands, including fire history, were related to wetland use. High brood mortality probably limits recruitment in scoters (Koskimies 1957, Hilden 1964, Brown and Brown 1981, Traylor 2003). Therefore, female scoters should select brood-rearing habitats that offer protection for ducklings. Wetlands with bays have more irregular shorelines than those that are round or long and narrow. Broods on bays may be less exposed to winds and waves. As such, I predicted that wetlands occupied by broods would have more irregular shorelines. In addition, I tested whether breeding pair density is a suitable index of habitat quality (as indexed by density of broods), an assumption that has been challenged and in some cases refuted in some previous studies of birds (e.g., van Horne 1993, Martin 1992, Vickery et al. 1992, Jones 2001, Morrison 2001).

2.2 STUDY AREA

Work was conducted in the Mackenzie Delta and surrounding upland area (Figure 2.1), south of Inuvik, Northwest Territories (68° N, 134° W). Delta sites fall within the Mackenzie Delta Ecoregion (Ecological Stratification Working Group 1995), an area characterized by many lakes and channels of the Mackenzie River. Common trees are paper birch (*Betula papyrifera*), black (*Picea mariana*) and white (*P. glauca*) spruce, and tamarack (*Larix laricina*). Willow (*Salix spp.*), dwarf birch (*Betula glandulosa*), alder (*Alnus crispa*), ericaceous shrubs (*Vaccinium and Ledum spp.*), cotton grass (*Eriophorum angustifolium*), lichen, and moss are among the common plants making up the understory in the delta forest (Ecological Stratification Working Group 1995). Burned and unburned upland sites fall within the Great Bear Lake Plain Ecoregion (Ecological Stratification Working Group 1995), an area with low relief. Wetlands ranging from small stagnant ponds to large deep lakes are found throughout this region. The forest of the unburned upland contains stunted black spruce, tamarack, and some birch. The understory is similar to that of the delta region. Standing dead timber is present throughout the burned region. The understory is limited to fireweed (*Epilobium angustifolium*) and some sedge (*Carex spp.*). The only road in the region, the Dempster Highway, runs through the upland along the southern and eastern sides of the Mackenzie Delta until it terminates in Inuvik.

2.3 METHODS

2.3.1 Study Plot and Wetland Selection

To more efficiently use helicopter time, a core study area (ca. 6200 km²) known to have scoters present (C. Ferguson, United States Fish and Wildlife Service (USFWS), pers. comm.) was chosen, that included portions of the Mackenzie Delta (hereafter delta) and adjoining upland areas (Figure 2.1). Study plots (2 km diameter) were randomly distributed on a Landsat image of the core study area using ArcView GIS software: 16 from the delta, and 15 from the upland

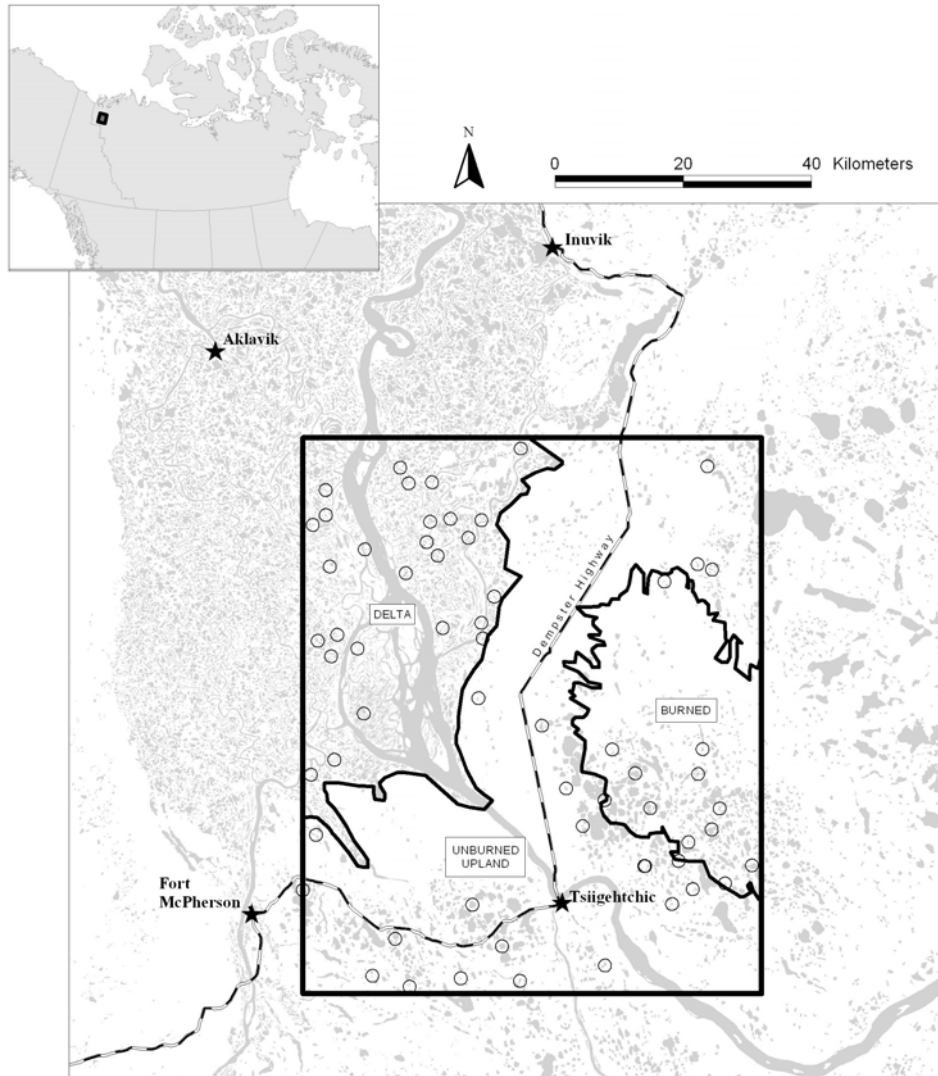


Figure 2.1. Locations of study area and study plots south of Inuvik, Northwest Territories.

region in 2001, and 11 delta and 18 upland plots in 2002. Overall, 13 upland plots had been burned in a 1999 forest fire. To assess annual variation in scoter abundance and wetland occupancy, I revisited 10 of the 31 plots in 2002 that were surveyed in 2001 (five in the delta and five in the upland) and sampled 29 plots. In upland plots, where wetlands are distinct, all wetlands entirely or partially within each study plot were surveyed. In delta plots wetland boundaries are not always distinct and there may be > 25 small wetlands per plot. In these cases a maximum of 12 wetlands ranging in size was randomly selected. Altogether, 385 wetlands were surveyed.

2.3.2 Aerial Surveys

In both years, a helicopter was used to conduct basin-specific surveys of wetlands for pairs in mid to late June and for broods in late July or early August. I conducted all surveys sitting in the front of the aircraft with a second observer sitting behind the pilot (i.e., opposite side from my position). I navigated to each study plot using a laptop computer outfitted with moving map software linked to a GPS unit. The pilot then navigated to each wetland using a printed map of the Landsat image at a scale of about 1:50,000. During pair surveys, the helicopter circled the perimeter of each wetland 15-50 m above ground level at a speed of 30 – 100 km/h. Observers used a tape recorder to record the number, sex, and social status of scoters detected. Wetland number and local time on and off each wetland were also recorded, enabling me to confirm the location of each observation using the tracking function of the moving map software. Data were downloaded and transcribed at the end of each flight. Brood surveys were conducted in a slightly different manner because we detected broods on far fewer wetlands, and because it was difficult to distinguish scoter hens and ducklings. As the helicopter circled the perimeter of each wetland, both observers and the pilot searched for broods. When a brood was observed, the helicopter approached carefully to avoid excessive disturbance and minimize diving by hens and ducklings. The helicopter hovered until one or both observers were able to identify the species.

2.3.3 Coarse-Scale Wetland Habitat Characteristics

Reconnaissance surveys and information provided by others suggest that not all wetlands are used even in areas where scoters are abundant (C. Ferguson, USFWS, pers. comm., D. Kay, DUC, pers. comm.). Survey data were used to assign each wetland to a category of use (separately for each species): used by pairs, used by broods, or not used. Area (ha) and perimeter (m) were calculated for all wetlands from Landsat imagery or digital topographic maps using ArcView GIS software. An index of shoreline irregularity (SI; Reid 1961:34) was calculated by the equation:

$$SI = \frac{p}{2\sqrt{a\pi}} \quad (2.1)$$

where p = wetland perimeter (m) and a = wetland area (m^2). $SI = 1.0$ for perfectly round wetlands and $SI \gg 1.0$ indicate more irregular shorelines. Land cover variables describing the vegetation characteristics in each plot were acquired from classified Landsat imagery (Ducks Unlimited Inc. 2002) using ArcView GIS software.

2.3.4 Data Analysis

All statistical tests were executed using SAS software (SAS Institute Inc. 1987). Unless otherwise specified, all analyses were conducted on data for 385 wetlands surveyed in 2001 and 2002. Seventy wetlands were surveyed both years and I randomly selected 35 of these wetlands from each year to include in the dataset. Wetland area and perimeter, SI, and 34 land cover variables describing plot-level upland vegetation characteristics (Appendix B) were log transformed to improve normality before conducting analyses.

To reduce the dimensionality of data used in subsequent analyses, I conducted a principal components analysis (PROC PRINCOMP) on plot-level land cover variables. The first and second principal component axes (PC1 and PC2) accounted for 22.2 % and 15.1% respectively of the total original variance, greater

than expected by chance based on “Broken Stick” criteria (Jackson 1993). PC1 describes a gradient ranging from heavily-forested vegetation (five highest positive component loadings range from 0.686 to 0.795) to burned or open tundra vegetation (five most negative component loading range from -0.470 to -0.915) (Table B.1). This axis provides clear separation between heavily forested delta plots and sparsely vegetated burned upland plots (Figure 2.2). PC2 describes a gradient between sparse conifer forest with a moss or lichen dominated understory (five highest positive component loadings range from 0.584 to 0.888) and areas dominated by open water or non-vegetated area (five most negative component loadings range from -0.329 to -0.467) (Table B.1). PC2 separates unburned upland plots from plots in the delta or burned upland (Figure 2.2). I used PC1 and PC2 scores describing plot-level land cover characteristics in subsequent analyses because they explain the environmental gradient among plots and do not assume that all burned plots are composed of the same land cover characteristics.

To evaluate factors influencing white-winged scoter pair density, surf scoter pair presence, and presence of white-winged scoter broods, I used model selection methods and regression techniques in PROC GENMOD. For white-winged scoter pair density, counts were analyzed with log-linear models assuming Poisson distribution (Jones et al. 2002). White-winged scoter pair counts were derived from the maximum number of pairs detected on a wetland during either the first or second pair survey in a given year. Because scoters are more abundant on larger wetlands (Figure 2.3), I used wetland area as an “offset” variable (i.e. to derive density). This means wetland area was assigned a fixed beta coefficient of +1 and as such was not included as a parameter in candidate models. SI, component scores for PC1 and PC2 describing plot-level vegetation characteristics, and surf scoter pair presence or absence were included as covariates in candidate models. Preliminary analyses indicated that the correlation between plot-level vegetation differences and white-winged scoter pair density depended on year, so I analyzed 2001 and 2002 data separately. I began with a suite of seven *a priori* models but because so little is known about scoter ecology I expanded this to include 5

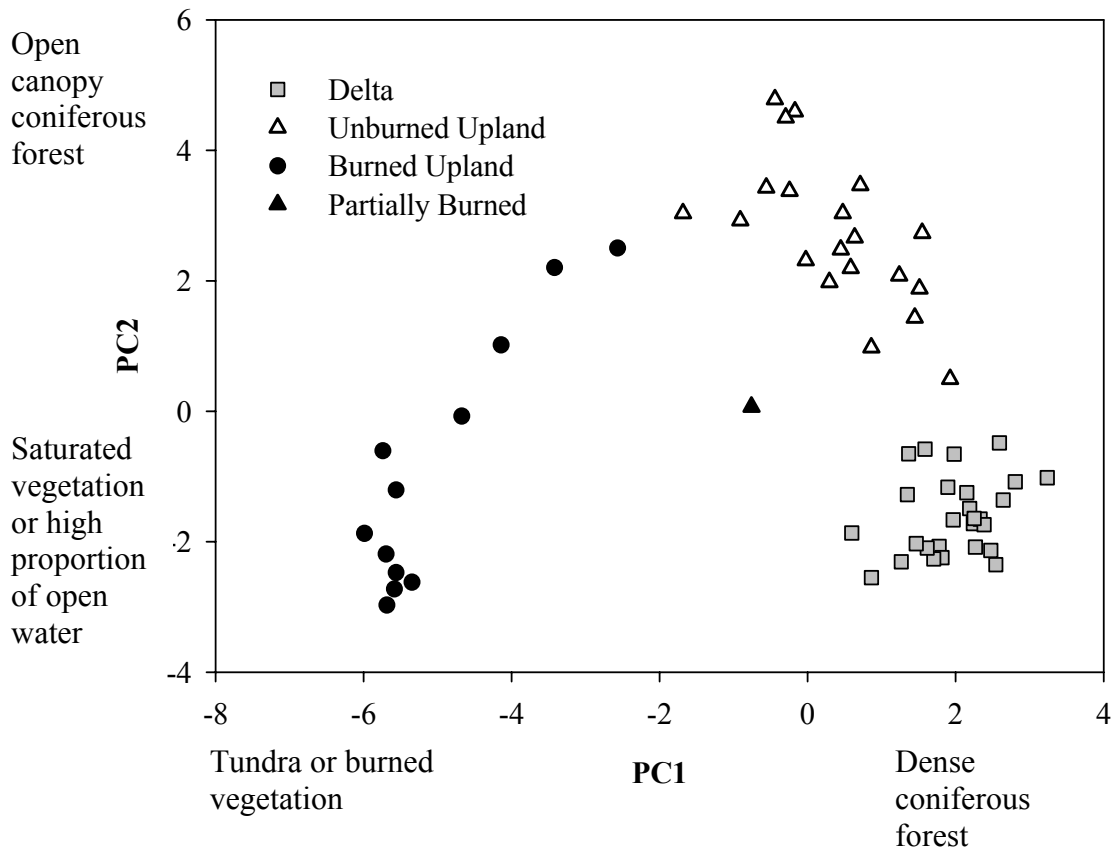


Figure 2.2. Component scores for the first and second principal component axes from a principal components analysis (PCA) on 34 land cover variables for 60 study plots. The first principal component axis (PC1) describes a gradient ranging from heavily forested vegetation to burned or open tundra vegetation. The second principal component axis (PC2) describes a gradient ranging from sparse coniferous forest to areas dominated by saturated ground or open water. Together PC1 and PC2 separate delta, burned upland, and unburned upland plots based on variation among plot-level land cover variables.

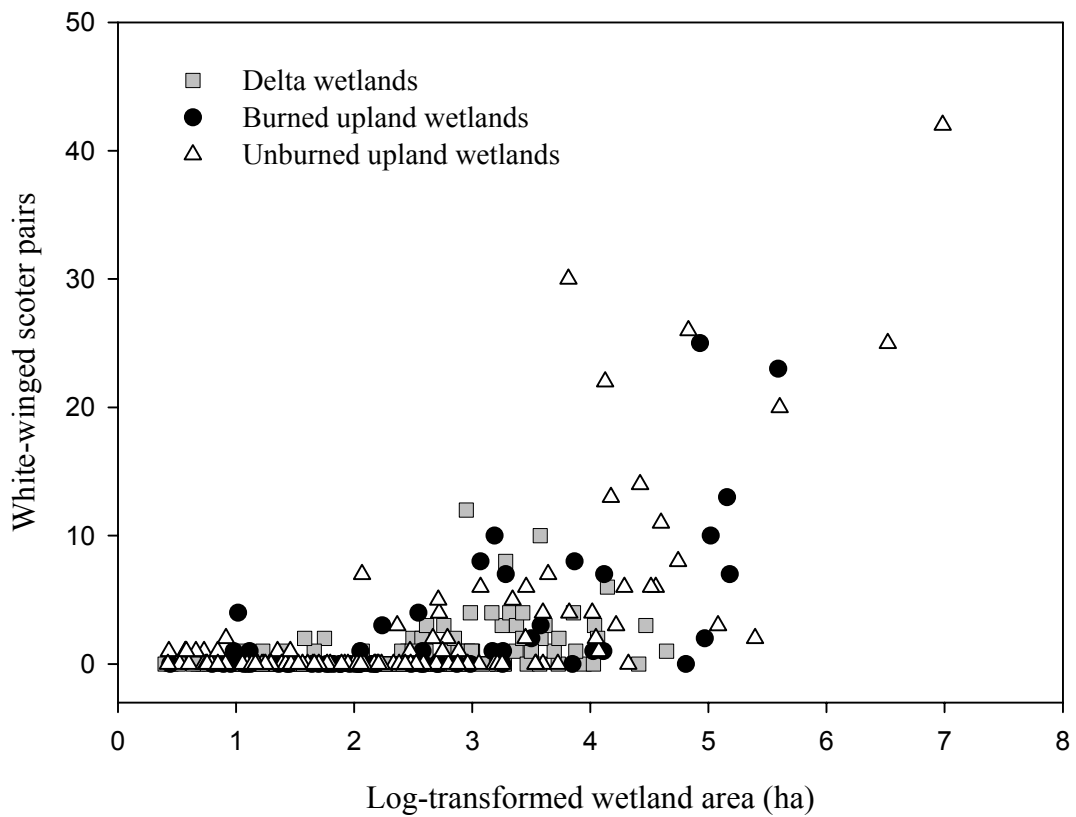


Figure 2.3. White-winged scoter pair abundance as a function of log-transformed area (ha) of 385 wetlands in the delta, burned upland, and unburned upland. In general larger wetlands supported higher numbers of white-winged scoter pairs than smaller wetlands.

additional *a posteriori* models which explored correlations between covariates and white-winged scoter pair density that became apparent after the first seven models were analyzed. I compared the plausibility of models in each candidate set using Akaike's Information Criterion (AIC) (Akaike 1973) with sample size adjustment (AIC_c) and Akaike weights (w_i) (Burnham and Anderson 2002). Models with $\Delta AIC_c < 2$ were considered to have substantial support (Burnham and Anderson 2002). In both years all four covariates were each present in at least one of the models with $\Delta AIC_c < 2$ so I used the sum of Akaike weights of all models that included a particular covariate to establish whether there was support for that covariate in the context of the candidate set (Burnham and Anderson 2002). Precision of parameter estimates (β_i) was evaluated based on the extent to which 95% confidence intervals overlapped zero. Unless otherwise specified, I reported parameter estimates and 95% confidence intervals of covariates from the most parsimonious model in the candidate set containing that particular covariate.

Surf scoter pairs and white-winged scoter broods were detected in low numbers on far fewer wetlands than white-winged scoter pairs (Tables 2.1 and 2.2), so I used logistic regression (logit models based on binomial distribution) and model selection methods to evaluate factors influencing occurrence of surf scoter pairs and white-winged scoter broods. As with white-winged scoter pair density, yearly data for white-winged scoter brood occurrence were analyzed separately because preliminary analyses indicated that the correlation between plot-level vegetation characteristics and wetland occupancy by white-winged scoter broods differed by year. The 2001 and 2002 surf scoter survey data were analyzed together because preliminary analyses indicated that the correlation between wetland occupancy by surf scoter pairs and plot-level vegetation characteristics did not differ by year. Wetland area, SI, PC1 and PC2 describing plot-level vegetation characteristics, and white-winged scoter pair presence/absence were entered as covariates into candidate models for white-winged scoter brood occurrence. I used the same covariates in candidate models assessing surf scoter pair occurrence as I did in models assessing white-winged scoter broods with the addition of year

Table 2.1. Percent surveyed wetlands occupied by white-winged (WWSC) and surf scoter (SUSC) pairs, broods, and both in the delta, burned upland, and unburned upland regions in 2001 and 2002.

Species	Year	Region	Pairs	Broods	Both
WWSC	2001	Delta (n = 118) ^a	19.5	17.8	5.9
		Burned Upland (n = 26)	42.3	3.8	3.8
		Unburned Upland (n = 61)	45.9	18.0	16.4
	2002	Delta (n = 129)	24.8	6.2	4.7
		Burned Upland (n = 43)	32.6	16.3	14.0
		Unburned Upland (n = 84)	30.9	13.1	11.9
SUSC	2001	Delta (n = 118)	12.7	5.1	1.7
		Burned Upland (n = 26)	19.2	0	0
		Unburned Upland (n = 61)	32.8	11.5	6.5
	2002	Delta (n = 129)	14.7	1.5	0
		Burned Upland (n = 43)	23.3	2.3	2.3
		Unburned Upland (n = 84)	19.0	4.8	3.6

^a Number of wetlands surveyed.

Table 2.2. Total number of white-winged (WWSC), surf (SUSC), and unknown scoter pairs and broods detected during surveys in 2001 and 2002. Counts are based on the maximum number detected on a wetland during either the first or the second pair survey in a given year. Also presented is the ratio of identified broods per identified pairs as an estimate of breeding success.

Year	Species	Pairs	Broods	Broods:Pairs
2001 (n = 167) ^a	WWSC	233	36	15.4
	SUSC	59	12	20.3
	Unknown scoter	52	8	-
2002 (n = 218)	WWSC	344	77	22.4
	SUSC	147	18	12.2
	Unknown scoter	3	6	-

^a Number of wetlands surveyed.

effects. I began with a set of *a priori* models (12 for white-winged scoter broods and 10 for surf scoter pairs) and added models (to a total of 25 and 20 for white-winged scoter broods in 2001 and 2002 respectively and 20 for surf scoter pairs) to explore correlations that became apparent through analysis of the *a priori* set. I used the same model selection procedures and methods to assess the relative importance of covariates for white-winged scoter broods and surf scoter pairs as I did for white-scoter pair density. The very low number of wetlands occupied by surf scoter broods (Table 2.1) prevented further analysis.

I looked for associations between white-winged scoter pairs and broods using Spearman rank correlation. Plot-level information was used for these analyses because scoter pairs and broods were present on individual wetlands in low numbers and few wetlands were occupied by both pairs and broods (Table 2.1). Plot-level pair and brood counts were derived by summing the maximum number of pairs or broods, respectively, detected on each wetland in a plot during either the first or second survey in a given year. Of the 10 plots surveyed in both years, I randomly selected five from 2001 and five from 2002 for use in plot-level analyses.

2.4 RESULTS

2.4.1 Coarse-scale scoter habitat associations

2.4.1.1 White-winged scoter pair density

In both years, there was a strong effect of SI on white-winged scoter pair density (2001 $\Sigma w = 0.99$; 2002 $\Sigma w = 0.99$). Negative parameter estimates for SI indicate that white-winged scoter pair density was lower on wetlands with irregular shorelines (2001: $\beta = -1.44$, 95% CI = -2.04 to -0.84, 2002: $\beta = -0.80$, 95% CI = -1.16 to -0.43).

PC1 and PC2 occurred in both 2001 models with $\Delta AIC_c < 2$ (Table 2.3) and both had high summed model weights (PC2 $\Sigma w = 0.99$, PC1 $\Sigma w = 0.99$). The most parsimonious model that included both covariates had positive parameter estimates for PC2 and PC1 ($\beta = 0.27$, 95% CI = 0.17 to 0.37 and $\beta = 0.15$, 95% CI = 0.07 to

0.23, respectively). These estimates indicate that white-winged scoter pair density was higher on wetlands in dry forested upland plots or densely forested delta plots than on wetlands in plots dominated by saturated tundra or burned vegetation. In 2002, PC2 and PC1 were each present in models with $\Delta\text{AIC}_c < 2$ (Table 2.4), however neither of these covariates were well supported by their summed model weights (PC2 $\Sigma w = 0.35$, PC1 $\Sigma w = 0.45$), and confidence intervals for their parameter estimates in all models with $\Delta\text{AIC}_c < 2$ overlapped zero. Thus, there was little evidence to suggest that density of white-winged scoter pairs was influenced by plot-level vegetation characteristics in 2002.

In 2001, surf scoter pair presence was included as a covariate in the most parsimonious model (Table 2.3). Although this covariate had only a moderate summed weight ($\Sigma w = 0.59$), a mostly positive 95% confidence interval for the parameter estimate ($\beta = 0.31$, 95% CI = -0.05 to 0.67) suggested a weak positive relationship between white-winged scoter pair density and surf scoter pair occurrence in 2001. Surf scoter pair presence was contained in all four models with $\Delta\text{AIC}_c < 2$ in 2002 (Table 2.4) and had high summed model weight ($\Sigma w = 0.99$) providing strong plausibility for a positive correlation ($\beta = -0.95$, 95% CI = 0.72 to 1.18) with white-winged scoter pair density.

2.4.4.2 Surf scoter pair occurrence

Predictably, wetland area was included in all models with $\Delta\text{AIC}_c < 2$ (Table 2.5) and had a very high summed weight ($\Sigma w = 0.99$) providing strong evidence that overall surf scoter pairs occurred more often on larger wetlands ($\beta = 0.91$, 95% CI = 0.58 to 1.23). White-winged scoter pair presence was also contained in all models with $\Delta\text{AIC}_c < 2$ and had a very high summed weight ($\Sigma w = 0.99$) suggesting that surf scoter pairs were more likely to occur on wetlands with white-winged scoter pairs present ($\beta = 1.13$, 95% CI = 0.44 to 1.82) (Table 2.5). There was little support ($\Sigma w = 0.40$) for a weak positive correlation between surf scoter pair occurrence and wetlands with irregular shorelines ($\beta = 0.76$, 95% CI = -0.35 to 1.87). The data provided very little support for the effects of plot-level vegetation

Table 2.3. Five highest ranking and null models used to describe relationships between wetland features and white-winged scoter pair density based on surveys of 167 wetlands sampled in 2001. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
PC1, PC2, SI, SSP	0	0.59	5	0
PC1, PC2, SI	0.78	0.40	4	2.90
PC2, SI	9.71	0	2	13.94
PC2, SI, SSP	11.06	0	4	13.19
PC1, PC2	21.98	0	3	26.21
Null	49.06	0	1	57.41

^a Model factors included: SI = shoreline irregularity index; PC1 = first principal axis describing plot-level land cover characteristics; PC2 = second principal axis describing plot-level land cover characteristics; SSP = surf scoter pair occurrence.

^b Difference between the AIC_c values of the model in question to the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

Table 2.4. Five highest ranking and null models used to describe relationships between wetland features and white-winged scoter pair density based on surveys of 218 wetlands sampled in 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
SI, SSP	0	0.39	3	2.86
PC1, SI, SSP	0.74	0.27	4	1.52
PC1, PC2, SI, SSP	1.13	0.20	5	0
PC2, SI, SSP	1.94	0.15	4	2.72
SSP	17.13	0	2	23.04
Null	70.59	0	1	77.55

^a Model factors included: SI = shoreline irregularity index; PC1 = first principal axis describing plot-level land cover characteristics; PC2 = second principal axis describing plot-level land cover characteristics; SSP = surf scoter pair occurrence.

^b Difference between the AIC_c values of the model in question to the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

Table 2.5. Five highest ranking and null models used to describe relationships between wetland features and surf scoter pair occurrence based on surveys of 385 wetlands sampled in 2001 and 2002. Support for each model is indicated by differences in AICc values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
Area, WWP	0	0.26	3	3.08
Area, SI, WWP	0.27	0.23	4	1.31
Area, PC2, WWP	1.96	0.10	4	3.00
Area, PC1, WWP	2.04	0.10	4	3.08
Year, Area, SI, WWP	2.31	0.08	5	1.30
Null	91.03	0	1	98.16

^a Model factors included: Area = wetland area (ha); WWP = white-winged scoter pair occurrence; Year = 2001 or 2002; PC1 = first principal axis describing plot-level land cover characteristics; PC2 = second principal axis describing plot-level land cover characteristics; SI = shoreline irregularity index.

^b Difference between the AIC_c values of the model in question to the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

characteristics (PC1 $\Sigma w = 0.24$, PC2 $\Sigma w = 0.25$) or year ($\Sigma w = 0.21$) on surf scoter pair occurrence.

2.4.4.3 White-winged scoter brood occurrence

In both years all models with $\Delta AIC_c < 2$ included wetland area as a covariate (Tables 2.6 and 2.7). High summed weights (2001 $\Sigma w = 0.99$, 2002 $\Sigma w = 0.86$) and positive parameter estimates from the most parsimonious models in both years further support the logical prediction that white-winged scoter broods were more likely to occur on larger wetlands (2001: $\beta = 1.01$, 95% CI = 0.57 to 1.45, 2002: $\beta = 0.60$, 95% CI = 0.13 to 1.08).

There was some evidence to support a correlation between plot-level vegetation characteristics and white-winged scoter brood occurrence in 2001. PC1 was present in three of four models with $\Delta AIC_c < 2$ and had a moderate summed weight ($\Sigma w = 0.66$). A positive parameter estimate ($\beta = 0.26$) and mostly positive 95% confidence interval (-0.05 to 0.57) suggests that white-winged scoter broods were more likely to be present on wetlands in densely forested delta or upland plots than on wetlands in plots dominated by burnt vegetation or tundra. There was very little support for the other covariate describing plot-level vegetation characteristics (PC2) in 2001 ($\Sigma w = 0.33$) and there was very little support for either plot-level vegetation characteristic covariates in 2002 (PC1 $\Sigma w = 0.30$, $\Sigma w = 0.27$).

In 2002, two of the three models for white-winged scoter brood presence with $\Delta AIC_c < 2$ contained white-winged scoter pair presence and the summed weight for this covariate was 0.99 indicating strong support for a positive effect on white-winged scoter brood occurrence ($\beta = 2.39$, 95% CI = 1.16 to 3.63). Although presence of white-winged scoter pairs was included in a 2001 model with $\Delta AIC_c < 2$, this effect was not as well supported by 2001 data ($\Sigma w = 0.56$) and had an imprecise parameter estimate ($\beta = 0.54$ 95% CI = -0.60 to 1.67).

There was no evidence to support my prediction that broods would favour wetlands with more irregular shorelines in 2001 as this covariate's summed weight was only 0.24. In 2002, shoreline irregularity was present in two of the three

Table 2.6. Five highest ranking and null models used to describe relationships between wetland features and white-winged scoter brood occurrence based on surveys of 167 wetlands sampled in 2001. Support for each model is indicated by differences in AICc values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
Area, PC1	0	0.22	2	1.67
Area, PC1, PC2	1.16	0.12	4	0.72
Area, PC1, WWP	1.27	0.12	4	0.84
Area	1.35	0.11	2	5.10
Area, PC1, SI	2.06	0.08	4	1.63
Null	22.01	0	1	27.80

^a Model factors included: Area = wetland area (ha); PC1 = first principal axis describing plot-level land cover characteristics; PC2 = second principal axis describing plot-level land cover characteristics; SI = shoreline irregularity index; WWP = white-winged scoter pair occurrence.

^b Difference between the AIC_c values of the model in question to the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

Table 2.7. Five highest ranking and null models used to describe relationships between wetland features and white-winged scoter brood occurrence based on surveys of 218 wetlands sampled in 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta\text{AIC}_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
Area, SI, WWP	0	0.26	4	0.14
Area, WWP	0.71	0.18	3	2.96
Area, PC1, SI, WWP,	1.99	0.10	5	0.01
Area, PC1, WWP	2.05	0.09	4	2.18
Area, PC2, SI, WWP	2.12	0.09	5	0.14
Null	40.00	0	1	46.13

^a Model factors included: Area = wetland area (ha); SI = shoreline irregularity index; WWP = white-winged scoter pair occurrence; PC1 = first principal axis describing plot-level land cover characteristics; PC2 = second principal axis describing plot-level land cover characteristics.

^b Difference between the AIC_c values of the model in question to the most parsimonious model ($\Delta\text{AIC}_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

models with $\Delta AIC_c < 2$ but did not have strong support ($\Sigma w = 0.56$). However, the parameter estimate from the most parsimonious model indicates a weak negative correlation ($\beta = -1.61$, 95% CI = -3.57 to 0.36) between white-winged scoter brood presence and irregular shorelines.

2.4.2 Plot-level pair and brood associations

Numbers of pairs and broods of white-winged scoters were positively correlated in delta ($r_s = 0.051$, $P = 0.002$, $n = 32$), burned upland ($r_s = 0.87$, $P < 0.001$, $n = 12$), and unburned upland ($r_s = 0.64$, $P < 0.001$, $n = 25$) plots (Figure 2.4). The number of surf scoter pairs and broods was also correlated in unburned upland plots ($r_s = 0.60$, $P = 0.001$, $n = 25$), but not in burned upland ($P = 0.47$, $n = 12$) or delta ($P = 0.48$, $n = 32$) plots.

2.5 DISCUSSION

2.5.1 Coarse-scale scoter habitat associations

My results indicate that coarse-scale habitat features can be used to delineate general patterns of habitat use by scoters. Predictably, scoters were consistently detected on larger wetlands. There was sufficient *a priori* evidence indicating that white-winged scoter pairs are more abundant on larger wetlands to include wetland area as an offset variable in those models (Figure 2.3). Wetlands occupied by white-winged scoter broods and surf scoter pairs also tended to be larger than unoccupied wetlands. It is likely that larger wetlands simply provide more habitat and can accommodate more scoter pairs and broods than smaller wetlands.

Plot-level vegetation characteristics indicate that white-winged scoter pair density was higher on wetlands surrounded by dense forest either in the delta or upland than on wetlands surrounded by burned or sparse tundra vegetation in 2001. However I detected no such difference in 2002. A similar effect was documented for white-winged scoter brood occurrence in 2001 but not 2002. Vermeer (1969), Brown and Brown (1981), and Traylor (2003) reported that scoters consistently

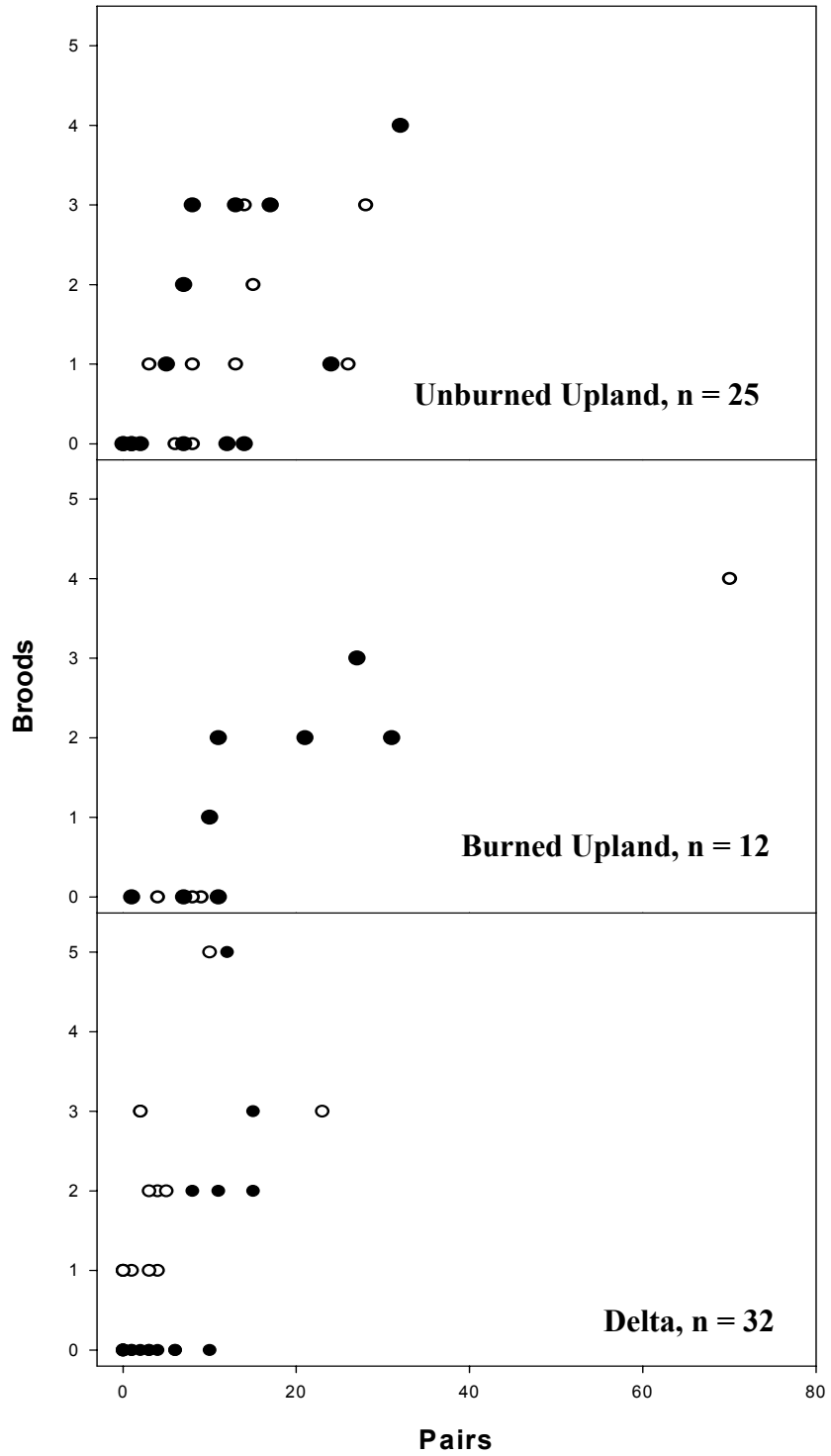


Figure 2.4. Plot-level white-winged scoter pair and brood associations, by region, in 2001 (open circles) and 2002 (closed circles).

nested in extremely dense cover. In the northern boreal forest it may take 10 – 15 years for shrubs or black spruce seedlings to re-establish (Wein 1975). Based on my observations in the burned upland, vegetation was still very sparse in 2001, seemingly with little or no ground concealment available for nests. However, by 2002 it appeared that sedge, fireweed, and horsetails had re-established throughout the burned area. Two years after a fire, burned areas may have had insufficient nesting cover to support successful reproduction thus explaining the lack of pairs or broods occupying wetlands surrounded by burned vegetation in 2001. By 2002, enough ground vegetation may have regenerated in burned uplands to support successful reproduction by scoters thus preventing detection of a difference in use depending on plot-level vegetation characteristics in this year.

White-winged and surf scoters consistently co-occurred on wetlands. This indicates that interspecific competition for resources did not prevent these two species from occurring on the same wetlands in my study area. Scoters of both species occurred in very low densities throughout the northern boreal forest, and such co-existence may indicate that populations in this part of their ranges are not resource-limited to the extent that interspecific competition prevents co-occurrence of the same wetlands (Elmberg et al. 1997). However, I was not able to evaluate whether white-winged and surf scoters utilize the same parts of wetlands or whether they partition resources within wetlands for feeding or spacing, so I am unable to rule out interspecific competition altogether. Presence of any scoter pair on a wetland may provide valuable information about habitat suitability and actually attract scoter pairs of either species (Stamps 1988). Both species of scoters rely exclusively on invertebrate prey as a breeding season food source (Brown and Fredrickson 1986, Savard et al. 1998), so presence of scoters on a wetland may be used as a cue indicating available food resources. During this study, I commonly observed pairs of both species grouped together on wetlands. Neither scoter species is known to have a fixed home range or to exhibit territoriality on wetlands except for males defending a moving space around females (Brown and Fredrickson 1997, Savard et al. 1998). This is consistent with Stamps' (1988) suggestion that there

must be more than sufficient space for territorial establishment in order for conspecific attraction to occur. I do not have data to evaluate whether heterospecific attraction between white-winged and surf scoter pairs in this study meets Stamps' (1988) second condition for conspecific attraction: territory quality must be uniform across the habitat or be difficult to assess. Aggregations have been documented in migratory birds breeding in northern latitudes and having large annual fluctuations in density (Stamps 1988), most likely the result of conspecific attraction, and this could be relevant to groups of breeding scoters in the Mackenzie Delta region.

Counter to my prediction, wetlands with highly irregular shorelines did not support high densities of white-winged scoter pairs. A strong negative correlation existed between shoreline irregularity and white-winged scoter pair density, and there was no compelling evidence that irregular shorelines had any effect on wetland use by surf scoter pairs or white-winged scoter broods. Most scoter broods were detected in open water or close to floating vegetation if it was present; very few broods were detected in the emergent vegetation close to shore. Selection of brood-rearing habitat may not be related to shoreline irregularity, or perhaps I was simply unable to detect scoter broods in dense emergent vegetation near shore.

2.5.2 Plot-level pair and brood associations

Looking at scoter pair and brood associations provides a method to compare habitat that is used by scoters to habitat that presumably enables scoters to breed successfully. I found that very few wetlands had both pairs and broods of either species present but, at a plot level, white-winged scoter pair abundance may indicate that habitats occupied by pairs have the necessary resources to support successful breeding in all regions. One possible explanation is that breeding females select an area for nesting and brood-rearing that encompasses several wetlands. The landscape in all regions of my study area is dominated by many wetlands located close together (i.e. less than one kilometer). Mainland nesting scoters typically nest several hundred meters from water (Rawls 1949, S. Slattery,

DUC, pers. comm.) and if several wetlands are a similar distance from a nest, females may use more than one wetland for feeding during laying and incubation, or for brood-rearing later in the season. Additionally, more than one wetland may be necessary to fulfill potentially different dietary needs of nesting females and ducklings.

Therefore, scoter habitat selection may not always occur at the wetland level. The two-kilometer diameter plots used in this study may provide a better scale to investigate scoter habitat associations. Unfortunately, the small number of surf scoter broods detected in the two years of this study (Table 2.2) prevented me from drawing strong conclusions about abundance-habitat quality relationships for this species.

2.6 CONCLUSIONS

Remote-sensing tools such as Landsat imagery and aerial survey data can be used to delineate general patterns of habitat use by white-winged and surf scoters in the northern boreal forest. My findings suggest that, at a spatial scale broader than the wetland level, scoter pair density may accurately represent areas in which scoters breed successfully. However, classified land cover data alone did not provide evidence to suggest that forest fire induced changes to upland vegetation negatively affects the ability of scoters to breed successfully two years after a burn. Aerial survey data was sufficient to demonstrate a correlation between white-winged and surf scoter pair presence, indicating that inter-specific competition between these two species may not prevent them from utilizing habitat. This level of information is useful because it allows researchers to answer broad questions about habitat features of areas in which scoters breed successfully. Research in the northern boreal forest is logistically difficult and cost-prohibitive, so using remote tools to answer general questions and form more specific hypotheses may contribute to an understanding of reasons for these species long-term population declines.

CHAPTER 3: FINE-SCALE HABITAT SELECTION BY WHITE-WINGED AND SURF SCOTERS IN THE MACKENZIE DELTA REGION

3.1 INTRODUCTION

Food availability is known to limit the reproductive success of individuals and, as a result, constrain productivity and population size (Martin 1992). Scoter females apparently rely almost entirely on daily dietary sources (exogenous reserves) for egg production (Brown 1981, Dobush 1986, Brown and Fredrickson 1987), unlike females of most waterfowl species that make some use of endogenous reserves to meet high daily nutrient demands of reproduction (Alisauskas and Ankney 1992). Limited study of white-winged scoter dietary habits showed that amphipods were an extremely important food item for breeding adults and ducklings at lakes in central Saskatchewan (Brown and Fredrickson 1986). Brown (1981) and Brown and Fredrickson (1989) found that the largest decline in the number of scoter ducklings coincided with a period of maximum energy demand, suggests that ducklings may die because of an inability to balance high energy demands needed for thermoregulation against demands for growth and vigilance needed to escape predation. Such a high demand for energy may account for scoter duckling dependence on predictable, energy-rich food resources (Brown 1981, Brown and Fredrickson 1986, Brown and Fredrickson 1989). Thus, scoter pairs may exhibit a high level of habitat selectivity related to specific wetland features that offer efficient foraging for nutrient-rich foods during nesting and brood-rearing periods. Here, I evaluate this hypothesis by testing the prediction that wetlands on which scoters settle and breed successfully will be more productive (i.e. higher concentrations of nutrients) and have greater abundance of amphipods than non-used wetlands.

Changes in concentrations of nutrients and water colour in wetlands occur after forest fire due to runoff from the burned watershed (Schindler et al. 1980) or through direct deposition of smoke and ash (Spenser and Hauer 1991). If such fire-related changes in turn affect amphipod abundance or reduce foraging efficiency, scoters may be unable to sequester adequate food to breed or raise broods. However, very little is known about responses of aquatic organisms or waterfowl to changes in northern boreal wetlands following forest fire (McEachern et al. 2001). Therefore, I also compared fine-scale characteristics of burned and unburned upland wetlands and looked at factors that might affect amphipod abundance in these wetlands.

3.2 Methods

A description of the study area, methods, and collection of aerial survey data is provided in Chapter 2.

3.2.1 Fine-scale wetland habitat characteristics

Using a float-equipped helicopter, I revisited a random sub-set of wetlands, used by pairs, used by broods, and not used, by each species (Table 3.1) in mid-August of both years to acquire data regarding wetland characteristics. In 2001, wetlands in the delta and unburned upland regions were sampled. In 2002, I expanded my investigation to include wetlands from burned upland as well as unburned upland and delta regions. At each wetland, I measured conductivity (μmho) using a portable meter and collected a surface water sample (250 ml taken from ca. 10 cm below the surface) which was kept in a cooler in the helicopter and transferred to a refrigerator at the end of each day. When water samples had been collected (< 5 days) they were packaged in a cooler and transported by air to the University of Alberta Limnology Laboratory. Water samples were analyzed for concentrations of total phosphorus and total nitrogen ($\mu\text{g/L}$) in both years, and for dissolved oxygen concentration (mg/L) and water colour (mg/L pt) in 2002.

Table 3.1. Number of sampled wetlands in each region occupied and not occupied by white-winged and surf scoter pairs and broods by year.

Year	Region	Total # wetlands sampled	# Wetlands occupied by				# Wetlands not occupied by either species
			White-winged scoter Pairs	White-winged scoter Broods	Surf scoter Pairs	Surf scoter Broods	
2001	Delta	17	7	11	6	4	2
	Unburned Upland	20	15	8	9	6	4
2002	Delta	22	6	4	5	0	12
	Unburned Upland	22	11	3	8	2	10
	Burned Upland	13	7	4	7	1	4

To determine amphipod abundance, I sampled each wetland in 5 locations (safe landing positions chosen by the pilot and located more-or-less systematically across the entire wetland) from the float of the helicopter using a D-frame aquatic net (0.3m base, 49 holes/cm²). Sweep sampling was conducted by pushing the flat opening of the net through the water column to a depth of 0.5 to 1.0 m, sweeping through the water parallel to the surface for 1.0 – 1.5 m, and then drawing the net to the surface. In 2001, I sweep-sampled at each location to a maximum of 10 times or until amphipods were detected at each location. After each sweep, I carefully inspected the net and if amphipods were detected I recorded the number present. Numbers of amphipods detected in 2001 were highly variable within and among wetlands, so an index of relative abundance of amphipods was developed based on the number of sweeps conducted before detecting amphipods and the number of amphipods detected in that sweep. If the total number of sweeps was > 31 and the total number of amphipods detected was < 5, the relative abundance of amphipods in the wetland was categorized as “low”. If the total number of sweeps was < 20 and the total number of amphipods detected was > 10, the relative abundance of amphipods in the wetland was categorized as “high”. The relative abundance of amphipods in all other wetlands was categorized as “moderate”. This index of relative abundance of amphipods was used in all 2001 analyses.

In 2002, I changed the amphipod sampling protocol to a more quantitative method I thought would provide more detailed information about amphipod abundance than the index of relative abundance used in 2001. I sampled 10 times at each location (50 sweeps per wetland) and after *each* sweep I recorded the number of amphipods captured in the net and collected them in ziplock bags (1 bag for each wetland). Amphipods collected from each wetland were then oven dried to constant mass at 60° C. Total number of amphipods captured per wetland (total amphipod count) and total amphipod biomass based on dry weight (g) of the total amphipod count (amphipod biomass) were used in 2002 analyses.

3.2.2 Data analyses

All statistical tests were executed using SAS software (SAS Institute Inc. 1987). Separate analyses were conducted on data collected in 2001 (n = 37 wetlands) and 2002 (n = 62 wetlands) because samples, measured variables, and methods were modified in 2002. Total phosphorus, total nitrogen, dissolved oxygen, water colour, total amphipod count, and amphipod biomass were log transformed and conductivity was square root transformed to improve normality prior to conducting analyses.

I used regression techniques and model selection methods (see Chapter 2) to evaluate fine-scale factors correlated with white-winged scoter pair density, and presence of white-winged scoter broods and surf scoter pairs, separately for 2001 and 2002. Total phosphorus, total nitrogen, conductivity, and relative abundance of amphipods were included as covariates in 2001 candidate models. Covariates in candidate models for 2002 included total phosphorus, total nitrogen, dissolved oxygen concentration, water color, total amphipod count, and amphipod biomass. As described in Chapter 2, wetland area was included as an offset variable to derive density in all white-winged scoter pair analyses.

To test the assumption that higher wetland productivity results in greater availability of scoter food, I used multiple regression and model selection techniques (PROC GENMOD) to determine which wetland variables most influenced total amphipod count per wetland and amphipod biomass in 2002. For both total number of amphipods and amphipod biomass I compared 17 candidate models which included the global model (total nitrogen, total phosphorus, conductivity, dissolved oxygen, and water colour), all two-way combinations, all individual covariates, and the null model.

To determine why differences in scoter density or occupancy on wetlands might exist between regions I conducted a multivariate analysis of variance (MANOVA; PROC GLM) to test for regional differences in values of fine-scale habitat characteristics each year. I compared means and 95% confidence limits of

transformed data for each habitat variable to determine where regional differences occurred.

To evaluate factors correlated with white-winged scoter pair density in 2001, I began with a suite of seven *a priori* models but because so little is known about scoter ecology, I expanded this set to include 15 models which explored correlations between covariates and white-winged scoter pair density that became apparent after the first seven models were analyzed. For 2002 data I began with a suite of eight *a priori* models and expanded this to a total of 23. My investigations of white-winged scoter brood and surf scoter pair occurrence were both evaluated initially with a suite of eight *a priori* models and expanded to explore correlations that became apparent through analysis of the *a priori* set (totals of 15 models in 2001 and 19 models in 2002 for white-winged scoter broods, and 14 models in 2001 and 25 models in 2002 for surf scoter pairs). As noted in Chapter 2, the low number of wetlands occupied by surf scoter broods prevented further analysis.

3.3 RESULTS

3.3.1 Amphipod – water chemistry associations

The global model best described factors associated with both total amphipod count (Table 3.2) and amphipod biomass (Table 3.3); however, effects of all covariates contained in these models were not supported by the data. Total nitrogen had very high summed weights in both the total amphipod count ($\Sigma w = 1.00$) and amphipod biomass ($\Sigma w = 0.99$) candidate sets which suggests strong support for positive correlations with total nitrogen (total amphipod count: $\beta = 2.71$, 95% CI = 1.13 to 4.29; amphipod biomass: $\beta = 0.20$, 95% CI = 0.06 to 0.34). There was also strong support for higher conductivity levels in both candidate sets of models (total amphipod count, $\Sigma w = 0.98$, $\beta = 0.23$, 95% CI = 0.04 to 0.39; amphipod biomass $\Sigma w = 1.00$, $\beta = 0.03$, 95% CI = 0.02 to 0.05).

Effects of total phosphorus, dissolved oxygen, and water colour were not strongly supported for total amphipod count (all $\Sigma w = 0.56$) or amphipod biomass (all $\Sigma w = 0.63$).

Table 3.2. Five highest ranking and null models used to describe relationships between water chemistry variables and total amphipod count based on 57 wetlands sub-sampled in 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta\text{AIC}_c = 0$).

Model ^a	ΔAIC_c^b	w_i^c	K ^d	Deviance ^e
TN, TP, Cond, DO, Colour	0	0.60	6	0
TN, Cond	0.89	0.38	3	8.12
TN, Colour	8.58	0.01	3	15.81
TN, DOC	9.10	0.01	3	16.34
TN	10.30	0.003	2	19.76
Null	30.37	0	1	41.97

^a Model factors included: TN = total nitrogen; TP = total phosphorus; Cond = conductivity; DO = dissolved oxygen; Colour = water colour.

^b Difference between the AIC_c value of the model in question to the most parsimonious model ($\Delta\text{AIC}_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

Table 3.3. Five highest ranking and null models used to describe relationships between water chemistry variables and amphipod biomass based on 57 wetlands sub-sampled in 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta\text{AIC}_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
TN, TP, Cond, DO, Colour	0	0.66	6	0
TN, Cond	1.39	0.33	3	8.61
TP, Cond	9.82	0.004	3	17.05
Cond, DO	11.34	0.002	3	18.57
Cond, Colour	15.80	0	3	23.03
Null	27.41	0	1	39.02

^a Model factors included: TN = total nitrogen; TP = total phosphorus; Cond = conductivity; DO = dissolved oxygen; Colour = water colour.

^b Difference between the AIC_c value of the model in question to the most parsimonious model ($\Delta\text{AIC}_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

3.3.2 Regional differences in fine-scale wetland characteristics

There were no regional differences detected in fine-scale habitat characteristics in 2001 (Wilks' Lambda = 0.75, $P = 0.53$) (Table 3.4). In 2002, differences were detected (Wilks' Lambda = 10.34, $P < 0.001$) in total nitrogen and dissolved oxygen (Table 3.4) but neither of these differences were between wetlands in the burned and unburned upland regions.

3.3.3 Scoter-wetland associations

3.3.3.1 White-winged scoter pair density

In both 2001 and 2002 there was strong support for my prediction that white-winged scoter pair density would be higher on wetlands with more amphipods. Relative amphipod abundance was included in the only model with $\Delta AIC_c < 2$ in 2001 (Table 3.5) and total amphipod count was contained in all models in the 2002 candidate set with $\Delta AIC_c < 2$ (Table 3.6). Both measures of amphipod abundance also had strong support based on $\Sigma w = 1.00$ for each. Parameter estimates for the most parsimonious model in the 2001 candidate set were positive for wetlands with high relative abundance of amphipods ($\beta = 0.94$, 95% CI = 0.58 to 1.29) and negative for wetlands with low relative abundance of amphipods ($\beta = -0.84$, 95% CI = -1.32 to -0.35) compared to wetlands with moderate relative abundance of amphipods. In 2002, wetlands with higher total amphipod counts had greater white-winged scoter pair densities ($\beta = 0.52$, 95% CI = 0.38 to 0.66). There was also strong support in 2002 for a negative effect of amphipod biomass on white-winged scoter pair density ($\beta = -2.04$, 95% CI = -3.21 to -0.86) as this covariate was present in all models with $\Delta AIC_c < 2$ and it had high summed weight ($\Sigma w = 0.98$) (Table 3.6).

Total phosphorus and total nitrogen concentrations were present in the only model in the 2001 candidate set with $\Delta AIC_c < 2$ (Table 3.5), and had summed weights of 1.00 and 0.75 respectively. Parameter estimates for these covariates suggest that white-winged scoter pair density may have been lower on wetlands with higher total phosphorus concentrations ($\beta = -1.76$, 95% CI = -2.17 to -1.34)

Table 3.4. Medians and 10% - 90% ranges of fine-scale habitat data for sampled wetlands in 2001 and 2002, by region.

Habitat Characteristic	Year	Delta	Burned Upland	Unburned Upland
Total Phosphorus ($\mu\text{g/L}$)	2001	14.10; 10.50 – 23.00	N/A	14.20; 7.90 – 29.15
	2002	17.20; 12.90 – 22.10	13.60; 11.00 – 19.10	19.75; 14.10 – 29.60
Total Nitrogen ($\mu\text{g/L}$)	2001	2224.07; 855.92 – 11,111.36	N/A	3288.21; 1623.03 – 12736.53
	2002	474.99; 363.20 – 632.32	952.87; 660.69 – 1406.31	1031.95; 752.22 – 1511.99
Total Nitrogen : Total Phosphorus Ratio	2001	148.72; 40.26 – 707.73	N/A	200.24; 80.10 – 1466.28
	2002	28.45; 18.58 – 37.87	47.09; 26.94 – 88.48	73.63; 44.25 – 90.08
Conductivity (μmho)	2001	135; 92 - 230	N/A	124; 55 - 205
	2002	150; 110 - 230	180; 45 - 230	93; 40 - 205
Dissolved Oxygen (mg/L)	2002	12.32; 10.53 – 19.09	20.93; 17.98 – 38.11	24.84; 19.45 – 30.73
Water Colour (mg/L Pt)	2002	26.75; 22.40 – 35.10	25.50; 15.50 – 81.60	41.60; 21.20 – 124.10
Total Number of Amphipods	2002	1; 0 - 36	2; 0 - 319	31; 0 - 218
Amphipod Biomass (g)	2002	0.01; 0 – 0.68	0.02; 0 – 0.50	0.09; 0 – 0.31

Table 3.5. Five highest ranking and null models used to describe relationships between wetland habitat features and white-winged scoter pair density for 37 wetlands sampled in 2001. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
TP, TN, Agroup	0	0.56	5	0.73
Cond, TP, TN, Agroup	2.13	0.19	6	0
TP, Agroup	2.73	0.14	4	6.16
Cond, TP, Agroup	3.34	0.11	5	4.08
TP, Cond	28.49	0	3	34.44
Null	74.20	0	1	82.18

^a Model factors included: SI = shoreline irregularity index; TP = total phosphorus; TN = total nitrogen; Agroup = relative abundance of amphipods; Region = delta or unburned upland.

^b Difference between the AIC_c value of the model in question and the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC_c was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

Table 3.6. Five highest ranking and null models used to describe relationships between wetland habitat features and white-winged scoter pair density for 57 wetlands sampled in 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta\text{AIC}_c = 0$).

Model ^a	ΔAIC_c^b	w_i^c	K ^d	Deviance ^e
DO, Cond, Tamph, Bamph	0	0.25	5	5.66
DO, Tamph, Bamph	0.45	0.20	4	8.52
TN, DO, Tamph, Bamph	1.40	0.12	5	7.07
TN, DO, Cond, Tamph, Bamph	1.44	0.12	6	4.60
DO, Colour, Tamph, Bamph	2.09	0.09	5	7.75
Null	51.64	0	1	66.41

^a Model factors included: Region = delta, burned upland, or unburned upland; SI = shoreline irregularity index; Colour = water colour; DO = dissolved oxygen; Tamph = total amphipod count; Bamph = amphipod biomass; Cond = conductivity; TP = total phosphorus; TN = total nitrogen.

^b Difference between the AIC_c value of the model in question and the most parsimonious model ($\Delta\text{AIC}_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models sums to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

and higher on wetlands with higher total nitrogen concentrations ($\beta = 0.26$, 95% CI = 0.04 to 0.47). Total nitrogen was present in two of the models in the 2002 candidate set with $\Delta AIC_c < 2$ (Table 3.6), but had low summed weight ($\Sigma w = 0.36$). Likewise, total phosphorus concentration had a low summed weight ($\Sigma w = 0.18$) in 2002 indicating that there was little support for the effect of total nitrogen or total phosphorus on white-winged scoter pair density.

Dissolved oxygen concentration was included in all four models with $\Delta AIC_c < 2$ (Table 3.6) in 2002 and had high summed model weight ($\Sigma w = 0.94$) providing strong support for a negative effect ($\beta = -1.30$, 95% CI = -2.11 to -0.49) on white-winged scoter pair density. The effect of conductivity on white-winged scoter pair density was not well supported by the data in either year (2001: $\Sigma w = 0.30$; 2002: $\Sigma w = 0.48$) and there was no support for the effect of water colour in 2002 ($\Sigma w = 0.21$).

3.3.3.2 White-winged scoter brood occurrence

None of the covariates I included in the 2001 candidate set of models describing white-winged scoter brood occurrence was well supported by the data (Table 3.7). Summed model weights ranged from 0.21 for relative abundance of amphipods to 0.31 for conductivity. The null model was the most parsimonious model in the candidate set.

In 2002 there was strong support ($\Sigma w = 0.97$) for a negative effect of water colour ($\beta = -3.60$, 95% CI = -6.39 to -0.81) on white-winged scoter brood occurrence suggesting that broods are more likely to occur on clearer wetlands. A positive effect of total phosphorus ($\beta = 5.31$, 95% CI = 0.98 to 9.65) was also supported by a high summed model weight ($\Sigma w = 0.95$) indicating that white-winged scoter broods were more likely to occur on wetlands with higher total phosphorus concentrations. Total amphipod count and amphipod biomass were present as covariates in three of the four models with $\Delta AIC_c < 2$ in 2002 (Table 3.8). Summed model weights of 0.73 and 0.78, respectively, provided support for white-winged scoter broods occupying wetlands with more abundant amphipods

Table 3.7. Five highest ranking models used to describe relationships between wetland habitat features and white-winged scoter brood occurrence for 37 wetlands sampled in 2001. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
Null	0	0.28	1	3.96
Cond	0.87	0.17	2	2.60
TP	2.07	0.10	2	3.79
TN	2.23	0.09	2	3.95
Agroup	2.58	0.08	3	1.93

^a Model factors included: Area = wetland area; SI = shoreline irregularity index; Region = delta, burned upland, or unburned upland; TP = total phosphorus.

^b Difference between the AIC_c value of the model in question and the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

Table 3.8. Five highest ranking and null models used to describe relationships between wetland habitat features and white-winged scoter brood occurrence for 57 wetlands sampled in 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
TP, Colour, Tamph, Bamph	0	0.25	5	2.16
TP, DO, Colour, Tamph, Bamph	0.66	0.18	7	0.32
TP, Colour	1.47	0.12	3	8.36
TP, Colour, Tamph	2.09	0.09	4	6.66
TP, TN, DO, Colour, Tamph, Bamph	3.00	0.05	7	0.05
Null	8.67	0	1	19.94

^a Model factors included: Area = wetland area; Region = delta, burned upland, or unburned upland; SI = shoreline irregularity index; Tamph = total amphipod count; Bamph = amphipod biomass; TP = total phosphorus; DO = dissolved oxygen.

^b Difference between the AIC_c value of the model in question and the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

(total amphipod count: $\beta = 0.96$, 95% CI = 0.12 to 1.81) and lower amphipod biomass ($\beta = -10.48$, 95% CI = -21.96 to 0.99). There was very little support for associations of dissolved oxygen concentration, total nitrogen concentration, or conductivity with white-winged scoter brood occurrence in 2002, with all $\Sigma w < 0.35$.

3.3.3.3 Surf scoter pair occurrence

No fine-scale habitat characteristics appeared to strongly affect surf scoter pair occurrence in 2001. The null model was the most parsimonious model in the 2001 candidate set and was the only model with $\Delta AIC_c < 2$ (Table 3.9). No covariate had a $\Sigma w > 0.25$ in 2001.

There was some support for effects of water colour and conductivity on surf scoter pair occurrence in 2002 ($\Sigma w = 0.78$ and $\Sigma w = 0.70$, respectively). The parameter estimates in the most parsimonious model for 2002 (Table 3.10) suggest surf scoter pairs are more likely to occur on clearer wetlands ($\beta = -1.56$, 95% CI = -2.93 to -0.18) with lower conductivity ($\beta = -0.41$, 95% CI = -0.75 to -0.06).

3.4 DISCUSSION

In general, white-winged scoter pair density was higher on wetlands with more abundant amphipods, and such wetlands also had a greater probability of being used by broods. This indicates that, as with many other species of waterfowl, the abundance and distribution of scoters may be linked to the availability of invertebrate prey (e.g. Nummi et al. 1994, Nummi and Pöysä 1995, Lindeman and Clark 1999, Pöysä et al. 2000, Elmberg et al. 2003). However, I was unable to detect any correlation between surf scoter pair occurrence and amphipod covariates in either year. I measured amphipod biomass, reasoning that it might be a good indicator of the amount of food available to scoters, so I was surprised by the negative correlation with both white-winged scoter pair density and brood occurrence. However, in my study, the biomass of one large amphipod sometimes equaled the biomass of up to 100 very small ones. Brown and Fredrickson (1986)

Table 3.9. Five highest ranking models used to describe relationships between wetland habitat features and surf scoter pair occurrence for 37 wetlands sub-sampled in 2001. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
Null	0	0.41	1	0.42
TN	2.01	0.15	2	0.20
TP	2.09	0.15	2	0.27
Cond	2.23	0.14	2	0.41
TP, TN	4.31	0.05	4	0.12

^a Model factors included: Area = wetland area; Cond = conductivity; TP = total phosphorus; SI = shoreline irregularity index; Region = delta, burned upland, or unburned upland.

^b Difference between the AIC_c value of the model in question and the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

Table 3.10. Five highest ranking and null models used to describe relationships between wetland habitat features and surf scoter pair occurrence for 57 wetlands sub-sampled in 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d	Deviance ^e
Cond, Colour, Bamph	0	0.24	4	3.28
Cond, Colour, Tamph	0.68	0.17	4	3.96
Cond, Colour	1.55	0.11	3	7.15
Null	1.98	0.09	1	11.96
Colour	2.55	0.07	2	10.38

^a Model factors included: Area = wetland area; Tamph = total amphipod count; Bamph = amphipod biomass; Cond = conductivity; DO = dissolved oxygen.

^b Difference between the AIC_c value of the model in question and the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters estimated in the model. Error term was accounted for as AIC was calculated using maximum likelihood estimates.

^e Difference between the -2 log likelihood of the model in question and the full model.

found that the mass of individual amphipods consumed by ducklings was less than the mass of those consumed by adults. Therefore, hens with broods may prefer wetlands with abundant, smaller-sized amphipods, possibly because this prey base provides more profitable foraging.

Wetlands with higher total amphipod counts and higher amphipod biomass also had higher total nitrogen concentrations, but evidence for the importance of higher concentrations of total phosphorus was weaker. This partially supports my prediction that wetlands with more abundant amphipods would also be more productive.

Several studies have documented the importance of wetland productivity for wetland selection by waterfowl (eg. Merendino et al. 1993, Merendino and Ankney 1994, Staicer et al. 1994, Paquette and Ankney 1996, Sjöberg et al. 2000), so I predicted that I would see similar relationships between wetland productivity and scoter use. In 2001, I found a positive correlation between white-winged scoter pair density and total nitrogen concentration but white-winged scoter pairs occurred at *lower* densities on wetlands with higher concentrations of total phosphorus. No correlation existed between white-winged scoter pair density and total nitrogen or total phosphorus in 2002 and no correlation was detected between surf scoter pair occurrence and wetland productivity covariates in either year. One possible explanation is that number of lakes sampled and occupied by surf scoters (Table 3.11) was too small to detect a correlation. However, the studies mentioned above reporting a correlation between wetland use by waterfowl and wetland productivity (as indicated by concentrations of total phosphorus) all focused on dabbling duck species, and with the exception of Sjöberg et al. (2000) none was conducted in the boreal forest. Total phosphorus concentrations in the wetlands I sampled were among the lowest reported (Table 3.4) and almost all total nitrogen to total phosphorus ratios were greater than 20:1, indicating severe phosphorus limitation (Wetzel 2001). This and the lack of a strong correlation between total phosphorus concentration and amphipod abundance in my study may suggest that phosphorus is

Table 3.11. Total phosphorus concentrations of wetlands reported in studies correlating waterfowl use and wetland productivity.

Author	Location	Total Phosphorus Concentration (mg/L)			
Merendino and Ankney (1994) ¹	Central Ontario	Used by Mallard mean = 0.04 SE = 0.002 n = 172	Used by Black Ducks mean = 0.003 SE = 0.003 n = 129	Used by Both Species mean = 0.03 SE = 0.003 n = 90	Not Used by Either Species mean = 0.03 SE = 0.002 n = 56
Stacier et al. (1994) ²	Nova Scotia	Used by Black Duck broods median = 0.14 n = 8		Not Used by Black Duck broods median = 0.007 n = 9	
Paquette and Ankney (1996) ³	South-Central British Columbia	Used by Green-winged Teal mean = 1.48 SE = 0.39 n = 49		Not Used by Green-winged Teal mean = 0.54 SE = 0.11 n = 47	
Seymour and Jackson (1996) ⁴	Nova Scotia	Used by Black Duck broods minimum of 0.005 – greater than 0.2			

¹ Contrast wetlands used by mallards, black ducks, both species, and neither species

² Contrast wetlands used and not used by black duck broods

³ Contrast wetlands used and not used by green-winged teal

⁴ Describe wetlands used by black duck broods

Table 3.11 continued. Total phosphorus concentrations of wetlands reported in studies correlating waterfowl use and wetland productivity.

Author	Location	Total Phosphorus Concentration (mg/L)	
Sjöberg et al. (2000) ⁵	North-Central Sweden	“Rich” ⁶ 0.019 – 0.030	“Poor” ¹ 0.008 – 0.018
Present Study ⁷ (Haszard unpubl. data)	Northwest Territories	Used by Scoters median = 0.015 10% - 90% range: 0.009 – 0.027 n = 60	Not Used by Scoters median = 0.017 10% - 90% range: 0.012 – 0.027 n = 32

⁵ Contrast wetlands with and without breeding mallards and broods

⁶ “Rich” and “Poor” are relative terms used in the study to separate wetlands into two groups by their total phosphorus concentrations.

⁷ Contrast wetlands used and not used by white-winged and surf scoters

limiting in *all* wetlands in my study area, making it difficult to detect a correlation between either amphipods or scoter pairs.

However, white-winged scoter broods were found more frequently on wetlands with higher concentrations of total phosphorus. Perhaps broods are cueing into a factor I did not measure that is sensitive to wetland productivity, or perhaps my measured indices of scoter invertebrate prey (amphipod abundance and biomass) were insufficient to capture a strong relationship between scoter food abundance and wetland productivity.

All sampled wetlands had a dissolved oxygen concentration > 6.5 mg/L, the minimum level deemed necessary to sustain aquatic life (Canadian Council of Ministers of the Environment 1999), and therefore should not limit the survival of amphipods. I found very little evidence for correlations between dissolved oxygen concentration and total amphipod count or amphipod biomass, so it follows that it would not have a strong positive correlation with scoter density or wetland occupancy. More productive wetlands may actually have lower levels of dissolved oxygen (but > 6.5 mg/L) if oxygen loss is attributed to bacterial, plant, and/or animal respiration (Wetzel 2001), and this may help to explain the negative correlation with white-winged scoter pair density.

I found no correlations between water colour and amphipod abundance or biomass, but my results indicate that clearer wetlands are more likely to be used by white-winged scoter broods and surf scoter pairs. Surf scoters in Québec breed more frequently on clear wetlands (Savard et al. 1998); presumably scoters may be more successful foraging in wetlands with better underwater visibility, particularly ducklings, but I am unable to explain why I did not detect a similar correlation with white-winged scoter pair density.

There have been few studies documenting impacts of forest fire on wetlands in the western portion of the boreal forest. One such study (McEachern et al. 2001) documented light limitation due to increased water colour and elevated nutrient concentrations. The forest fire in my study area was intense and large, burning most of the soil and vegetation in the area, so I had expected that nutrient levels and

water chemistry would vary between wetlands surrounded by the burned area and those not. However, I did not detect differences in any of the fine-scale habitat characteristics I measured. Some of the wetlands I sampled in 2001 had what I perceived to be very high concentrations of total nitrogen (Table 3.11), but none of these was surrounded by burned vegetation. An overall lack of variation in nutrient levels and water chemistry throughout my study area may have resulted in no differences in measured variables between burned and unburned wetland being detected. Alternatively, the forest fire in my study area may not have affected any of the variables I measured or effects may have receded within two years of the fire.

I was unable to draw any conclusions about correlates of white-winged brood or surf scoter pair occurrence in 2001 because none of my candidate models was well supported by the data. In 2001, I measured only four variables and sampled 37 wetlands and this was insufficient to capture enough variation between wetlands used and not used by white-winged scoter broods or surf scoter pairs.

3.5 CONCLUSIONS

Many studies examining habitat selection in waterfowl have documented food availability as a major factor influencing wetland choice by pairs and brooding hens (Nummi et al. 1994, Nummi and Pöysä 1995, Lindeman and Clark 1999, Pöysä et al. 2000, Elmberg et al. 2003). Likewise, in my study area, amphipod abundance was a correlate of white-winged scoter pair distribution and abundance. I had also set out to document evidence suggesting that availability of invertebrate prey is indicative of wetland productivity and, as such, correlations should exist between indices of wetland productivity and wetland use by scoters. However, I was unable to detect consistent correlations between either of my measured indices of wetland productivity and scoter pair *and* brood use. Additionally, a substantial amount of model uncertainty and unexplained variation exists in my results indicating that the fine-scale habitat features I measured do not accurately reflect biological reasons contributing to scoter habitat selection in my study area. This, and my inability to detect differences in habitat features between burned and

unburned wetlands, could be in part due to low variability among wetlands in my study area.

Further research is needed to learn more about relationships between scoter pairs and broods and invertebrate prey, and whether abundance of invertebrate prey is affected by habitat disturbance such as forest fire. More frequent invertebrate and water sampling would allow documentation of possible relationships throughout the open water season. Repeated sampling of water chemistry and wetland productivity parameters in burned and unburned wetlands prior to, and for several years post-burn, would enable researchers to more directly draw inferences about the affect of fire on wetland systems and determine how long such effects persist.

CHAPTER 4: SYNTHESIS

White-winged and surf scoters have shown apparent declining population trends since the 1970s; these patterns mirror those of several other boreal-nesting waterfowl species (S. Slattery, DUC, pers. comm., U. S. Fish and Wildlife Service unpubl. data). During the breeding season these species share wetland and upland habitats, whereas most have different wintering areas. Thus, focusing on breeding areas seems justified. Very few studies have been conducted on boreal-nesting waterfowl species to determine breeding season factors responsible for these widespread trends. As a result, reasons for these declines are not well understood. One breeding season hypothesis suggests that habitat changes due to climate warming or increased forest fire frequency could adversely affect upland nesting habitats or key food sources on which breeding females and their broods depend thus resulting in lower recruitment or productivity. An understanding of habitat features needed by ducks in the boreal forest to breed and raise offspring successfully will contribute to a better understanding of their population processes and may aid development of appropriate conservation measures to mitigate these declining trends. This study began to work towards achieving these goals by determining habitat associations of breeding white-winged and surf scoters at two spatial scales in part of their core breeding range. I characterized biotic and abiotic features of wetlands used by pairs and broods of these species and then contrasted these patterns in areas burned in a recent forest fire.

In the vast and largely inaccessible northern boreal forest, it is difficult and expensive to conduct ground-based research necessary to demonstrate that individuals have a full range of habitats to choose from (i.e. Johnson 1980, Martin 1998), or that features of occupied habitats positively influence breeding success (i.e. Hutto 1985, Martin 1992), thereby demonstrating that the process of habitat selection is taking place. Therefore, in Chapter 2, I investigated whether I could

determine coarse-scale habitat characteristics of areas used by scoter pairs and broods using Landsat imagery and aerial survey data. Although this scale of study does not allow documentation of specific habitat features influencing habitat selection, it offers a good starting point to answer general questions about habitat associations. In this chapter, I found that numbers of white-winged scoter pairs and broods were correlated at the two-kilometer diameter plot-level. This is consistent with the notion that breeding pair density is a suitable index of habitat quality. Coarse-scale plot-level vegetation characteristics suggested that scoter pairs and broods settled more frequently on wetlands not immediately surrounded by burned upland vegetation in 2001, two years post-burn. In 2002, I found no difference. White-winged and surf scoters consistently co-occurred on wetlands, indicating that competition for resources between these two species did not prevent them from settling on the same wetlands and gives reason to question whether heterospecific attraction may influence these species' co-occurrence (Stamps 1988, Elmberg et al. 1997). I did not detect any evidence to support my prediction that female scoters would settle on wetlands with irregular shorelines offering protection for ducklings.

In Chapter 3, I investigated fine-scale correlates of scoter pair and brood habitat use at the wetland level. Based on other studies of waterfowl habitat associations, I predicted that scoters would settle on wetlands with higher amphipod abundance (Brown and Fredrickson 1986, Sedinger 1992, Cooper and Anderson 1996, Cox et al. 1998) and that these wetlands would be more productive as indicated by higher nutrient levels (Merendino et al. 1993, Merendino and Ankney 1994, Staicer et al. 1994, Paquette and Ankney 1996, Sjöberg et al. 2000). I also wanted to determine if coarse-scale patterns of habitat use documented in Chapter 2 relating to forest fire could be further explained by differences in nutrient levels, water quality, or food abundance by comparing these fine-scale characteristics between burned and unburned wetlands. Consistent with previous studies, I found that white-winged scoter pairs and broods tended to use wetlands with more abundant amphipods. I did find some correlations between wetland use by scoter pairs and broods and indices of wetland productivity, but these were

inconsistent. I also found evidence to indicate that phosphorus may be limiting in wetlands in my study area. I did not find any difference in the food abundance, nutrient level, or water quality variables I measured between burned and unburned uplands in 2002, three years post-fire. This was surprising, but is consistent with my coarse-scale findings in Chapter 2; no negative association between scoter habitat use and plot-level vegetation characteristics was detected in the burned area in 2002.

This study had several limitations. First, it is unrealistic to assume that I was able to measure, or even identify, all of the abiotic and biotic variables potentially influencing habitat selection by scoters. In Chapter 2, I limited my investigation to coarse-scale variables obtained from aerial surveys and Landsat imagery. Although these variables did allow me to characterize general habitat associations and patterns of habitat use, they were measured at too coarse of a scale to draw many inferences about specific features or processes affecting habitat choice or individual fitness. In Chapter 3, I measured very few fine-scale habitat variables that other studies had found influenced habitat selection or habitat use by waterfowl. Most of these studies researched different waterfowl species in much different habitat types and it is unlikely that scoter habitat selection or use in the northern boreal forest would be similarly influenced. Therefore, models used in this study and the subsequent results are heavily influenced by my choice of variables and may not accurately reflect scoter habitat associations or true biological relationships.

Also, as discussed in Appendix A, I know that I incorrectly classified approximately 10% of wetlands on which scoter pairs were present, but not detected during aerial surveys, as being “unused”. This will have somewhat affected the results of the presence/absence and the density based habitat association modeling used in both data chapters.

This was a first attempt to determine whether coarse-scale habitat features can be used to determine habitat selection processes by white-winged and surf scoters, two species for which there is very little documented information in the core portion of their breeding range. This lack of information is at least partially a

result of research in the northern boreal forest being logistically difficult and cost-prohibitive. Therefore, it was important to explore the feasibility of using Landsat imagery to identify characteristics of habitat used by scoters. Also, to my knowledge, this is one of the largest studies on scoters, amphipods, and fine-scale habitat features in burned and unburned wetlands in the northern boreal forest. Although results from this study should not be over-interpreted, they may provide information needed to begin to develop conservation programs for these species.

Because the northern boreal forest is likely to experience intense industrial development activity due to oil and gas exploration and extraction, and diamond mining over the next decade, it may be necessary to implement conservation programs before reasons for scoter population declines are well understood. In the short-term, land managers and biologists may wish to protect or monitor wetland complexes in my study area where scoters occurred in higher densities to ensure that they are not adversely affected by industrial development. During the course of my study, the Cardinal Lakes area in the upland region east of the delta was used by higher numbers of scoter pairs than any other area I surveyed. The Gwich'in people have long identified this area as being important for scoters and other breeding waterfowl and as such have included it as a "Special Management Zone" in their Land Use Plan (Gwich'in Land Use Planning Board 2003). DUC has established a research program investigating scoter population dynamics and habitat requirements in the Cardinal Lakes area because they believe this area currently provides the best opportunity to conduct scoter research in the northern boreal forest (S. Slattery, pers. comm.). For these reasons, I recommend protecting the Cardinal Lakes Special Management Zone from any development activities that might degraded the habitat, until researchers learn more about scoter habitat requirements and population dynamics in the northern boreal forest.

Any new information that contributes to a better understanding of scoter habitat requirements and population processes will help develop conservation initiatives and inform managers making land use decisions and attempting to find a balance between capitalizing on industrial development opportunities and

maintaining a viable ecosystem. Besides the urgency to conduct research on scoters in their northern breeding range because of imminent intense industrial development activity in this region, there are two other main reasons to focus future research on scoters on the northern boreal forest. First, this region makes up the core breeding range for most of the combined continental scoter population (Bellrose 1980, U.S. Fish and Wildlife Service unpubl. data). Most information presently available about scoters comes from the southern portion of their breeding range, in the prairie-parkland region of Canada for white-winged scoters and in Québec for surf scoters. Although this information provides a good basis for research in the northern boreal forest, it is not known how applicable it is to scoter populations breeding further north. Second, it is in the northern boreal region that most of the long-term decline in the combined scoter population has occurred. This region has not experienced the same type of habitat loss and alteration as the prairie-parkland region of Canada, so reasons for long-term declines in the northern boreal forest may be unrelated to southern scoter population declines.

There are still many more unanswered questions than answered about scoters breeding in the northern boreal forest. Basic information about both of these species and the habitat itself is needed before we will understand factors limiting their population growth. An important next step to this study is to determine whether information about scoter distribution and habitat features in areas used by scoters can be used to predict areas where scoters may occur in high densities in other parts of the northern boreal forest so that those areas may also be managed appropriately.

In my study, I suggest that female scoters may use more than one wetland during the laying, incubation, and brood rearing period. I believe that investigating scoter home range size would allow future research on scoter habitat selection to focus at a scale known to be biologically important to female breeding scoters. Ongoing research about scoter upland nesting habitat and factors limiting nest success in the northern boreal forest is important and may add valuable information about micro-habitat features needed to support successful reproduction.

My study only looked for associations between scoters and amphipod abundance and did not consider that scoter may rely on food sources other than amphipods. Therefore, more information is required about food sources of breeding females and broods and whether they rely almost exclusively on amphipods or if they also depend on other aquatic invertebrates. It is also necessary to learn about the spatial and temporal distribution and abundance of scoter food sources in northern wetlands and whether such variation influences scoter distribution.

During the course of my investigation, it became clear to me that very little is known about wetlands in the northern boreal forest. Basic information about boreal wetland limnology and boreal forest hydrology would contribute to a greater overall understanding of the northern boreal ecosystem. Also needed is more information about fire ecology in the northern boreal forest and a better understanding of the short and long-term impacts of forest fire on wetland systems and hydrology. Stratifying study plots by burn class in future investigations may provide useful information in future studies about the effect of fire as a dynamic force on the landscape.

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APPENDIX A: ASSESSING WETLAND USE BY SCOTERS

A.1 INTRODUCTION

The ability to accurately predict species occurrence and abundance is crucial to understanding wildlife-habitat relationships (Nichols et al. 2000, Anderson 2001, Buckland et al. 2001, Thompson 2002, Gu and Swihart 2004). Aerial surveys have been commonly used to determine the occurrence or abundance of waterfowl populations in habitat association studies (e.g. Merendino and Ankney 1994, Stacier et al. 1994, Décarie et al. 1995, Gordon et al. 2002). In the northern boreal forest, aerial surveys are of particular importance because ground surveys are logistically difficult. However, it is commonly understood that count data collected during aerial surveys are inherently flawed because animals present are often not detected (Cook and Jacobson 1979, Pollock and Kendall 1987, Gabor et al. 1995, Smith 1995, Cordts et al. 2002).

Correct interpretation of results derived from count data relies on a thorough understanding of detection probability or the probability of observing an individual given it is present in the sampling area (Defos du Rau 2003). A count statistic is a product of actual abundance and detection probability (Anderson 2001). Detection probability depends on dynamic observer-specific, environmental, and species-specific factors that individually or in combination may influence count data (eg. Pollock and Kendall 1987, Anderson 2001, MacKenzie et al. 2002, MacKenzie and Kendall 2002).

Although detecting an individual indicates a species' presence, non-detection is not equal to absence unless detection probability equals one (MacKenzie et al. 2002), and very few species are so conspicuous that all individuals present are always detected during every survey. Density estimates derived from raw count data may be low due to animals missed during surveys (Pollock and Kendall 1987). Falsely-recorded absences may result in an underestimation of site occupancy (Mackenzie et al. 2002, Gu and Swihart 2004). It is therefore necessary to consider detection probability when interpreting count data

to avoid drawing false conclusions regarding habitat associations based on flawed data (Anderson 2001, Mackenzie and Kendall 2002, Thompson 2002).

Techniques that have proven useful to estimate detection probabilities for count data collected during aerial surveys include conducting ground counts, implementing a visibility correction factor, using a marked sub-population, and double-observer methods (Cook and Jacobson 1979, Pollock and Kendall 1987, Smith 1995). Recently, Mackenzie et al. (2002) developed a method to estimate the fraction of locations used by a species when detection probability is less than one using a variation of a closed-population, mark-recapture model.

In 2001 and 2002, I conducted helicopter surveys of wetlands and counted the number of white-winged and surf scoter pairs and broods detected on each wetland. Scoter density and presence-absence data derived from counts were used in main data chapters as response variables in multiple and logistic regression models to look for evidence of habitat selection by scoters. Therefore, my main objective was to evaluate how detection probability influenced estimates of scoter density and presence absence and subsequent results of scoter-habitat modeling.

A.2 METHODS

A description of the study area, methods, and collection of aerial survey data is provided in Chapter 2.

A.2.1 Assessing the Proportion of Wetlands Used

Survey data were used to assign each wetland to a category of use (separately for each species): used by pairs, used by broods, or not used. To lower the possibility of incorrectly classifying a wetland as being unused, I repeated pair surveys on all 385 wetlands in both years. A sub-sample of 76 wetlands was surveyed 4 times over 2 years for pairs, and 3 times for broods.

Presence/absence data were used to create encounter histories for white-winged scoter and surf scoter pairs and broods for the sub-set of 76 wetlands surveyed on four occasions. White-winged scoter broods and surf scoter pairs and

broods were detected on very few of the sub-sampled wetlands preventing further analyses due to insufficient data. White-winged scoter pair encounter histories were entered into Program Presence which models the probability of wetland use (Ψ) and probability of detection given use (p), using maximum likelihood techniques (MacKenzie et al. 2002). Because this study is part of a larger project assessing habitat features of wetlands used by scoters, I assumed that habitat covariates could influence Ψ . Therefore, I entered each wetland's area, index of shoreline irregularity (SI), and the PC1 and PC2 scores describing plot-level land cover characteristics (a description of PC1 and PC2 scores is provided in Chapter 2) into the program as covariates which may influence scoter wetland use. Because the program assumes a closed population, Ψ does not change over time. However, I considered both time constant and survey specific p .

A null model ($p\{\cdot\}, \Psi\{\cdot\}$), global model ($p\{\text{survey}\}, \Psi\{\text{Area, SI, PC1, PC2}\}$), and all combinations totaling 32 models were fit to the data. Model selection was based on Akaike's Information Criterion adjusted for small sample size (AIC_c) and Akaike weights (w_i) (Burnham and Anderson 2002). Models with $\Delta AIC_c < 2$ were considered to have substantial support (Burnham and Anderson 2002). I used the sum of Akaike weights over all models that include a particular covariate to establish whether there was support for that covariate in the context of the candidate set (Burnham and Anderson 2002). Precision of parameter estimates (β_i) was evaluated based on 95% confidence intervals. Unless otherwise specified, I reported parameter estimates and standard errors from the most parsimonious model in the candidate set containing a covariate. Standard error of Ψ was calculated using a nonparametric bootstrap method to account for the small sample size in my dataset (MacKenzie et al. 2002).

A.3 RESULTS

A.3.1 Assessing the Proportion of Wetlands Used

White-winged scoter pairs (hereafter scoter pairs) were detected at least once on 27 of 76 wetlands surveyed on four occasions producing a raw estimate of

wetland use by scoter pairs of 0.36. Model selection and summed Akaike weights indicate that the probability of wetland use by scoter pairs was greater on larger wetlands ($\beta = 0.80$, 95% CI = 0.21 to 1.39) and detection probability was higher on the first and third survey compared to the fourth (survey 1: $\beta = 2.89$, 95% CI = 1.50 to 4.28, survey 3: $\beta = 1.47$, 95% CI = 0.18 to 2.76). Parameter estimates for detection probability for the second survey were imprecise (survey 2: $\beta = 0.68$, 95% CI = -0.65 to 2.03). All three models in the candidate set with $\Delta AIC_c < 2$ (Table A.1) provided similar estimates of wetland use by scoter pairs ($\Psi \sim 0.40$, 95% CI = 0.37 to 0.54), 10% greater than the raw estimate based on the number of wetlands on which scoters pairs were detected at least once. Detection probabilities were estimated separately for each survey (survey 1 $p = 0.72$, survey 2 $p = 0.23$, survey 3 $p = 0.39$, survey 4 $p = 0.13$).

A.4 DISCUSSION

My results indicate that raw count data under-estimated the number of wetlands used by white-winged scoter pairs by approximately 10%. Therefore, I can be certain that I have incorrectly classified wetlands on which scoter pairs were not detected as being “unused”. It is also reasonable to assume that my scoter abundance data is similarly underestimated and this may have affected the scoter habitat association modeling I have conducted based on scoter density.

The probability of detecting scoter pairs given wetland use was quite low for all but the first survey. This was surprising because scoters appear to be highly visible compared to most other species of waterfowl. However, I did not include specific sampling occasion covariates (temperature, wind speed, light conditions) that might affect detection probability into the analyses, as I did not record such data during the surveys. As well, I did not include site specific covariates that might influence the ability to detect scoter pairs (shoreline irregularity, emergent vegetation) into the analyses. Further, I was not able to sufficiently assess between observer detection probability via a double-observer method (Nichols et al. 2000) suitable for a noisy, fast moving, and costly helicopter that accurately represents the

Table A.1. Five highest ranking and null models assessing factors influencing wetland use by white-winged scoter pairs (Ψ) and white-winged scoter pair detection probability (p) for 76 wetlands surveyed on four occasions in 2001 and 2002. Support for each model is indicated by differences in AIC_c values (ΔAIC_c) relative to the best approximating model ($\Delta AIC_c = 0$).

Model ^a	ΔAIC_c ^b	w_i ^c	K ^d
$\Psi(\text{Area}, \text{PC2}), p(\text{survey})$	0	0.25	7
$\Psi(\text{Area}), p(\text{survey})$	0.30	0.23	6
$\Psi(\text{Area}, \text{PC1}), p(\text{survey})$	1.88	0.10	7
$\Psi(\text{Area}, \text{SI}, \text{PC2}), p(\text{survey})$	2.11	0.09	8
$\Psi(\text{Area}, \text{PC1}, \text{PC2}), p(\text{survey})$	2.39	0.07	8
$\Psi(\cdot), p(\cdot)$	19.65	0	2

^a Model factors included: Area = wetland area; SI = shoreline irregularity index; PC1 = first principal axis describing plot-level vegetation characteristics; PC2 = second principal axis describing plot-level vegetation characteristics; survey = survey specific detection probability.

^b Difference between the AIC_c values of the model in question and the most parsimonious model ($\Delta AIC_c = 0$).

^c Weight of evidence in favour of the models considered. Weights of all models in the candidate set sum to 1.0.

^d Number of parameters in the model.

specific challenges of surveying scoter pairs and broods (sporadic and clumped distribution). The model framework was therefore limited to assuming that detection probability was constant across all sites and all observers. In reality detection probability was likely affected by these factors and failing to include these in the model may have resulted in occupancy being underestimated (MacKenzie et al. 2002).

Including false zeros or density estimates that are biased low as response variables in habitat models in Chapters 2 and 3 has likely somewhat affected resulting parameter estimates (Moilanen 2002). Gu and Swihart (2004) found when detection probabilities are not site-specific, coefficients for parameter estimates positively related to occupancy were underestimated. In this study I assumed that detection probability was constant across all sites, so it is possible that Gu and Swihart's (2004) findings may apply to results in Chapters 2 and 3. If this is the case, then my results may not have identified one of my measured habitat variables as being important to scoter habitat use because of a non-detection error.

A.5 RECOMMENDATIONS

Conducting additional pair and brood surveys may have allowed me to more precisely estimate wetland use by scoter pairs based on wetland specific covariates. However, the cost of conducting aerial surveys, particularly by helicopter, is limiting. In this case, increasing the number of sampling occasions for all wetlands would have dramatically decreased the number of wetlands surveyed overall. Even so, it may have been worthwhile to budget helicopter time to re-visit the sub-set of 76 wetlands surveyed in both years one or two additional times each year to increase the number of sampling occasions to six or eight. This would have required one or two days of additional helicopter time each year, but I believe the benefits gained from unbiased estimates are worth the additional cost.

It would have been worthwhile to collect data about environmental factors that likely influence detection probability. Air temperature, wind speed, and light conditions are obvious factors that impact the ability to observe waterfowl on

wetlands during aerial surveys. I also recommend that future studies using aerial surveys to collect information about waterfowl abundance and distribution develop a double-observer method to assess observer specific detection probability, especially if observers change between surveys. Acquiring this information requires some additional effort and results in an increased cost, however including such data in analyses would lead to more realistic estimates of detection probability, more precise estimates of wetland occupancy and will prevent management recommendations and conservation programs from being developed based on misleading information.

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**APPENDIX B. LOWER MACKENZIE RIVER DELTA LAND COVER
CLASSIFICATION CLASS DESCRIPTIONS AND SUPPLEMENTAL**

TABLE

This section contains detailed habitat class descriptions taken directly from the Lower Mackenzie River Delta, NT, Earth Cover Classification User's Guide (Ducks Unlimited, Inc. 2002).

B.1.0 Forest

Needleleaf and Deciduous Trees

The needleleaf species generally found were white spruce (*Picea glauca*) and black spruce (*P. mariana*). White spruce tended to occur on warmer sites with better drainage, while black spruce dominated poorly drained sites.

The deciduous tree species generally found were paper birch (*Betula papyfera*), aspen (*Populus tremuloides*) and Balsam Poplar (*P. balsamifera*). Under some conditions willow (*Salix* spp.) and alder (*Alnus rubra*) formed a significant part of the tree canopy. Deciduous stands were found in major river valleys, on alluvial flats, surrounding lakes, or most commonly, on the steep slopes of small hills. Mixed deciduous/coniferous stands were present in the same areas as pure deciduous stands. While needleleaf stands were often extensive, deciduous and mixed deciduous/needleleaf stands were generally limited in size.

B.1.1 Closed Spruce

At least 40% of the cover was trees, and $\geq 75\%$ of the trees were spruce trees. Closed spruce sites were rare because even where stem densities were high, the crown closure remained low. Closed spruce sites are often found along major rivers.

B.1.2 Open Spruce

From 25-39% of the cover was trees, and $\geq 75\%$ of the trees were spruce. This class was very common throughout the project area. A wide variety of understory plant groups were present, including low and tall shrubs, forbs, grasses, sedges, horsetails, mosses and lichens.

B.1.2.1 Open Spruce Lichen

From 25-39% of the cover was trees, $\geq 75\%$ of the trees were spruce, and $\geq 20\%$ of the site cover was lichen.

B.1.2.2 Open Spruce Moss

From 25-39% of the cover was trees, $\geq 75\%$ of the trees were spruce, and $\geq 20\%$ of the site cover was moss.

B.1.3 Woodland Needleleaf

From 10-24% of the cover was trees, and $\geq 75\%$ of the trees were needleleaf trees taller than 1 meter. Woodland understory was extremely varied and included most of the shrub, herbaceous, or graminoid types present in the study area.

B.1.3.1 Woodland Needleleaf Lichen

From 10-24% of the cover was trees, $\geq 75\%$ of the trees were needleleaf trees taller than 1 meter, and $\geq 20\%$ of the understory was lichen. The lichen often occurred in small patches between trees.

B.1.3.2 Woodland Needleleaf Moss

From 10-24% of the cover was trees, $\geq 75\%$ of the trees were needleleaf trees taller than 1 meter, and $\geq 20\%$ of the understory was moss.

B.1.3.3 Woodland Needleleaf Other

From 10-24% of the cover was trees, $\geq 75\%$ of the trees were needleleaf trees taller than 1 meter, and a mixture of lichen, moss and herbs with no predominant understory species.

B.1.4 Closed Deciduous

At least 40% of the cover was trees, and $\geq 75\%$ of the trees were deciduous. Occurred in stands of limited size, generally on the floodplains of major rivers, but occasionally on hillsides, riparian gravel bars, or bordering small lakes. This class included Paper Birch and Balsam Poplar.

B.1.4.1 Closed Birch

At least 40% of the cover was trees, $\geq 75\%$ of the trees were deciduous, and $\geq 75\%$ of the deciduous trees were Paper Birch (*Betula Papyfera*). This class was very limited.

B.1.4.2 Closed Poplar

At least 40% of the cover was trees, $\geq 75\%$ of the trees were deciduous, and $\geq 75\%$ of the deciduous trees were Balsam Poplar. This class was rarely found in pure stands, but was more commonly mixed with other deciduous species.

B.1.5 Open Mixed Deciduous

From 25-39% of the cover was trees, and \geq of the trees were deciduous. There was generally a needleleaf component to this class though it was less than 25%. This was a relatively uncommon class.

B.1.6 Closed Mixed Needleleaf/Deciduous

At least 40% of the cover was trees, but neither needleleaf nor deciduous trees made up $\geq 75\%$ of the tree cover. This class was found mainly within the delta region and south of the Mackenzie River.

B.1.7 Open Mixed Needleleaf/Deciduous

From 25-39% of the cover was trees, but neither needleleaf nor deciduous trees made up $\geq 75\%$ of the tree cover. This class occurred throughout the scene, but was more prevalent on the Fort McPherson plateau.

B.2.0 Shrub

The tall and low shrub classes were dominated by willow species, dwarf birch (*Betula nana* and *Betula glandulosa*) and blueberry (*Vaccinium*) species, with alder being somewhat less common. However, the proportions of willow to birch and the relative heights of the shrub species varied widely, which created difficulties in determining whether a site was made up of tall or low shrub. As a result, the height of the shrub species making up the largest proportion of the site dictated whether the site was called a low or tall shrub. The shrub heights were averaged within a genus, as in the case of a site with both tall and low willow shrubs. Dwarf shrub was usually composed of dwarf ericaceous shrubs and *Dryas* species, but often included a variety of forbs and graminoids. The species composition of this class varied widely from site to site and included rare plant species. It is nearly always found on hilltops or mountain plateaus, and may have included some rock.

B.2.1 Tall Shrub

Shrubs made up 25-100% of the cover, with the majority of shrubs being ≥ 1.3 meters in height. This class generally had a major willow component that was mixed with dwarf birch and/or alder, but could also have been dominated by nearly pure stands of alder. It was found most often in wet drainages, at the head of streams, or on slopes.

B.2.1.1 Closed Tall Shrub

Shrubs made up 60-100% of the cover, with the majority of shrubs being ≥ 1.3 meters in height.

B.2.1.2 Open Tall Shrub

Shrubs made up 25-59% of the cover, with the majority of shrubs being ≥ 1.3 meters in height, and the understory was mixed.

B.2.2.1 Low Shrub Willow Alder

Shrubs made up 25 – 100% of the cover, with the majority of shrubs being .25-1.29 meters in height, and willow/alder species constituted $\geq 75\%$ of the shrub cover.

B.2.2.2 Low Shrub Tussock Tundra

Shrubs made up 25 – 100% of the cover, with the majority of shrubs being .25-1.29 meters in height, and a total of $\geq 35\%$ cover was tussock tundra.

B.2.2.3 Low Shrub Lichen

Shrubs made up 25-100% of the cover, with the majority of shrubs being .25-1.29 meters in height, and $\geq 20\%$ of the cover was made up of lichen. The shrub species in this class were normally either dwarf birch or tussock tundra.

B.2.2.4 Low Shrub Other

Shrubs made up 25-100% of the cover, with the majority of shrubs being .25-1.29 meters in height. This was the most common low shrub class. It was generally composed of dwarf birch, willow species, *Vaccinium* species, and *Ledum* species.

B.2.3.1 Dwarf Shrub Lichen

Shrubs made up 25-100% of the cover, with the majority of shrubs being $< .25$ meters in height, and $\geq 20\%$ of the cover was made up of lichen. This class was generally made up of dwarf ericaceous shrubs and *Dryas* species, but often included a variety of forbs and graminoids. It was nearly always found at higher elevations on hilltops, mountain slopes and plateaus.

B.2.3.2 Dwarf Shrub Other

Shrubs made up 25-100% of the cover, with the majority of shrubs being $< .25$ meters. This class was generally made up of dwarf ericaceous shrubs and *Dryas* species, but often included a variety of forbs and graminoids, and some rock. It was nearly always found at higher elevations on hilltops, mountain slopes, and plateaus.

B.3.0 Herbaceous

The classes in this category included bryoids, forbs, and graminoids. Bryoids and forbs were present as a component of most of the other classes but rarely appeared in pure stands. Graminoids such as *Carex* spp., *Eriophorum* spp., or bluejoint grass (*Calamagrostis canadensis*) may have dominated a community.

B.3.1.1 Lichen

Composed of $\geq 40\%$ herbaceous species, $\leq 25\%$ water, $\geq 50\%$ of the herbaceous species are Bryoids (lichen or moss species), with lichen making up the majority of the moss/lichen component.

B.3.2.1 Wet Graminoid

Composed of $\geq 40\%$ herbaceous species, $> 5\%$ and $\leq 25\%$ water or $\geq 20\%$ *Carex aquatilis*, and where $\geq 50\%$ of the herbaceous cover was graminoid. This class represented wet or seasonally flooded sites.

B.3.2.2 Wet Forb

Composed of $\geq 40\%$ herbaceous species, $> 5\%$ and $\leq 25\%$ water or $\geq 20\%$ *Carex aquatilis*, and where $< 50\%$ of the herbaceous cover was graminoid. This class represented wet or seasonally flooded sites.

B.3.3.1 Tussock Tundra Lichen

Composed of $\geq 40\%$ herbaceous species, $\leq 25\%$ water, and $\geq 50\%$ of herbaceous species are Graminoid and ≥ 35 of these are Tussock. Lichen is present in the site with $\geq 20\%$ cover.

B.3.3.2 Tussock Tundra

Composed of $\geq 40\%$ herbaceous species, $\leq 25\%$ water, and $\geq 50\%$ of herbaceous species are graminoid and ≥ 35 of these are tussock.

B.3.3.3 Mesic Dry Graminoid

Composed of $\geq 40\%$ herbaceous species, $\leq 5\%$ water, with $< 50\%$ sedge. This class was not common.

B.3.3.4 Mesic Dry Forb

Composed of $\geq 40\%$ herbaceous species, $\leq 5\%$ water, with $< 50\%$ graminoids. Regenerating burn areas dominated by fireweed (*Epilobium angustifolium*) fell into the mesic/dry forb category.

B.4.0 Aquatic Vegetation

The aquatic vegetation was divided into Aquatic Bed and Emergent classes. The Aquatic Bed class was dominated by plants with leaves that float on the water surface, generally pond lilies (*Nuphar polysepalum*). The Emergent Vegetation class was composed of species that were partially submerged in the water, and included freshwater herbs such as horsetails (*Equisetum* spp.), maretail (*Hippuris* spp.), and buckbean (*Menyanthes trifoliata*).

B.4.1 Aquatic Bed

Aquatic vegetation made up $\geq 20\%$ of the cover, and $\geq 20\%$ of this vegetation was composed of plants with floating leaves. This class was generally dominated by pond lilies.

B.4.2 Emergent Vegetation

Aquatic vegetation made up $\geq 20\%$ of the cover, and $\geq 20\%$ of this vegetation was composed of plants other than pond lilies. Generally included freshwater herbs such as Horsetails, Maretail, or Buckbean.

B.5.0 Water

Composed of $\geq 80\%$ water.

B.6.0 Barren

This class included very sparsely vegetated sites, e.g., riparian gravel bars, along with non-vegetated sites, e.g., barren mountaintops or glacial till.

B.6.1 Sparse Vegetation

At least 50% of the area was barren, but vegetation made up $\geq 20\%$ of the cover. This class was often found on riparian gravel bars, on rocky or very steep slopes and in abandoned gravel pits. The plant species were generally herbs, graminoids and bryoids.

B.6.2 Burn

Recently burned areas were dominated by standing dead timber, litter, burned vegetation and charred soil.

B.6.3 Non-vegetated Soil

At least 50% of the area was barren, $\geq 50\%$ of the cover was composed of mud, silt or sand, and vegetation made up less than 20% of the cover. This type was generally along shorelines or rivers.

B.7.0 Other

Sites that did not fall into any other category were assigned to Other. For example, sites containing 25%-79% water, <25% shrub and <20% aquatic vegetation were classed as Other. Sites classed as Other may have also included extensive areas of vegetative litter, such as downed wood. These sites were assessed individually and generally treated as the land cover that they most closely resembled.

Table B.1. Component loadings of the first and second principal component axes for 34 earth cover classes present in 60 study plots. Also shown is the percent variance explained by the first and second principle component axes.

Earth cover class	PC1	PC2
Closed spruce	0.790	-0.467
Open spruce	0.798	-0.657
Open spruce lichen	-0.143	0.383
Open spruce moss	0.124	0.276
Woodland needleleaf lichen	0.047	0.859
Woodland needleleaf moss	0.088	0.888
Woodland needleleaf other	0.399	0.716
Closed birch	0.542	-0.261
Closed poplar	0.418	-0.329
Closed mixed needleleaf deciduous	0.685	-0.279
Open mixed needleleaf deciduous	0.685	0.435
Open mixed needleleaf other	0.160	0.675
Closed tall shrub	0.768	-0.102
Open tall shrub	0.462	0.204
Low shrub willow alder	0.506	-0.097
Low shrub tussock tundra	0.085	0.261
Low shrub lichen	0.008	0.585
Low shrub other	0.149	0.585
Dwarf shrub lichen	-0.113	0.254
Dwarf shrub other	0.072	0.050
Lichen	-0.047	0.390
Wet graminoid	-0.560	-0.335
Wet forb	0.116	-0.097
Tussock tundra lichen	0.039	0.270
Tussock tundra	-0.828	-0.073
Mesic dry grass meadow	-0.754	-0.079
Mesic dry forb	-0.470	0.206
Aquatic bed	0.624	-0.073
Emergent vegetation	0.382	-0.324
Water	-0.058	-0.347
Sparse vegetation	0.286	-0.140
Burned vegetation	-0.916	-0.215
Non-vegetated soil	0.223	-0.376
Other	0.457	-0.186
% Variance	22.2	15.1