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Mink and muskrat interactions across Canada

by

Catherine Josefa Shier ©

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"The mass of men lead lives of quiet desperation. What is called resignation is confirmed desperation. From the desperate city you go into the desperate country, and have to console yourself with the bravery of minks and muskrats."

~ Henry David Thoreau (1817 - 1862), *Walden*

In dedication to two amazing women that my life was blessed with:
Josefa Gies (September 18, 1921 to February 23, 2004) and
Ruth Jean Shier (January 21, 1913 to August 13, 2005).

Love always from your Grand daughter

ABSTRACT

The primary prey for mink is presumed to be muskrats, but the interaction between mink and muskrat is not well known. Numerical evaluation of Hudson's Bay Company fur-return data suggests that mink-muskrat predator-prey interactions in Canada increase in strength from east to west while synchrony between the two populations increase from west to east. My research aims to evaluate these patterns by assessing two potential mechanisms of mink-muskrat interactions: 1) decreased strength in eastern mink-muskrat interactions are caused by increases in mink prey species richness and 2) regional climate patterns in eastern Canada synchronize trapping returns resulting in increased synchronization. Contemporary assessments of mink diet indicate that prey species richness was inversely related to the degree of specialization of mink on muskrat. The North Atlantic Oscillation, on the other hand, periodically synchronized trapping returns in eastern Canada. My research suggests that both mechanisms are important determinants of mink-muskrat interactions.

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CHAPTER 1: General Introduction

Documenting and understanding how wildlife populations fluctuate synchronously over large spatial scales has baffled interested parties for centuries (Elton 1924, 1942). MacFarlane (1905) was one of the first North American explorers to suggest the existence of periodic fluctuations in red fox, mink, muskrat, snowshoe hare, lynx, and marten. However, it was Seton (1911) who first graphed the Hudson's Bay Company fur return data, illustrating not only the fluctuations of important furbearers in North America, but also the extraordinary regularity of fluctuations.

Ultimately, Elton (1924) brought the study of population cycles to the interest of the biological community. What was once debated as random fluctuations in animal abundance (Cole 1951) has now become a widely accepted ecological phenomenon simply referred to as the "10-year cycle of wildlife populations" (Keith 1963). Species exhibiting such trends in Canada's Boreal forest included voles, lemmings (Elton & Nicholson 1942), snowshoe hare (Keith 1963), lynx, grouse (Taverner 1929; Keith 1963), mink (Viljugrein et al. 2001), and muskrat (Elton and Nicholson 1942).

Since the recognition of population cycles, many hypotheses have been developed to explain their mechanism, including intrinsic (Christian 1950; Christian 1961; Chitty 1967) and extrinsic effects (Elton 1924, 1963). Of the extrinsic factors proposed, predator-prey relationships have received the most attention in the last half century (Korpimaki et al. 1991; Hanski et al. 1991; Krebs et al. 2001). Abundances in predator species closely follow those of their primary prey species and are often synchronized across large spatial scales (Keith 1963; Haydon et al. 2001). With the development of large-scale field experiments (Krebs *et al.* 2001) and the advent of new modeling techniques (Yao et al. 2000), researchers have found an intricate system of interactions that can be attributed to more than one trophic level. Underlying population dynamics of the predator-prey interaction have now been found to vary geographically (Hanski et al. 1991; Erb et al. 2000), requiring more comprehensive theories to explain the spatial extent of the 10-year cycle while taking into account observed geographic variation in population dynamics.

To evaluate theories that have been proposed to explain the 10-year cycle and its underlying variation in population dynamics, a large amount of abundance data is required. Such data exists in the Hudson's Bay Company fur return records for mink, a geographically wide-ranging predator of the boreal forest, and its proposed primary prey species, the muskrat (Charles Elton's files at Oxford University and the Hudson's Bay Company Archives, Winnipeg, Manitoba). This study follows upon work outlining the geographically varying interactions and underlying population dynamics of mink and muskrat across Canada (Yao et al. 2000; Viljugrein et al. 2001; Erb et al. 2001; Haydon et al. 2001). In Chapter 1 I evaluate the hypothesis that variation in the strength of the mink-muskrat interactions across Canada can partly be attributed to changes in mink prey species richness. In contrast, in Chapter 2 I test the contribution of regional climate effects, captured in large-scale climatic features such as the North Atlantic Oscillation, on synchronizing trapping returns for both mink and muskrat. Chapters of the thesis have been formatted for publication in the *Canadian Journal of Zoology*.

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CHAPTER 2: Mink population dynamics and prey species richness in Canada

Introduction

Similar to the often cited Hudson's Bay Company Canadian lynx (*Lynx canadensis*) records, fur return data also exist for muskrat (*Ondatra zibethicus*) and mink (*Mustela vison*). Cycles in muskrat abundance have been reported since 1927 (Innis 1927; Elton and Nicholson 1942) and both muskrat and mink harvests have been shown to oscillate approximately every 8-9-years throughout most of Canada's Boreal Forest (Viljugrein et al. 2001; Erb et al. 2001). While it is tempting to link the abundance of muskrat and mink to the well-known snowshoe hare-lynx cycle (via the alternative prey hypothesis, Lack 1954) researchers in the past have indicated that a connection is unlikely (Elton and Nicholson 1942). Instead, mink pelt data follow the historical density fluctuations of muskrat so well that past researchers have suggested the existence of a predator-prey interaction between the two species (Keith 1963; Bulmer 1975; Finerty 1980; Viljugrein et al. 2001).

Mink and muskrat occupy the same wetland habitats throughout much of North America (Eagle and Whitman 1987; Boutin and Birkenholz 1987) and the mink is considered the primary predator of muskrat and waterfowl in wetland areas (Eagle and Whitman 1987). Mink are successful predators of muskrats (Banfield 1974; Proulx et al. 1987), especially when muskrat are stressed (Errington 1963). This, in combination with the apparent adaptation of the mink to predation on muskrat (Nelson 1918), and extensive field observations provides support for the existence of a mink-muskrat predator-prey interaction (Errington 1943, 1963; Keith 1963).

Further support for such an interaction between mink and muskrat, a microtine rodent, comes from studies in Fennoscandia where it has been shown that geographically wide-ranging smaller mustelid species, in particular the least weasel (*M. nivalis*), act as specialist predators in the north and generalist predators in the south to cause or stabilize respectively cyclic population fluctuations in microtine prey. Current theory states that specialist predators respond numerically to their main prey species, which produces a lag in the predators' population thereby causing cyclic fluctuations in the prey species. When several prey species are available for generalist predators (behavioural response by prey switching) the predators are buffered by the abundance of alternative prey species and thereby promote stability in the system (Hansson and Henttonen 1985). As in Fennoscandia, the diversity of mammals in North America increases from north to south (Simpson 1964; Badgley and Fox 2000), suggesting that locality could influence the degree of specialization of mink on muskrat throughout North America.

Using Hudson's Bay Company fur-return data it has been determined that mink and muskrat population dynamics are best grouped into three ecological zones (Yao et al. 2000) with geographically varying numerical dependences between the two species (Erb et al. 2001). Western Canada HBC Posts show the strongest numerical dependencies between mink and muskrat and it has been argued that mink specialization on muskrat is highest in the west, particularly the northwest, due to decreased prey diversity at the higher latitude HBC Posts. The dependencies found in Central Canada were ascribed to intermediate trophic interactions (Erb et al. 2001) while specialization of mink on muskrat is at its weakest in the eastern posts. In the east, it is argued that there is "... a larger array of prey species for the mink to feed on (making it less dependant on the muskrat)…" (Yao et al. 2000) even though mammal species richness increases from east to west (Simpson 1964).

Mink have been characterized as generalist predators (Eagle and Whitman 1987). Indeed there have been a number of studies that document high diversity of mammalian, avian (waterfowl and passerine), invertebrate, and fish prey in the mink diet (Sargeant and Doty 1973; Jennings et al. 1982; Gilbert and Nancekivell 1982; Proulx et al. 1987; Arnold and Fritzell 1987). Unfortunately, to date there have been no studies on variation in mink prey species richness across Canada and most studies of latitudinal gradients in species richness in North America have focused solely on mammals (Simpson 1964; Badgley and Fox 2000). This investigation was developed with the goal of a) determining mink prey species richness patterns across Canada and b) determining if there is a change in percent muskrat in mink diet due to prey species richness as suggested by Yao et al. (2000).

Methods

Mink prey species richness

Mink carcasses were collected from Canadian biologists, trappers, and fur buyers and gut (stomach and intestine) contents were examined. Mink from all across Canada were accepted with an emphasis on obtaining large mink collections from areas representing a gradient in latitude and longitude representative of the HBC post distribution across Canada. Mink were labeled with the date of death, trapping location, trapping method and bait type used and were frozen on site before being sent to the

University of Alberta for further examination. During post-mortem examination sex and standard measurements were taken in addition to removal of the whole digestive tract.

Stomach and large intestine contents were removed and washed with warm water in a fine-mesh sieve (0.5 mm) and then placed in Petri dishes. Before analyzing all samples from a trapping area a sub sample of 20 mink guts were examined for identifiable microscopic prey remains (Reynolds and Aebischer 1991). No samples contained any identifiable microscopic remains so further analysis considered only macroscopic remains. Food items were separated and identified using relevant identification guides. Fish were identified using scales (Oates et al. 1993) and comparing operculae and diagnostic vertebrae to reference samples (University of Alberta Zoology Museum) of species known to inhabit the areas where mink were trapped (Scott and Crossman 1998). Birds were identified to Order using Day's (1966) key to downy barbules and mammals were identified using tooth and hair characteristics (Hausman 1920; Williams 1938; Dearborn 1939; Hall and Kelson 1959; Day 1966; Adorjan and Kolenosky 1969; Banfield 1974; Brunner and Coman 1974; Moore et al. 1974; Wallis 1993; Smith 1993). Amphibian and insect remains often were difficult to identify lower than order but attempts were made when diagnostic parts were available (Conant 1958; Peckarsky et al. 1990).

Diet data are presented as frequency of occurrence (number of mink in which a prey item occurred) and percent occurrence (the relative frequency of each prey item expressed as a percentage of all prey items in the sample). Use of frequency of occurrence and percent occurrence data in estimating principle prey species has been criticized because it tends to overestimate small prey items (more indigestible matter in relation to bulk) and underestimate large ones (little of what is eaten is indigestible) (Lockie 1959). Because the frequency of occurrence method tends to under-represent larger food items (i.e. muskrat and birds) and over-represent smaller prey species (i.e. voles, shrews, insects) predominant food items were also recorded. When a sample contained remains of more than one prey type the item occupying the greatest proportion of the sample was identified as the predominant food item. The frequency of occurrence method was useful for this study because it gives an indication of the relative importance of larger food categories (i.e. mammals, fish, birds, etc) (Erlinge 1968; Melquist and Hornocker 1983) and is useful in the generation of a mink prey species-richness list from across Canada. Chi-square analysis ($p < 0.05$) was used to test for bias between the following samples: a) stomach and intestine, b) male and female, c) mink from different trapping seasons, and d) baited and non-baited mink.

In addition to the prey identified in mink collected from across Canada a comprehensive literature search of North American mink-diet studies was performed to generate a list of all known mink prey. Distribution maps (Scott and Crossman 1998; Patterson et al. 2003) of prey species were combined in a geographical information system (GIS) to produce a mink prey species richness map. The geographical distribution and richness of prey species of the present are presumed to have been the same as those of the past 100 years (Graham and Mead 1987). Prey species available and used by mink are assumed to have not changed significantly.

HBC posts were entered into a GIS database in Lambert's azimuthal equal area projection and were surrounded by a 100 km buffer zone (31,416 km^2) within which prey species richness was determined. Poisson regression analysis was used to evaluate latitudinal or longitudinal gradients in mink species richness across HBC posts and mink collection sites.

Modelling percent occurrence of muskrat in mink diet

Muskrat in mink diet (%) across collection areas was modelled (model “Hyp”) using linear regression to determine if percent muskrat in mink diet is influenced by mink prey species richness (based on diet study and comprehensive literature search) across Canada (easting). Percentage of muskrat in mink diet data was logit transformed to constrain the original proportion variable between 0 and 1. Since logit transformation cannot be performed on observations where the dependent variable is 0 or 1 these values were replaced by 0.0001 and 0.9999 respectively. Prey species richness counts were normalized using square root transformation and all model variables were weighted according to mink sample size at each collection site.

Alternative models that included additional predictor variables considered important in influencing percent muskrat in diet were also considered and compared to the hypothesis model above (Hyp). In addition to easting and prey species richness, northing and prey species richness observed in mink diet (stomach and intestine samples) were included in the models. Mink body mass (no pelt) was also included to ensure that its inclusion in the model does not confound the pattern that we expect to see in the influence of prey species richness on percent muskrat in mink diet. It is suspected that body mass could have an influence on percent muskrat in diet because larger mink (often male) are known to take larger prey items (i.e. muskrat and hare) than smaller (often female) mink due to this size difference (Sealander 1943; Soper 1964). Model selection was facilitated by information-theoretic methods. Small sample Akaike information criteria (AIC_c) and weight was used to choose the most parsimonious model (Burnham and Anderson 2002). Model variables were weighted according to mink sample size at each collection site.

Results

Mink prey species richness

A total of 756 mink carcasses were collected by 93 trappers from 7 provinces and 2 territories ($\bar{x} = 8$ mink per trapper, $s.d. = 14$). The majority of mink were captured during the 2003/04 trapping season, however an additional 89 mink were collected in 2004/05 from the Inuvik region of the North West Territories (mink collection site #5, Figure 2-1) because only 28 mink were obtained from that area in 2003/04. To increase mink sample size per area traplines within 100km from the center point of each other were grouped together ($\bar{x} = 43.1$ kilometers, $s.d. = 38.1$) to form 40 mink collection areas ($\bar{x} = 19$ mink per collection area, $s.d. = 26$, Figure 2-1).

Of the 756 mink collected 617 (81.6%) contained food items and 1,188 prey items were identified (Appendix A). The majority of mink contained one or two prey items (269 and 207 mink respectively), 81 mink contained 3 prey items, 41 contained four, 17 contained five, and two mink contained six prey items. The number of prey items per mink decreases as one goes north (β_1= -0.025, 755 df, p=0.002) along a constant longitude.

The two major prey groups found in the winter diet of mink were mammals (36.8%) and fish (34.3%). Insects were the third predominant food group at 9.4% with amphibians (8.0%) and birds (5.6%) following in percent occurrence. Miscellaneous prey items grouped into an "other" category (5.9%) were composed of snails, mollusks, unidentified invertebrates, and crustaceans (crab, crayfish, and unidentified crustaceans).

Muskrat (26.8% of mammals), snowshoe hare (*Lepus americanus*, 11.4%), and red squirrel (*Tamiasciurus hudsonicus*, 5.9%) were the predominant mammals used by mink. When grouped by prey species type both voles and insectivores were heavily used (17.6% and 15.8% of mammals respectively). Mink predation on mustelids seemed to occur mainly in the north with 10 of 14 predation events occurring north of 54° (including all 4 predation events on mink). Unidentified *Mustela* species were *M. erminea*, *M.frenata*, or *M. nivalis* because hair characteristics made it easy to separate mink and marten from other mustelids. Deer (*Odocoileus* spp.) and otter (*Lontra canadensis*) were found in an Alberta and Ontario mink respectively. Otter and deer were not considered to be normal prey for mink.

Fifty-five percent of fish prey items were unidentified due to lack of diagnostic bones or scales. Of those identified Cypriniformes (29.5%), Salmoniformes (23.5%), and Esociformes (*Esox esox*, 19.1%) predominated the diet sample. Amphibians were found only in Ontario and Quebec mink samples and birds were equally distributed across the country. Crabs were identified from the BC coastal mink collection area (collection area #1, Figure 2-1) where there were no mammalian prey.

Mink hair was found in 29.6% of sample animals, presumably from grooming. However, 15 mink also contained mink claws, toe hair, and bones that were not considered predation events on mink. In 12 of these cases either the sample mink was missing one of its feet or another mink caught on the trap line was missing a foot. Plant material such as leaves, grass, and bark, was common in gut remains but this was considered incidental and expected considering the feeding habits of mink (i.e. scavenging, eating prey on the ground).

A significant difference was found between stomach and intestine diet contents for both frequency of occurrence ($\chi^2 = 61.884$, 15 df, $p < 0.001$) and predominant prey item counts ($\chi^2 = 53.681$, 15 df, $p < 0.001$) indicating that grouping stomach and intestine data for further analysis would be a significant source of bias (Day 1968). Significant differences between observed and expected frequencies were concentrated in Salmoniformes ($\chi^2 = 28.826$, 1 df, $p < 0.001$), unidentified fish ($\chi^2 = 11.037$, 1 df, $p < 0.001$), Cypriniformes ($\chi^2 = 8.728$, 1 df, $0.005 < p < 0.001$), and Rodentia ($\chi^2 = 6.502$, 1 df, $0.025 > p > 0.01$) (Figure 2-2).

There was no significant difference in diet between the 2003/04 and 2004/05 collection years for the Inuvik mink collection site (stomach: $\chi^2 = 16.013$, 13 df, $0.25 < p < 0.10$, intestine: $\chi^2 = 12.645$, 10 df, $0.50 < p < 0.25$). There was also no difference between the diets of male (body mass: $n = 428$, $\bar{x} = 768.1$ g, *S.D.* = 256.6; total length: $n = 457$, $\bar{x} = 572.2$ g, *S.D.* = 55.3) and female (body mass: $n = 237$, $\bar{x} = 508.5$ g, *S.D.* = 169.2; total length: $n = 255$, $\bar{x} = 515.3$ g, *S.D.* = 47.9) mink (stomach: $\chi^2 = 17.401$, 15 df, $0.50 > p > 0.25$, intestine: $\chi^2 = 15.449$, 15 df, $0.50 > p > 0.25$) despite a significant difference in both body mass (no pelt, $t = 15.667$, 663 df, $p < 0.001$) and total length ($t = 14.373$, 710 df, $p < 0.001$). While no difference in diet was seen in the intestine sample between baited ($n = 419$, 55.4%) and non-baited ($n = 105$, 13.9%, unknown = 232, 30.7%) mink ($X^2 = 17.177$, 15 df, $0.50 > p > 0.25$) the stomach sample shows a marginally significant difference ($\chi^2 = 23.207$, 15 df, $0.10 > p > 0.05$).

The most common bait used for mink was fish (91% of baited mink). Fish bait was composed of 38.2% Salmoniformes (33.2% lake whitefish, 5.0% inconnu), Cypriniformes (17.7% sucker), Clupeiformes (7.4% herring), and Esociformes (0.2% pike). The remaining 36.5% of fish bait were either 1) a baiting mixture of a fish species composed mainly of whitefish (17.8%) or pike (13.4%) mixed with other fish species (i.e. trout, sucker, burbot) and beaver or lynx meat or 2) unknown because the trapper only indicated "fish" as bait. Trapping methods included using Conibear (killer) traps (71.5%), leghold drowning sets (18.0%), and incidental catches (0.3% muskrat basket, 0.3% shot). Method of trapping for the remaining 10% of the mink was unknown.

The literature search on mink diet across North America generated a list of 44 mammal and 14 fish mink prey species (Cowan W. F. and Reilly 1958; Dearborn 1932; Errington 1936; Hamilton W. J. Jr. 1936; Hamilton 1940; Sealander 1943; Guilday 1949; Goodpaster and Hoffmeister 1950; Llewellyn 1952; Wilson 1954; Korschgen 1958; Harbo Samuel J. 1958; Waller 1962; Sargeant and Doty 1973; Eberhardt 1973; Eberhardt and Sargeant 1977; Burgess 1978; Melquist et al. 1981; Gilbert and Nancekivell 1982; Jennings et al. 1982; Racey and Euler 1983; Arnold and Fritzell 1987; Proulx et al. 1987; Arnold and Fritzell 1989; Soper and Payne 1997). The current study added an additional eight mammal species (*Sorex arcticus, Sorex palustris, Sorex hoyi, Microtus longicaudus, Glaucomys sabrinus, Castor canadensis, Mustela martes*, and *Lontra canadensis*) and seven fish species (*Percopsis omiscomaycus, Pimephales promelas, Semotilus atromaculatus, Lota lota, Prosopium cylindraceum, Stizostedion vitreum*, and *Pungitius pungitius*). Other taxa of prey (i.e. birds, amphibians, and insects) were rarely identified to species in the literature or in this study. However, because most prey used by mink were mainly from mammals and fish (71.1%) a mink prey species richness map was generated using data from those two prey groups (Figure 2-3, Appendix B). We believe that focusing only on mammal and fish prey will not seriously bias the results because of the dominant role these two taxa have in mink diet.

Prey species richness at HBC posts (Figure 2-3, Appendix C) is inversely related to easting (β_1= -0.239, 79 df, $p = 0.013$) along a constant latitude. Prey species richness decreases as latitude increases (β_2= -0.585, 79 df, $p < 0.001$) along a constant longitude; likewise, prey species richness in the sample of mink collections decreases with latitude (β_1= -0.506, 32 df, $p = 0.005$). The eastern grouping of HBC posts (Figure 2-3, Yao et al. 2000) had the lowest prey species richness ($\bar{x} = 23$, $S.D. = 3$) and was significantly different from the Central grouping ($t = 6.307$, 32 df, $p < 0.001$) which contained those posts with high prey species richness ($\bar{x} = 30$, $S.D. = 3$). The Western grouping showed intermediate prey species richness ($\bar{x} = 28$, $S.D. = 3$) and was significantly different from the eastern grouping ($t = 4.25$, 22 df, $p < 0.001$). When a Bonferroni adjustment is considered ($\alpha = 0.017$) the western grouping is not significantly different from the central group ($t = 2.338$, 40 df, $0.05 > p > 0.02$).

Modelling percent occurrence of muskrat in mink diet

Thirty-five mink collection sites (Appendix D) were used in the analysis of the percent occurrence of muskrat in mink diets (the remaining five collection sites were not used because they contained only one mink). The null hypothesis that prey species richness and easting had no effect on muskrat in mink diet was rejected for intestine ($F_{31} = 3.61$, $p = 0.024$, adjusted $R^2 = 0.19$) and stomach ($F_{31} = 3.82$, $p = 0.02$, adjusted $R^2 = 0.20$) samples (Table 2-1). Both easting (intestine: $\beta = 58.127$, $p = 0.024$, stomach: $\beta =$

23.142, $p = 0.014$) and the interaction term with prey species richness (intestine: $\beta = -11.228$, $p = 0.019$, stomach: $\beta = -11.481$, $p = 0.012$) was significant in both samples. However, the relationship of prey species richness on percent muskrat in mink diet is modified by easting showing that the amount of muskrat in mink diet was negatively influenced by greater prey species richness at eastern HBC posts (Table 2-1).

When compared to alternative models including additional predictor variables (Table 2-2) the null hypothesis model (Hyp) was the second ranked AIC_c-selected model in both the intestine (Table 2-3) and stomach (Table 2-4) samples. Northing was highly correlated with both prey species richness ($r = -0.7749$) and easting ($r = -0.6254$) so it was not incorporated into those models that included prey species richness or easting. Northing, prey species richness, easting, and weight appeared in the top four models in both the intestine and stomach diet samples. The greatest variation in muskrat in mink diet was explained when prey richness, easting, and weight were included in one model (intestine: $R^2 = 0.22$, stomach: $R^2 = 0.24$). Estimated coefficients (β_i) and standard errors (*S.E.*) for the top AIC_c-selected models for the intestine and stomach samples are outlined in Table 2-5.

Discussion

Mink prey species richness

The first goal of this investigation was to document mink prey species richness patterns across Canada and test the hypothesis that mink prey species richness is greater in the eastern cluster of HBC posts as grouped by Yao et al. (2000). By identifying mink prey species through a cross Canada mink diet study and comprehensive literature search we have provided evidence for the rejection of this hypothesis.

When prey species richness was determined at each HBC post it was shown that prey species richness is lower at eastern posts (β_1= -0.239, 79 df, $p = 0.013$) when latitude is taken into account. Looking at Figure 2-3 it is clear that HBC posts grouped into an eastern cluster (Yao et al. 2000) are found at higher latitudes, resulting in decreased prey species richness compared to the central and western groupings. In addition to being of relatively higher latitude, 7 of the 8 eastern posts are coastal, therefore, a completely different assemblage of mink prey would be expected (Dunstone 1987; Ben-David et al. 1997). While mammals and fish make up the majority of prey for mink throughout most of the boreal, mink diet at collection area #1 (a coastal mink collection site, Figure 2-1) contained no mammal prey and 35.1% of their diet consisted of crab. It is likely that the different prey composition of mink diet at coastal HBC posts provides a better explanation to the weaker interaction between mink and muskrat in Eastern Canada than prey species richness (Erb et al. 2001).

Modelling percent occurrence of muskrat in mink diet

Although prey species richness at eastern HBC posts was shown to be the lowest of the HBC groupings the hypothesis that the amount of muskrat in mink diet is influenced by prey richness is an interesting one. Given the pattern of prey richness across Canada it is more likely that mink and muskrat interactions within central Canada are affected to a greater extent by mink having access to a greater diversity of prey. Through modelling percent occurrence of muskrat in mink diet across Canada we provide support for the second goal of this investigation: to determine if change in percent muskrat in mink diet is influenced by mink prey species richness (Yao et al. 2000).

Intestine and stomach diet analysis shows that percent muskrat in mink diet decreases in areas of high prey species richness at eastern mink collection sites, which are located mainly in southern Ontario and Quebec (Table 2-1). The interaction term of easting by prey species richness is highly significant and supports the hypothesis that mink diet is influenced by prey species richness, thereby potentially affecting the predator-prey relationship between mink and muskrat as proposed by Yao et al. (2000). However, Yao et al. (2000) was incorrect in attempting to ascribe the weaker predator-prey interactions of mink and muskrat at the eastern HBC post cluster to high prey densities.

When compared to the alternative models, my hypothesis (model "Hyp", Table 2-3 & 2-4) is selected as one of the best models to describe the relationship between percent muskrat in mink diet and prey species richness and easting. Focusing on the alternative models based on the intestine sample (Table 2-3) prey species richness (model #6), by itself, poorly predicted percent of muskrat in mink diet although northing (#1), which is highly correlated with prey species richness ($r = -0.7749$), was selected as the top model according to small sample Akaike's information criterion (Table 2-5). From the standpoint of parsimony model 1 looks to be the best model, however, northing as an indicator of the amount of mink specialization on muskrat does not lead to an understanding of mechanisms working in this system. Although there was support for multiple models it was determined that model 2 (Hyp plus weight variable) most appropriately describes the system based on the amount of variation it explains (22%).

Model 2 was chosen over our original hypothesis model ("Hyp") because previous diet studies indicate that mink size is an important factor in muskrat predation (Sealander 1943; Soper 1964). Also, when identifying mink prey items during laboratory analysis it was noted that larger mink were more likely to contain larger prey items (i.e. muskrat, snowshoe hare, bird, and fish scales of larger size) than smaller mink.

Models 2 and 3 indicate that there is a slight increase in the percent muskrat in mink diet as mink weight increases. Given that there is greater size variation between rather than within mink populations (Eagle and Whitman 1987) it is likely that male and female mink showed no difference in diet in this study because regional geographical variation in mink weight masked differences that occur at local mink collection sites.

Insights for future diet studies

Because mink are sometimes baited into a trap it is necessary to determine if bias was introduced into the diet if the trapped animal ate the bait. The marginal difference between the baited and non-baited stomach, but not intestine, samples suggests that such a bias exists for the stomach sample in this diet study. Compared to the intestine sample the stomach sample contained a greater number of Salmoniform and Cypriniform fish (Figure 2-2); baits that were used in > 55.9% of traps. When questioned, trappers indicated that it was not likely that mink could have obtained bait prior to being caught because 89.3% of the traps used were designed to either instantaneously kill or hold mink under water until death with little probability of the mink reaching bait. However, once a mink has been caught it is possible for another following mink to obtain the bait, and this second mink might be subsequently caught in another trap.

Alternatively, the difference between stomach and intestine samples could be the result of sharp fish bones staying in the stomach for longer periods of time for digestion prior to being shunted to the intestine. While identifying food items it was noted that there was a greater amount of disintegrated fish bones in the intestine resulting in fewer fish prey items being identified from the intestine (67%) as compared to the stomach (41%) sample. Because of the possible bias involved the intestine samples more appropriately reflects the composition of mink diet across Canada.

Conclusion

Diet evidence from this study suggests that while mink prey species richness does not follow the geographical pattern hypothesized by Yao *et al.* (2000) muskrat is still found to a much lesser degree in southern Ontario and Quebec mink diets than those of the northwest due to the greater species richness of mink prey in Southeastern Canada. Similar to smaller mustelid studies in Fennoscandia (Hansson and Henttonen 1985) we have shown that locality is influencing the degree of specialization of mink on its primary microtine prey.

In northern Canada muskrats make up a much larger proportion in a mink's diet and it seems a case is building for a strong predator-prey relationship between mink and muskrat in northwestern Canada. In addition to this study others point to increased numerical dependencies between the two species (Yao et al. 2000; Erb et al. 2001) as well as cycle lags reflective of a specialized predator prey relationship (Erb et al. 2001) at western HBC posts. Increased muskrat:mink ratios (Viljugrein et al. 2001) also illustrate that muskrats are relatively more abundant in northwestern areas of Canada. All of these factors combined with the significant decrease in mink prey diversity and increased ability for mink to use muskrat (due to mink size) provide support for a stronger predator-prey interaction between mink and muskrat in northwestern Canada.

In southern Canada, however, we still must be cautious in linking muskrat cycles to mink predation because mink are generalist predators (Gilbert and Nancekivell 1982; Proulx et al. 1987; Arnold T. W. and Fritzell 1987; Eagle and Whitman 1987) that "reflects changes in the abundance and availability of prey in its diet" (Racey and Euler 1983). Indeed, even though Errington was convinced that the muskrat is one of the favorite foods of the mink, he indicated that it was unlikely that mink predation on muskrat would be significant and felt it was mainly compensatory, taking muskrat that were vulnerable as a result of habitat disruption (Errington 1961, 1967).

Whether or not mink are driving muskrat population fluctuations or simply following them is best determined by long term experimental studies. Other long term studies point to pronounced fluctuations in muskrat numbers as mainly driven by vegetation-muskrat trophic interactions, particularly by muskrat eat outs (O'Neil 1949; Weller and Fredrickson 1973). However, while there are references to muskrat eat outs in the southern areas of their range (Weller and Spatcher 1965; Weller and Fredrickson 1973), none have been recorded in Canada's boreal forest (Boutin and Birkenholz 1987). Of 23 trappers asked (873 years of combined trapping experience, range: 22-68 years) only one indicated he had ever seen a muskrat eat out on his trap line 50 km south of lake Winnipeg. This follows the suggestion that northern populations of muskrat that experience shorter growing seasons and often experience winter freezouts are not likely to reach eat out conditions (Errington 1961).

While a case is building for a possible mink-muskrat predator-prey interaction producing cycles in northwestern Canada and a decoupling of the predator-prey relationship due to increased prey richness in south-central Canada there is still a lack of understanding around why mink and muskrat trophic interactions are weakest in Eastern Canada and yet still cycle every 8-9 years (Erb et al. 2001). The fact that no time lag is seen between the troughs and peaks of these two species in eastern Canada further confuses any potential relationship between the two. Contrary to what Yao *et al.* (2000) proposed, this weak relationship can not be explained by increased prey species richness.

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Table 2-1. Estimated coefficients (β_i), p-values (p), and model fit parameters (F statistic, p-value (p), degrees of freedom (d.f.)) for regression describing the influence of mink prey species richness on change in percent muskrat in mink diet and how this varies from western to eastern Canada. Regressions were estimated using mink diet data from 35 mink collection areas from across Canada. Models are weighted by number of mink at each mink collection site.

	Intestine		**Stomach**	
	β_i	p	β_i	p
preyrichness (Mink prey species richness)	+3.828	0.120	+3.831	0.101
easting	+58.127	0.024	+60.035	0.014
preyrichness*easting (Interaction term)	-11.228	0.019	-11.481	0.012
constant	-21.429	0.090	-22.108	0.066
F statistic	3.610		3.820	
p	0.024		0.020	
d.f.	31		31	
Adjusted R^2	0.19		0.20	

Table 2-2. Predictor variables hypothesized to influence muskrat in mink diets in Canada

Variable Name	Description	Range	Data Transformation
preyrichness	Prey species richness at mink collection areas as determined by literature search	21 to 42	Square root
ssrich	Prey species richness count in mink diet at each mink collection area (stomach)	1 to 32	Square root
isrich	Prey species richness count in mink diet at each mink collection area (intestine)	1 to 32	Square root
north	Northing metric based on UTM	0 to 1 (S to N)	Calculated to range 0 and 1
east	Easting metric based on UTM	0 to 1 (W to E)	Calculated to range 0 and 1
weight	Average mink weight (not including pelt) at mink collection area (g)	406.2 to 1053.7	None

Table 2-3. AIC$_c$ selected models for percent muskrat in mink diet (*intestine sample*) across 35 mink collection sites. Model loglikelihood (*LL*), number of model parameters (K_i), small sample AIC (AIC$_c$), change in AIC (Δ_i) from lowest model, Akaike weights (w_i), cumulative AIC$_c$ weight ($\sum w_i$), and adjusted R^2 of model support are reported. Models are weighted by number of mink at each mink collection site.

Model #	Model structure	*LL*	K_i	AIC$_c$	Δ_i	w_i	$\sum w_i$	R^2
1	northing	-88.554	2	181.48	0.00	0.25	0.25	0.14
Hyp	preyrichness+easting+easting*preyrichness	-86.429	4	182.19	0.71	0.17	0.42	0.19
2	preyrichness+easting+weight+easting*preyrichness	-85.151	5	182.37	0.89	0.16	0.58	0.22
3	weight	-89.403	2	183.18	1.70	0.11	0.69	0.10
4	easting	-89.862	2	184.10	2.62	0.07	0.76	0.07
5	weight+isrich	-88.942	3	184.66	3.18	0.05	0.81	0.09
6	preyrichness	-90.168	2	184.71	3.23	0.05	0.86	0.05
7	easting+isrich+easting*isrich	-87.750	4	184.83	3.35	0.05	0.90	0.12
8	preyrichness+weight	-89.185	3	185.14	3.66	0.04	0.94	0.08
9	northing+weight+northing*weight	-88.385	4	186.10	4.62	0.02	0.97	0.09
10	isrich+easting+weight+easting*isrich	-87.740	5	187.55	6.07	0.01	0.98	0.10
11	isrich	-91.649	2	187.67	6.19	0.01	0.99	0.00
12	easting+weight+ easting* weight	-89.288	4	187.91	6.43	0.01	1.00	0.04
Null	Null model	-105.666	1	213.45	31.97	0.00	1.00	0.00

Table 2-4. AIC_c selected models for percent muskrat in mink diet (*stomach sample*) across 35 mink collection sites. Model loglikelihood (*LL*), number of model parameters (K_i), small sample AIC (AIC_c), change in AIC (Δ_i) from lowest model, Akaike weights (w_i), cumulative AIC_c weight ($\sum w_i$), and adjusted R^2 of model support are reported. Models are weighted by number of mink at each mink collection site.

Model #	**Model structure**	***LL***	K_i	**AIC_c**	Δ_i	w_i	$\sum w_i$	R^2
2	preyrichness+easting+weight+easting*preyrichness	-83.10	5	178.28	0.00	0.25	0.24	0.24
Hyp	preyrichness+easting+easting*preyrichness	-84.48	4	178.30	0.02	0.24	0.49	0.20
1	northing	-87.25	2	178.87	0.60	0.18	0.67	0.12
3	weight	-87.98	2	180.33	2.05	0.09	0.76	0.08
4	easting	-88.48	2	181.33	3.06	0.05	0.81	0.05
6	preyrichness	-88.51	2	181.39	3.11	0.05	0.86	0.05
5	weight+ssrich	-87.65	3	182.07	3.79	0.04	0.90	0.07
8	preyrichness+weight	-87.72	3	182.21	3.93	0.03	0.93	0.07
7	easting+ssrich+easting*ssrich	-86.97	4	183.28	5.00	0.02	0.95	0.08
9	northing+weight+northing*weight	-86.98	4	183.30	5.02	0.02	0.97	0.08
11	ssrich	-89.93	2	184.23	5.96	0.01	0.99	0.00
12	easting+weight+easting*weight	-87.87	4	185.08	6.80	0.01	0.99	0.03
10	ssrich+easting+weight+easting*ssrich	-86.97	5	186.01	7.74	0.01	1.00	0.05
Null	Null model	-105.19	1	212.51	34.23	0.00	1.00	0.00

Table 2-5. Estimated coefficients (β_i) and standard errors (S.E.) for top AICc selected models (cumulative AIC$_c$ weight of 0.75) for regression describing the percent of muskrat in mink diet for intestine and stomach diet samples across 35 mink collection areas. Models are weighted by number of mink at each mink collection site.

	constant		**preyrichness**		**easting**		**weight**		**easting* preyrichness**		**north**	
Model	β_i	*S.E.*	β_i	*S.E.*	β_i	*S.E.*	β_i	*S.E.*	β_i	*S.E.*	β_i	*S.E.*
Intestine sample												
1	-4.794	0.801									4.029	1.587
Hyp	-21.429	12.261	3.828	2.396	58.127	24.467			-11.228	4.523		
2	-32.739	14.165	4.738	2.424	68.862	25.014	0.007	0.005	-12.615	4.527		
3	-7.435	2.021					0.006	0.003				
4	-1.537	1.064			-3.387	1.783						
Stomach sample												
2	-33.195	13.361	4.723	2.286	70.558	23.593	0.007	0.005	-12.841	4.270		
Hyp	-22.108	11.597	3.831	2.266	60.035	23.142			-11.481	4.278		
1	-5.056	0.772									3.610	1.529
3	-7.430	1.941					0.006	0.003				

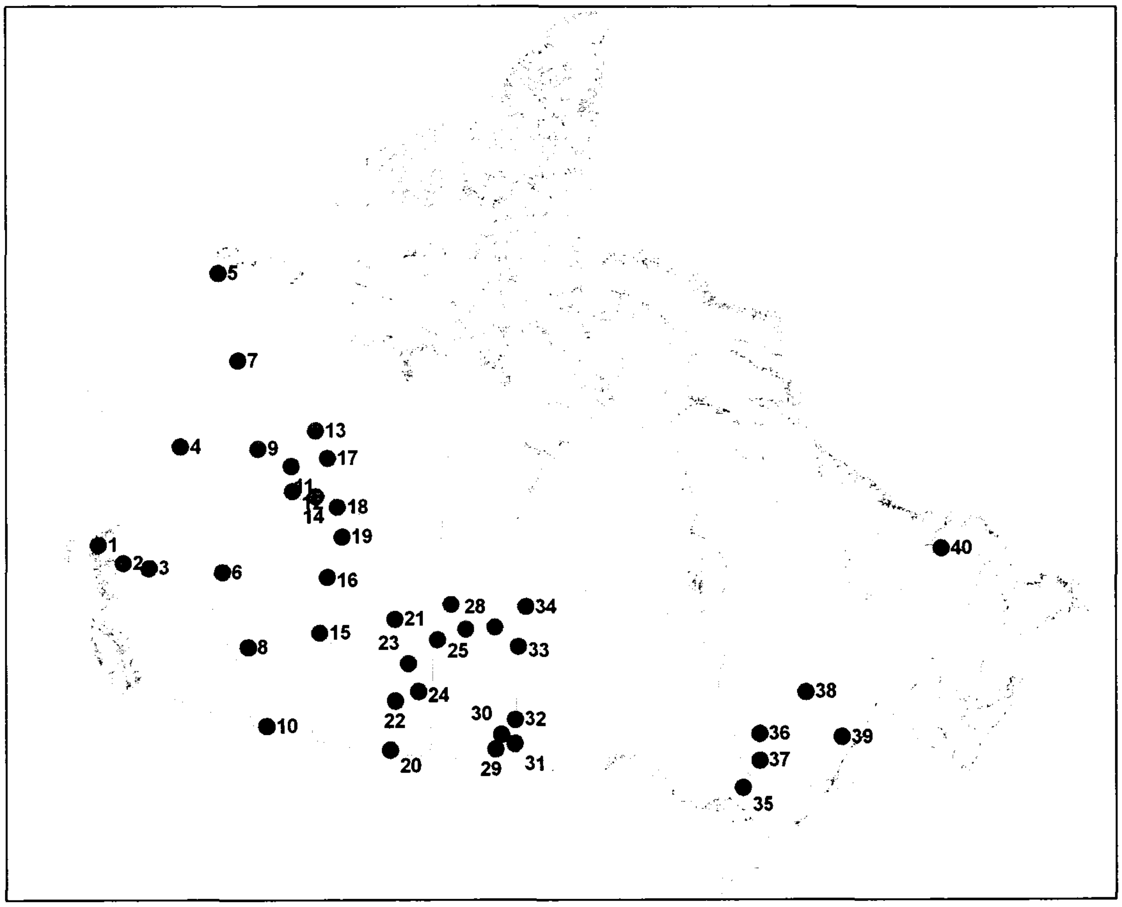

Figure 2-1. Map of Canada with provincial boundaries depicting 40 mink collection sites.

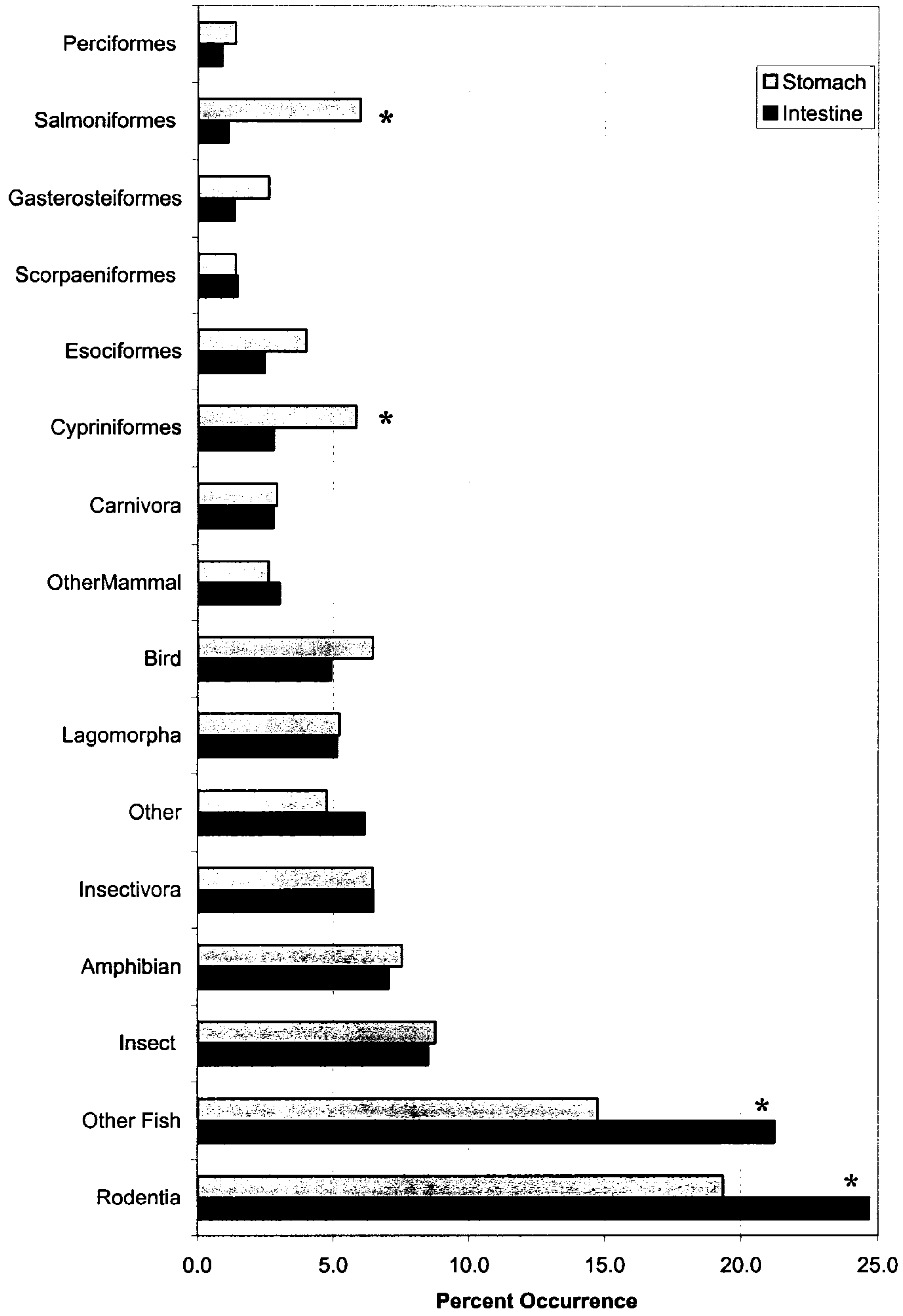

Figure 2-2. Percent occurrence of food items in stomach (n = 644) and intestines (n = 878) of 756 mink from across Canada ($\chi^2 = 61.884$, 15 df, $p < 0.001$). Asterisks represent significant χ^2 differences between stomach and intestine contents ($p < 0.05$).

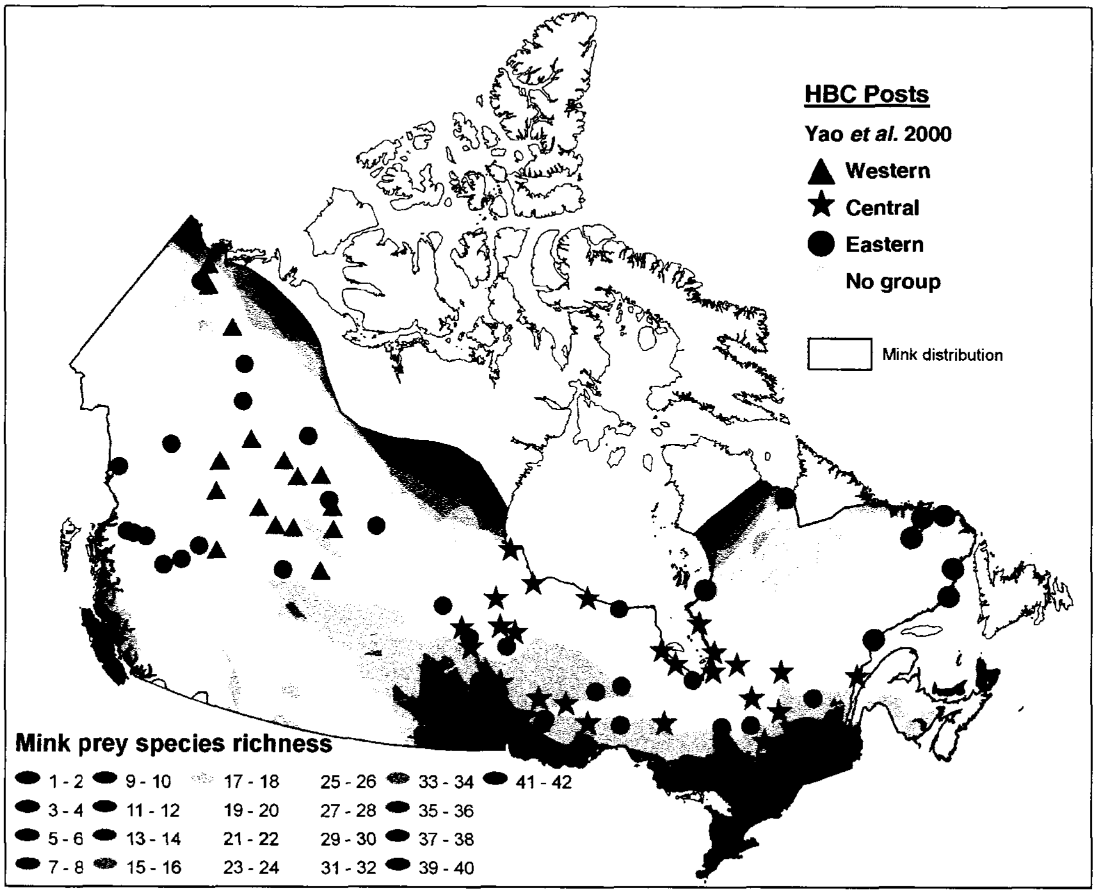

Figure 2-3. Estimated mink prey species richness based on the diet study reported here and previous literature. Points are Hudson's Bay Company fur trade posts divided into three groupings: Western, Central, and Eastern groupings (Yao *et al.* 2000). HBC posts represented by light gray circles were not grouped by Yao et al. (2000).

CHAPTER 3: Synchrony between mink and muskrat populations in Canada

Introduction

Understanding how large-scale climate fluctuations promote synchrony in wildlife populations has become an important area of ecological study (Stenseth et al. 2002). Early on, attempts were made to link the 10-year cycle of the Canadian Boreal forest to meteorological patterns with similar cycles (Elton 1924; Huntington 1945; Grange 1949; Rowan 1950). Recently, continental scale climatic influences that exhibit decadal and regional (Hurrell and Vanloon 1997) variability, such as the North Atlantic Oscillation (NAO), have been shown to have an effect on population dynamics, abundance, spatial distribution, and competition (for an overview see Ottersen et al. 2001). Even geographical variation in the 10-year lynx-snowshoe hare cycle has been linked to the NAO (Stenseth et al. 1999).

Climate effects such as precipitation and temperature vary regionally across North America separating Canada into three climate-based regions related to the geographical influence of the NAO (Hurrell and Vanloon 1997). In particular, the NAO strongly influences winter wind, temperature and precipitation of the Atlantic region (Ottersen et al. 2001) leading some to suggest a connection between synchrony of eastern mink and muskrat populations with region-specific winter conditions of eastern Canada associated with the NAO (Viljugrein et al. 2001).

Mink and muskrat trophic interactions are weakest in Eastern Canada and no time lag is seen between the two populations (Erb et al. 2001). In addition, eastern populations of mink and muskrat have a stronger correlation to the NAO index than mink and muskrat populations from central and western Canada (Viljugrein et al. 2001).

Paired time-series panel data available for mink and muskrat are from Hudson's Bay Company Post fur-return data (1925-1949). While the use of fur-return data in the analysis of animal abundance is generally accepted (Stenseth et al. 1998) the assumption is that trapping effort and success is constant. Given consistent effort and success, fur-return data are believed to be directly related, although not necessarily proportional to, actual population levels (Keith 1963). However, if this assumption is not met alternate hypotheses that consider the effect of trapper behaviour on harvested populations should be examined (Gilpin 1973; Weinstein 1977; Winterhalder 1980).

Variables such as weather (temperature and precipitation), season length, and trapper behavior can influence harvest rate (Erickson 1981; Clark 1986). In addition, timing of season opening relative to weather conditions has been shown to be influential in determining harvest rate of muskrat (Clark 1986). Trappers are well aware of this factor in relation to mink trapping as well where "... an early freeze-up may end the effective mink trapping season long before harvestable surplus can be taken" because trapping for mink is more effective when traps can be placed in open water (Hatler and Beal 2006).

In high (positive) NAO years precipitation is below normal in eastern Canada (Dai et al. 1997). In addition, enhanced northerly flow over eastern Canada cools surface temperatures resulting in cold, dry winters (Forchhammer et al. 2002). Indirect influences of climate, captured in large-scale climatic features such as the NAO, could cause perturbations in harvest data due to non-biological influences resulting in increased synchrony between mink and muskrat in eastern Canada (Viljugrein et al. 2001). Specifically, high NAO years result in reduced ability to trap both mink and muskrat due to early freeze up. In this study I test the hypothesis that the harvest rate for mink and muskrat at eastern HBC Posts decreases in years of early freeze up, thereby providing a possible mechanism for synchronizing eastern mink and muskrat fur-return data and the influence of the NAO on mink and muskrat populations.

Methods

Data

Fur-return data were obtained from Charles Elton's files at Oxford University and the Hudson's Bay Company archives in Winnipeg, Manitoba and consist of mink and muskrat pelt records from 82 posts distributed throughout Canada (Figure 3-1, Appendix C). A total of 164 time series were compiled for 1925-1949. Each time series was transformed with the natural log and detrended by differencing, i.e.,

$$R_t = LN(N_t) - LN(N_{t-1}).$$

Where R_t is the per capita growth rate in harvests, N_t.

Historical homogenized temperature data for 90 Canadian weather stations (Figure 3-1, Appendix E) were acquired from the Meteorological Service of Canada (Climate Monitoring and Data Interpretation Division 2004). Monthly NAO index values were based on the difference of normalized sea level pressures between Ponta Delgada, Azores and Reykjavik, Iceland (Hurrell 2003).

Statistical analysis

Temperature stations were identified within a 100 km radius of all Hudson's Bay Company Posts with average monthly temperature data for 1925-1949. Mink and muskrat fur return data at HBC posts with associated temperature data were regressed against average November temperature to describe the influence of November temperature on change in mink and muskrat harvest across Canada. A binomial test was used to determine if change in mink and muskrat harvest at HBC posts across Canada is more frequently affected negatively by colder Novembers than would be expected by chance.

Average November temperature was chosen *a priori* because the majority of mink are trapped during November and December (Todd and Boggess 1987). A larger number of mink are expected to be harvested in years with warmer than average November temperatures extending the period before freeze up thereby maximizing the trappers' ability to harvest mink (Viljugrein et al. 2001).

Average November temperature also was regressed against muskrat harvest even though muskrat might have been trapped during both the fall and spring, as well as through the ice during winter months (Todd and Boggess 1987). Despite these complications I used average November temperature for analysis of muskrat harvests because: 1) I wished to maintain consistency with mink harvest analysis, 2) it is difficult to identify a temperature variable that could encompass both fall, winter, and spring trapping conditions for muskrats, and 3) muskrat yield is a product of fall density and harvest rate, which in turn relates to temperature, water-level, and trapper behavior (Clark 1986).

While it is well known that the winter (December through March) index of the NAO corresponds to cold winters in eastern Canada (Forchhammer et al. 2002) the relationship between November temperature and the November NAO index is not. To determine this relationship the correlation between November NAO and average and minimum November temperature at 90 temperature stations across Canada were determined using Pearson's correlation coefficient. A second order polynomial function was fit to the data to describe the longitudinal relationship between November NAO and November temperature across Canada.

To confirm that synchrony in mink and muskrat harvests is greater in eastern Canada as reported by Yao et al. (2000), correlations were calculated between mink and muskrat harvests at each HBC post. Linear regression was used to evaluate if there was a longitudinal gradient in mink-muskrat correlations across Canada.

To test the hypothesis that harvests of mink and muskrat at eastern HBC Posts decreased in years of early freeze up (as influenced by November NAO) I performed a fixed-effects regression analysis. Fixed-effects regression is an extension of multiple regression that exploits panel time-series data, such as the 82 HBC Post mink and muskrat harvest data, to control for variables that differ among HBC Posts but are constant over time (Stock and Watson 2003). Basically, fixed-effects regression lets one use the changes over time to estimate the effects of independent variables on the dependent variable. Independent variables included in the models were November NAO and a November NAO/easting interaction term. November NAO and easting variables were scaled so that values fell between 0 and 1. Mink and muskrat models were tested for serial correlation (Drukker 2003).

Results

Fifteen Hudson's Bay Company Posts had temperature stations with November temperature data corresponding to the 1925-1949 mink and muskrat datasets within 100 km ($\bar{x}$=30.3 km, *S.D.* = 29.9; Figure 3-1, Table 3-1). Mink harvest at two HBC Posts showed a significant positive relationship with average November temperature (Table 3-1, Fort St. James; 23 df, $p = 0.026$, adjusted $R^2 = 0.17$ and Moose Factory; 23 df, $p = 0.029$, adjusted $R^2 = 0.16$) and two showed a weaker relationship (Fort Chipewyan; 23 df, $p = 0.060$, adjusted $R^2 = 0.11$ and Fort Fitzgerald; 23 df, $p = 0.093$, adjusted $R^2 = 0.08$). For mink, fourteen of the fifteen regressions showed a positive relationship between mink harvest and warmer average November temperatures ($Z = 3.357$, $p < 0.001$). A similar although non-significant relationship was seen when average November temperature was regressed on muskrat harvest (10 of 15 regressions, $Z = 1.291$, $p = 0.098$), and only one muskrat harvest time series was positively correlated with average November temperature (Moose Factory; 23 df, $p = 0.025$, adjusted $R^2 = 0.16$) (Table 3-1).

November NAO was related to both minimum ($y = -0.00007x^2 - 0.0152x - 0.803$, $R^2 = 0.58$) and average ($y = -0.00007x^2 - 0.0165x - 0.8717$, $R^2 = 0.64$) November temperature in eastern Canada; particularly for weather stations east of -70.00° longitude (Figure 3-2). Correlation between change in ln mink and ln muskrat harvest levels increased with easting across the 82 Hudson's Bay Company Posts ($\beta = 0.3907$, 81 df, $p < 0.001$; Figure 3-3).

Change in ln mink harvests was influenced by November NAO ($F_{1896} = 8.03$, $p < 0.001$, $R^2 = 0.17$; Table 3-2) and both November NAO ($\beta = 0.436$, *S.E.* = 0.112) and the interaction between November NAO and easting ($\beta = -0.592$, *S.E.* = 0.206) were significant. The interaction term demonstrates that the effect of November NAO on change in ln mink harvest is modified by easting such that mink harvests were negatively influenced by November NAO at eastern HBC posts (Table 3-2). The comparable model of change in ln muskrat harvests was not statistically significant ($F_{1896} = 2.16, p = 0.115, R^2 < 0.01$; Table 3-2) although the confidence interval for the regression coefficient for November NAO does not include zero ($\beta = -0.245$, $S.E. = 0.118$).

Easting was not included in the fixed-effect regression models because there was no variation in this variable (i.e. easting does not change over time) for the fixed-effects model to explain. Serial correlation was not detected in either the mink ($F_{81} = 1.163, p = 0.284$) or muskrat ($F_{81} = 0.023, p = 0.880$) fixed-effects regression model.

Discussion

The apparent synchrony between mink and muskrat harvests in eastern Canada might be confounded by perturbations from non-biological influences (Viljugrein et al. 2001). One such influence could be regional climate effects, captured in large-scale climatic features such as the NAO, which periodically synchronize trapping returns for both mink and muskrat in eastern Canada. After analyzing mink and muskrat harvest data from 82 Hudson's Bay Company Posts distributed across Canada, support for this hypothesis is provided.

Both mink and, to a lesser extent, muskrat harvests were positively influenced by average November temperature across Canada (Table 3-1). This relationship is not surprising given that reduced fall harvest of aquatic furbearers occurs in years of early freeze up. The weaker relationship between muskrat harvest and average November temperature can be attributed to spring harvests for muskrats in some areas. While mink are mostly trapped in November and December, in some areas muskrat are trapped from fall through to spring. As a result mink harvest is affected to a greater extent by early freeze up than muskrat harvest.

Across Canada there is a positive influence of November temperature on change in mink and muskrat harvest. However, Canada is separated into three climatic regions (the Pacific-maritime, Continental, and Atlantic-maritime) which are based on climate effects such as temperature and precipitation (Hurrell and Vanloon 1997). In particular, the NAO has significant "impacts on weather and climate in the North Atlantic region" (Ottersen et al. 2001). When we compare both average and minimum November temperatures from across Canada with the November NAO index we see that there is a consistent negative correlation between November temperature and NAO at locations east of -70.00° longitude (Figure 3-2). So, even in November a positive NAO is associated with colder winters. Only a very weak correlation is seen between November temperatures and November NAO in western and central Canada.

The NAO has been suggested to operate through temperature effects on wildlife populations to either promote earlier food availability (Myneni et al. 1997) or to increase population densities by influencing the timing of reproduction (Crick et al. 1997). Viljugrein *et al.* (2001) went a step further to suggest that the NAO influences mink and muskrat harvest data by promoting higher fur returns for both species in mild winters as a result of an extended autumn trapping season. This hypothesis accounts for a) the lack of lags between the two species at eastern HBC posts (Viljugrein et al. 2001), b) greater mean correlation between winter NAO and the eastern harvest data of the two populations (Viljugrein et al. 2001), and c) greater correlation between eastern mink and muskrat populations (Figure 3-3).

We tested the hypothesis that harvests of mink and muskrat at eastern HBC Posts decreased during years of early freeze up, thereby providing a possible mechanism for synchronizing eastern mink and muskrat fur-returns. Change in mink harvest rate was shown to be influenced by November NAO at more eastern HBC Posts with November NAO describing 17% of the variation in change in ln mink harvests among HBC posts (Table 3-2). The change in mink harvest was shown to depend jointly upon November NAO and easting where eastern mink harvest decreased in positive November NAO years. This model demonstrates that in cold years with early freeze up mink harvests at eastern HBC posts are reduced.

November NAO poorly described the change in muskrat harvests (Table 3-2). However, November NAO had a significant negative affect on the change in muskrat harvest suggesting that the effects of November NAO are not restricted solely to eastern Canada. Of course, again we need to consider the impact that winter trapping and spring ratting might have on annual muskrat fur returns. Because muskrats have a longer trapping season than mink it is difficult to directly compare mink and muskrat harvest data.

The use of HBC fur-returns in the analysis of animal abundance has provided a great deal of valuable ecological data for ecologists to explore. Generally, the use of harvest data in the analysis of animal abundance is accepted (Stenseth et al. 1998) with the HBC data proving to be of particular quality given how the data are distributed through both time and space. Indeed, mink and muskrat trapping pressure was not originally suspected of being influenced by fur value because the Hudson's Bay Company made steady payments to trappers even while pelt prices in London fluctuated (Anderson 1928) and the only restrictive trade policy on pelts (for muskrat) ended in 1845 (Keith 1963). In addition, questionnaires completed by HBC post managers about the relative abundance of animals from year to year confirm that the muskrat cycle is a natural one (Elton and Nicholson 1942). Although fur returns are a useful surrogate for furbearer population size (Stenseth et al. 1998), our results demonstrate that external influences can affect trapping success in eastern Canada in ways that do not necessarily reflect abundance.

The results of this study should not deter those from using harvest data as an index to population levels of furbearers (Erickson 1981; Clark 1986). However, as we have shown, special consideration should be taken into account should one suspect that harvest levels are not constant through time due to trapper biases. This is of particular importance to those who are attempting to disentangle a potential predator-prey relationship between two species whose association varies in strength over space (Erb et al. 2001), Chapter 2). With respect to mink and muskrat it appears that climate factors promote synchrony in eastern HBC fur harvests by working through strong perturbations that affect the ability of trappers to capture mink and muskrat in cold years.

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Table 3-1. Effect of November temperature, *p*-values, and adjusted R^2 for Prais-Winsten regression describing the influence of average November temperature on change in mink and muskrat harvest (*t*-1 to *t*) across Canada. Regressions were estimated using fur return panel data from 15 Hudson's Bay Company Posts (1925-1949) and November average temperature from temperature stations less than 100 km from HBC posts.

		Mink models			**Muskrat models**		
HBC Post	**Temperature Station**	**Ave. Nov. Temp.**	***p***	R^2	**Ave. Nov. Temp.**	***p***	R^2
Fort St. James	Fort St. James	+	0.026	0.17	+	ns	0.00
Aklavik	Inuvik A	+	ns	0.05	+	ns	0.00
Fort Simpson	Fort Simpson A	+	ns	0.01	+	ns	0.00
Upper Hay	High Level A	+	ns	0.00	-	ns	0.00
Fort Vermillion	High Level A	+	ns	0.00	-	ns	0.06
Hay River	Hay River A	+	ns	0.00	-	ns	0.00
Fort McMurray	Fort McMurray A	+	ns	0.00	+	ns	0.02
Fort Smith	Fort Smith A	+	ns	0.00	-	ns	0.00
Fort Fitzgerald	Fort Smith A	+	0.093	0.08	+	ns	0.00
Fort Chipewyan	Fort Chipewyan A	+	0.060	0.11	+	ns	0.00
Minaki	Kenora A	+	ns	0.00	+	ns	0.00
Grassy Narrows	Kenora A	+	ns	0.01	+	ns	0.00
Mattice	Kapuskasing CDA	-	ns	0.05	-	ns	0.00
Moose Factory	Moosonee UA	+	0.029	0.16	+	0.025	0.16
Senneterre	Amos	+	ns	0.01	+	ns	0.02
	Total "+"	**14**			**10**		
	Total "-"	**1**			**5**		
	Z stat	**3.357**			**1.291**		
	p	**<0.001**			**0.098**		

Table 3-2. Estimated coefficients (β_i, * denotes significance with $p < 0.05$), standard errors (S.E.), and model fit parameters (F statistic, p-value (p), degrees of freedom ($d.f.$)) for fixed-effects regression describing the influence of the November North Atlantic Oscillation (NAO) index on change in mink and muskrat harvest (t-1 to t) and how this varies from western to eastern Canada. Regressions were estimated using fur return panel data from 82 Hudson's Bay Company Posts (1925-1949). November NAO and easting variables were scaled so that values fell between 0 and 1.

	Mink		**Muskrat**	
	β_i	**S.E.**	β_i	**S.E.**
November NAO	0.436*	0.112	-0.245*	0.118
Easting*	-	-	-	-
Nov NAO*Easting (Interaction term)	-0.592*	0.206	0.365	0.218
Constant	-0.131*	0.041	0.059	0.043
F statistic	8.03*		2.16	
p	< 0.001		0.115	
$d.f.$	1896		1956	
R^2 **within**	0.01		< 0.01	
R^2 **between**	0.17		< 0.01	
R^2 **Overall**	<0.01		< 0.01	

* Easting could not be included as a covariate in the fixed-effect regression models because there was no variation in this variable over time for the model to explain.

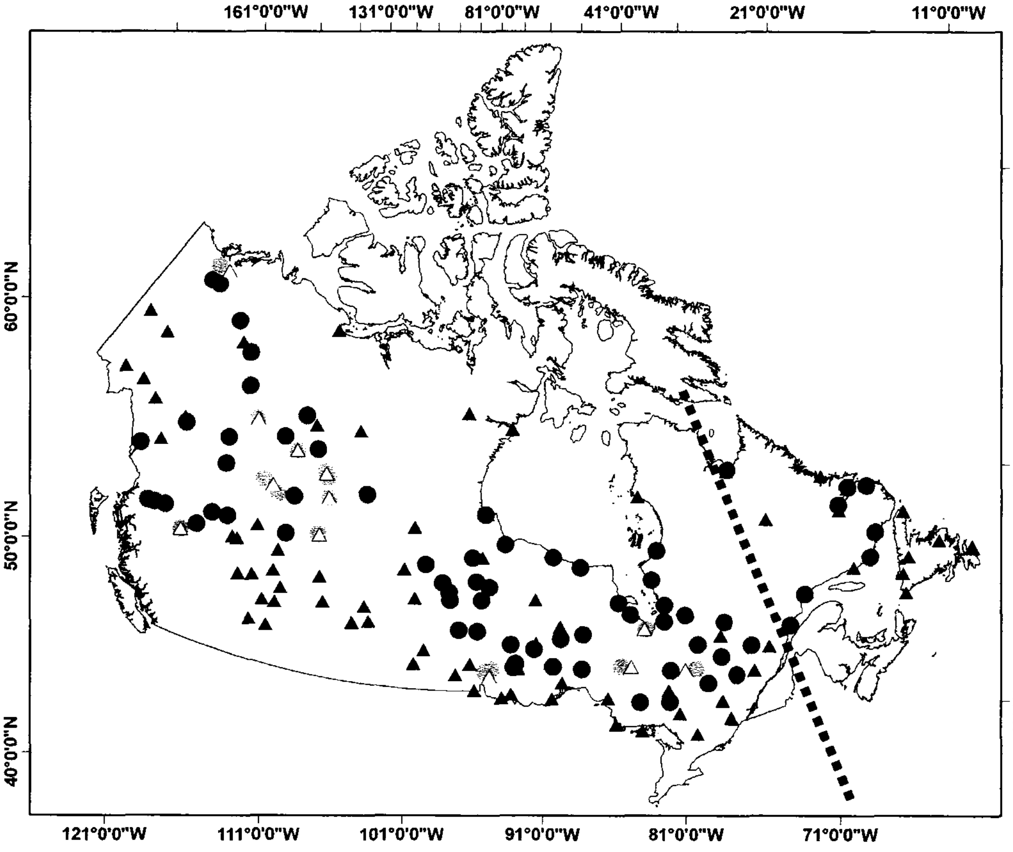

Figure 3-1. Map of 82 Hudson's Bay Company Posts (circles) and 90 Meteorological Service of Canada temperature stations (triangles). Light grey circles represent those HBC posts that have associated temperature data for 1925-1949 from temperature stations within a 100 km radius (white triangles). Dotted line highlights -70.00° longitude.

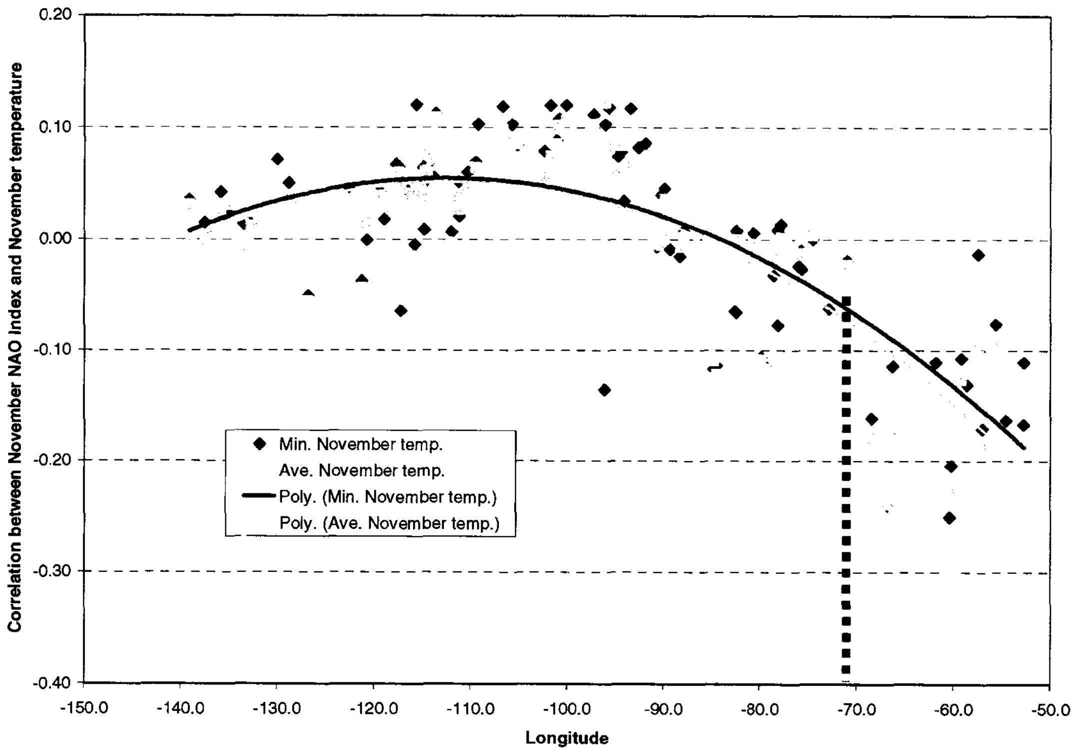

Figure 3-2. Correlation between November NAO index and both minimum November temperature (y = $-0.00007x^2 - 0.0152x - 0.803$, $R^2 = 0.58$) and average November temperature (y = $-0.00007x^2 - 0.0165x - 0.8717$, $R^2 = 0.64$) across 90 Canadian weather stations (Appendix E). Dotted line highlights -70.00° longitude.

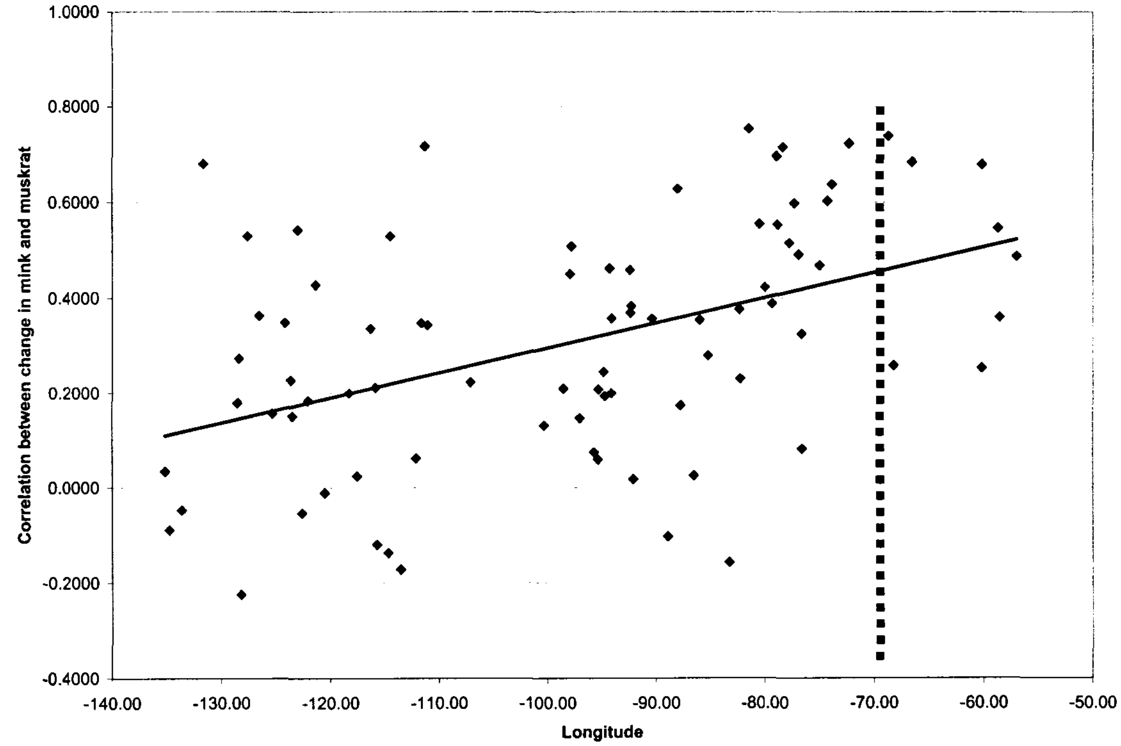

Figure 3-3. Correlation between change in ln mink harvest and change in ln muskrat harvest as a function of degrees longitude (correlation = 0.0053 longitude + 0.8219, R^2 = 0.21) across 82 Hudson's Bay Company Posts (Appendix C). Dotted line highlights -70.00° longitude.

CHAPTER 4: Conclusion

The goal of my research was to test two prominent hypotheses that attempt to explain geographical patterns in mink-muskrat predator-prey interactions in Canada. It has been suggested that mink and muskrat harvest data at Labrador and eastern Quebec Hudson's Bay Company posts 1) show the weakest mink-muskrat interactions because of greater mink prey species richness in Eastern Canada (Yao et al. 2000), and 2) are synchronous because regional climate effects periodically synchronize trapping returns resulting in increased synchronization of eastern populations (Viljugrein et al. 2001).

By documenting mink prey species richness patterns across Canada, I have shown that the diet of mink is not richer in Labrador and eastern Quebec. Prey species richness was highest near the Great Lakes-St. Lawrence region and across the boreal-prairie ecotone from Manitoba to Alberta. HBC posts in Labrador and Quebec were at high latitudes compared to the Great Lakes region with prey species richness more typical of western and northern populations (British Columbia, Yukon, and the Northwest Territories) where mink-muskrat interactions are strongest. I found percent occurrence of muskrat in mink diet was much lower in areas of high prey species richness as compared to areas of low prey richness supporting previous research on the interaction between smaller mustelid predators and their microtine prey (Hansson and Henttonen 1985). Local prey species richness therefore influences the degree of specialization of mink on muskrat.

Mink in northwestern Canada, where prey species richness was low, used muskrat to a much greater degree than those of southern Canada. These results provide further support for a strong predator-prey relationship between mink and muskrat in northwestern Canada. In contrast, I found weak support for linking muskrat cycles to mink predation in southern areas of Canada where prey species richness is greater.

In the end it was concluded that the weaker interaction between mink and muskrat at eastern HBC posts of Quebec and Labrador could not be explained by increased prey species richness in eastern Canada. It was suggested that eastern HBC posts were either a) not influenced by the prey pattern because mink of these posts use a completely different (i.e. coastal) prey composition than mink from other areas of Canada or b) the predator-prey relationship between mink and muskrat is confounded by perturbations to trapping effort and success which results in synchronization of mink and muskrat fur-return data.

After analyzing mink and muskrat harvest data from 82 Hudson's Bay Company Posts distributed across Canada, support was provided for the hypothesis that regional climate effects, as influenced by the North Atlantic Oscillation, periodically synchronize trapping returns for both mink and muskrat in eastern Canada. It appears that regional climatic effects as well as the effect that prey species richness has on muskrat specialization by mink are both important mechanisms that need to be understood to successfully describe mink-muskrat interactions across Canada.

To study aspects of the "10-year cycle of wildlife populations" long-term data sets for both predator and prey are required (Keith 1963). Hudson's Bay Company fur return data have been and continue to be used extensively for analyses of predator prey interactions over areas of large geographical extent. However, results of this study highlight one limitation of using harvest data as an index of furbearer populations. This study reaffirms the need for large-scale long-term experimental testing of the mink-muskrat predator-prey interaction to discover underlying mechanisms. By documenting mink prey species richness patterns and exploring the effect of North Atlantic Oscillation on Hudson's Bay Company mink and muskrat harvests we continue to develop greater insight into mink and muskrat interactions across Canada.

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APPENDIX A: Occurrence of food items in 756 mink digestive tracts collected from across Canada during winter, 2003/04 and 2004/05.

Prey Species	Stomach				Intestine				Total	
	Occurrence		Pred. Food*		Occurrence		Pred. Food*		Occurrence	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Ondatra zibethicus	53	(8.2)	38	(8.8)	107	(12.2)	95	(16.3)	117	(9.8)
Castor canadensis	9	(1.4)	6	(1.4)	10	(1.1)	6	(1.0)	12	(1.0)
Tamiasciurus hudsonicus	14	(2.2)	12	(2.8)	23	(2.6)	15	(2.6)	26	(2.2)
Glaucomys sabrinus	1	(0.2)	1	(0.2)	1	(0.1)	1	(0.2)	1	(0.1)
Glaucomys spp	0	(0.0)	0	(0.0)	1	(0.1)	1	(0.2)	1	(0.1)
Unidentified sciurid	1	(0.2)	1	(0.2)	4	(0.5)	2	(0.3)	5	(0.4)
Microtus longicaudus	0	(0.0)	0	(0.0)	1	(0.1)	1	(0.2)	1	(0.1)
Microtus ochrogaster	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Microtus pennsylvanicus	6	(0.9)	6	(1.4)	9	(1.0)	9	(1.5)	13	(1.1)
Microtus spp.	16	(2.5)	16	(3.7)	23	(2.6)	23	(3.9)	30	(2.5)
Clethrionomys spp.	3	(0.5)	3	(0.7)	2	(0.2)	2	(0.3)	5	(0.4)
Synaptomys borealis	2	(0.3)	2	(0.5)	2	(0.2)	2	(0.3)	2	(0.2)
Phenacomys intermedius	2	(0.3)	2	(0.5)	3	(0.3)	2	(0.3)	4	(0.3)
Phenacomys/Synaptomys	6	(0.9)	5	(1.2)	8	(0.9)	7	(1.2)	11	(0.9)
Unidentified vole	1	(0.2)	1	(0.2)	9	(1.0)	3	(0.5)	10	(0.8)
Mus musculus	2	(0.3)	1	(0.2)	3	(0.3)	3	(0.5)	3	(0.3)
Peromyscus maniculatus	1	(0.2)	1	(0.2)	1	(0.1)	1	(0.2)	1	(0.1)
Zapus hudsonius	1	(0.2)	1	(0.2)	1	(0.1)	1	(0.2)	1	(0.1)
Unidentified Rodent	6	(0.9)	2	(0.5)	11	(1.3)	5	(0.9)	14	(1.2)
Lepus americanus	30	(4.7)	21	(4.8)	41	(4.7)	33	(5.7)	50	(4.2)
Sylvilagus florianus	4	(0.6)	4	(0.9)	3	(0.3)	3	(0.5)	4	(0.3)
Unidentified lagomorph	0	(0.0)	0	(0.0)	2	(0.2)	2	(0.3)	2	(0.2)
Sorex arcticus	4	(0.6)	3	(0.7)	4	(0.5)	4	(0.7)	4	(0.3)

	Stomach				Intestine				Total	
Prey Species	**Occurrence**		**Pred. Food***		**Occurrence**		**Pred. Food***		**Occurrence**	
	n	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**
Sorex cinereus	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Sorex hoyi	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Sorex palustris	3	(0.5)	2	(0.5)	3	(0.3)	3	(0.5)	4	(0.3)
Sorex spp.	23	(3.6)	14	(3.2)	34	(3.9)	20	(3.4)	40	(3.4)
Blarina brevicaua	3	(0.5)	2	(0.5)	3	(0.3)	2	(0.3)	4	(0.3)
Condylura cristata	3	(0.5)	3	(0.7)	8	(0.9)	3	(0.5)	8	(0.7)
Unidentified insectivore	4	(0.6)	1	(0.2)	5	(0.6)	2	(0.3)	7	(0.6)
Mustela erminea	1	(0.2)	1	(0.2)	1	(0.1)	1	(0.2)	1	(0.1)
Mustela martes	3	(0.5)	2	(0.5)	3	(0.3)	2	(0.3)	3	(0.3)
*Mustela vison***	4	(0.6)	4	(0.9)	3	(0.3)	2	(0.3)	4	(0.3)
Lutra canadensis	1	(0.2)	0	(0.0)	1	(0.1)	1	(0.2)	1	(0.1)
*Mustela spp.****	5	(0.8)	5	(1.2)	4	(0.5)	4	(0.7)	6	(0.5)
Odocoileus spp.	0	(0.0)	0	(0.0)	2	(0.2)	2	(0.3)	2	(0.2)
Unidentified mammal	17	(2.6)	13	(3.0)	25	(2.8)	18	(3.1)	37	(3.1)
Mammal total	**232**	**(36.0)**	**176**	**(40.6)**	**361**	**(41.1)**	**281**	**(48.1)**	**437**	**(36.8)**
Pimephales promelas	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Cyprinidae spp.	26	(4.0)	21	(4.8)	17	(1.9)	14	(2.4)	39	(3.3)
Catostomus spp.	10	(1.6)	9	(2.1)	8	(0.9)	6	(1.0)	13	(1.1)
Semotilus atromaculatus	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Esox lucius	26	(4.0)	21	(4.8)	22	(2.5)	18	(3.1)	35	(2.9)
Culaea inconstans	12	(1.9)	11	(2.5)	9	(1.0)	6	(1.0)	17	(1.4)
Pungitius pungitius	5	(0.8)	4	(0.9)	3	(0.3)	3	(0.5)	7	(0.6)
Lota lota	0	(0.0)	0	(0.0)	1	(0.1)	1	(0.2)	1	(0.1)
Stizostedion spp.	8	(1.2)	6	(1.4)	8	(0.9)	5	(0.9)	10	(0.8)
Perca flavescens	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Percopsis omiscomaycus	1	(0.2)	1	(0.2)	1	(0.1)	1	(0.2)	2	(0.2)

Prey Species	Stomach				Intestine				Total	
	Occurrence		Pred. Food*		Occurrence		Pred. Food*		Occurrence	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Prosopium cylindraceum	2	(0.3)	2	(0.5)	1	(0.1)	1	(0.2)	2	(0.2)
Coregonus clupeaformis	16	(2.5)	11	(2.5)	3	(0.3)	3	(0.5)	19	(1.6)
Coregonus spp.	20	(3.1)	16	(3.7)	6	(0.7)	4	(0.7)	21	(1.8)
Oncorhynchus spp.	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Cottus spp.	9	(1.4)	9	(2.1)	13	(1.5)	11	(1.9)	16	(1.3)
Unidentified fish	95	(14.8)	60	(13.8)	188	(21.4)	124	(21.2)	221	(18.6)
Fish total	**234**	**(36.3)**	**175**	**(40.3)**	**280**	**(31.9)**	**197**	**(33.7)**	**407**	**(34.3)**
Anseriformes	7	(1.1)	5	(1.2)	2	(0.2)	2	(0.3)	8	(0.7)
Galliformes	6	(0.9)	6	(1.4)	5	(0.6)	4	(0.7)	8	(0.7)
Charadriiformes	2	(0.3)	2	(0.5)	2	(0.2)	1	(0.2)	3	(0.3)
Passerifromes	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Bird egg	2	(0.3)	1	(0.2)	2	(0.2)	0	(0.0)	2	(0.2)
Unidentified Bird	24	(3.7)	14	(3.2)	32	(3.6)	21	(3.6)	45	(3.8)
Bird total	**42**	**(6.5)**	**29**	**(6.7)**	**43**	**(4.9)**	**28**	**(4.8)**	**67**	**(5.6)**
Salamander	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Toad	1	(0.2)	1	(0.2)	0	(0.0)	0	(0.0)	1	(0.1)
Ranas pipiens	2	(0.3)	2	(0.5)	0	(0.0)	0	(0.0)	2	(0.2)
Frog Eggs	1	(0.2)	0	(0.0)	1	(0.1)	0	(0.0)	1	(0.1)
Rana spp.	23	(3.6)	15	(3.5)	11	(1.3)	7	(1.2)	30	(2.5)
Unidentified Amphibian	21	(3.3)	12	(2.8)	51	(5.8)	29	(5.0)	60	(5.1)
Amphibian total	**49**	**(7.6)**	**31**	**(7.1)**	**63**	**(7.2)**	**36**	**(6.2)**	**95**	**(8.0)**
Stonefly	0	(0.0)	0	(0.0)	1	(0.1)	0	(0.0)	1	(0.1)
Ant	2	(0.3)	0	(0.0)	0	(0.0)	0	(0.0)	2	(0.2)
Cadicefly larvae	0	(0.0)	0	(0.0)	1	(0.1)	0	(0.0)	1	(0.1)

Prey Species	Stomach				Intestine				Total	
	Occurrence		Pred. Food*		Occurrence		Pred. Food*		Occurrence	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Beetle	2	(0.3)	0	(0.0)	9	(1.0)	3	(0.5)	11	(0.9)
True bugs	1	(0.2)	1	(0.2)	2	(0.2)	2	(0.3)	2	(0.2)
Unidentified Insect	51	(7.9)	10	(2.3)	63	(7.2)	13	(2.2)	95	(8.0)
Insect total	**56**	**(8.7)**	**11**	**(2.5)**	**76**	**(8.7)**	**18**	**(3.1)**	**112**	**(9.4)**
Snail	1	(0.2)	0	(0.0)	4	(0.5)	1	(0.2)	5	(0.4)
Mollusks	3	(0.5)	0	(0.0)	13	(1.5)	1	(0.2)	16	(1.3)
Fresh water shrimp	1	(0.2)	1	(0.2)	1	(0.1)	0	(0.0)	1	(0.1)
Crab	10	(1.6)	7	(1.6)	11	(1.3)	10	(1.7)	13	(1.1)
Crayfish	11	(1.7)	4	(0.9)	10	(1.1)	4	(0.7)	15	(1.3)
Crustaceans	4	(0.6)	0	(0.0)	14	(1.6)	8	(1.4)	17	(1.4)
Unidentified invertebrate	1	(0.2)	0	(0.0)	2	(0.2)	0	(0.0)	3	(0.3)
Other total	**31**	**(4.8)**	**12**	**(2.8)**	**55**	**(6.3)**	**24**	**(4.1)**	**70**	**(5.9)**
Total no. of prey items	**644**	**(100)**	**434**	**(100)**	**878**	**(100)**	**584**	**(100)**	**1188**	**(100)**
Mustela vison hair	76		0		182		3		224	
Mustela vison toes	11		6		10		7		16	
Plant	342		0		510		0		581	
Number of mink examined	756				756				756	
No. of empty guts	279				108				139	

*Predominant food: species composed the greatest percent by volume of each scat

**Classified as predation event (Mink guard hair greater than 50% volume of contents)

***Mustela erminea, M. frenata, or M. nivalis

APPENDIX B: List of North American mink prey species identified in the literature.

	Common name	Scientific name
	MAMMALS	
1	Opossum	_Didelphis virginiana_
2	Arctic shrew*	_Sorex arcticus_**
3	Masked shrew*	_Sorex cinereus_
4	Long-tailed shrew	_Sorex dispar_
5	Pigmy shrew*	_Sorex hoyi_**
6	Water shrew*	_Sorex palustris_**
7	Short-tailed shrew*	_Blarina brevicaua_
8	Least shrew	_Cryptotis parva_
9	Star-nosed mole*	_Condylura cristata_
10	Eastern mole	_Scalopus aquaticus_
11	Little brown bat	_Myotis lucifugus_
12	Indiana myotis	_Myotis sodalis_
13	Eastern cottontail*	_Sylvilagus floridanus_
14	Snowshoe hare*	_Lepus americanus_
15	Yellow-pine chipmunk	_Tamias amoenus_
16	Marmot (woodchuck)	_Marmota monax_
17	Richardson's ground squirrel	_Spermophilus richardsonii_
18	Columbian ground squirrel	_Spermophilus columbianus_
19	Thirteen-lined ground squirrel	_Spermophilus tridecemlineatus_
20	Gray squirrel	_Sciurus carolinus_
21	Fox squirrel	_Sciurus niger_
22	Red squirrel*	_Tamiasciurus husonicus_
23	Southern flying squirrel	_Glaucomys volans_
24	Northern flying squirrel*	_Glaucomys sabrinus_**
25	Plains pocket gopher	_Geomys bursarius_
26	Beaver*	_Castor canadensis_**
27	Rice rat	_Oryzomys palustris_
28	Western harvest mouse	_Reithrodontomys megalotis_
29	Deer mouse*	_Peromyscus maniculatus_
30	White-footed mouse	_Peromyscus leucopus_

	Common name	**Scientific name**
	MAMMALS continued	
31	Cotton rat	*Sigmodon hispidus*
32	Northern red-backed vole	*Clethrionomys rutilus*
33	Southern red-backed vole	*Clethrionomys gapperi*
34	Heather vole*	*Phenacomys intermedius*
35	Meadow vole*	*Microtus pennsylvanicus*
36	Tundra vole	*Microtus oeconomus*
37	Long-tailed vole*	*Microtus longicaudus***
38	Prairie vole*	*Microtus ochrogaster*
39	Pine mouse	*Microtus pinetorum*
40	Muskrat*	*Ondatra zibethicus*
41	Brown lemming	*Lemmus sibiricus*
42	Southern bog lemming	*Synaptomis cooperi*
43	Northern bog lemming*	*Synaptomis borealis*
44	Brown (Norway) rat	*Rattus norvegicus*
45	House mouse*	*Mus musculus*
46	Meadow jumping mouse*	*Zapus hudsonius*
47	Marten*	*Martes americana***
48	Ermine*	*Mustela erminea*
49	Mink*	*Mustela vison*
50	Otter*	*Lontra canadensis***[t]
51	House cat	*Felis domestica*
52	Deer*	*Odocoileus* spp.[t]
	FISH	
53	Fathead minnow*	*Pimephales promelas***
54	White Sucker	*Catostomus commersoni*
55	Creek chub*	*Semotilus atromaculatus***
56	Nothern pike*	*Esox lucius*
57	Brook Stickleback*	*Culaea inconstans*
58	Ninespine Stickleback*	*Pungitius pungitius***
59	Burbot*	*Lota lota***
60	Walleye	*Stizostedion vitreum*
61	Yellow perch*	*Perca flavescens*
62	Trout-perch*	*Percopsis omiscomaycus***

	Common name	**Scientific name**
	FISH continued	
63	Round Whitefish*	*Prosopium cylindraceum***
64	Lake Whitefish*	*Coregonus clupeaformis***
65	Dog (Chum) Salmon	*Oncorhynchus keta*
66	Kokanee (Sockeye) Salmon	*Oncorhynchus nerka*
67	Mottled Sculpin	*Cottus bairdii*
68	Arctic Grayling	*Thymallus arcticus*
69	Mosquito fish	*Gambusia affinis*
70	Golden shiner	*Notemigonus crysoleucas*
71	Lingcod	*Ophiodon elongatus*
72	Shinner	*Notropus cornutus*
73	Eel	*Anguilla bostoniensis*

*Prey items identified in this study

**New prey items found in this study

[t] Not included in mink prey species richness map

APPENDIX C: List of 82 Hudson's Bay Company (HBC) fur trading posts with Latitude, Longitude, northing, easting, and prey species richness ("Richness").

Post	HBC post name	Latitude	Longitude	northing	easting	Richness
1	Telegraph Creek	57.68	-131.64	0.59559	0.00000	26
2	Kitwanga	55.12	-128.21	0.46461	0.00967	26
3	Hazelton	55.20	-127.61	0.46085	0.01812	26
4	Babine	55.33	-126.56	0.45457	0.03277	25
5	Fort St. James	54.48	-124.20	0.39825	0.05403	24
6	Lower Liard	59.87	-128.42	0.64017	0.06247	26
7	McLeod's Lake	55.07	-123.01	0.40917	0.07552	25
8	Hudson Hope	56.00	-122.08	0.43572	0.09656	26
9	Fort McPherson	67.38	-134.77	0.96678	0.09816	23
10	Fort Wrigley	63.24	-123.68	0.72389	0.14909	25
11	Fort Norman	64.91	-125.31	0.79913	0.15036	26
12	Trout Lake	56.27	-114.50	0.38807	0.19720	29
13	Fort Rae	62.82	-115.90	0.65598	0.22694	25
14	Fort Smith	60.12	-112.12	0.52836	0.25187	30
15	Fond du Lac	59.36	-107.13	0.47625	0.30875	27
16	Nelson House	55.88	-100.31	0.31564	0.38824	29
17	Cross Lake	54.41	-97.94	0.25243	0.42007	31
18	Berens River	52.33	-97.03	0.16513	0.43243	34
19	Island Lake	53.96	-94.88	0.23329	0.46448	30
20	Grassy Narrows	50.13	-94.16	0.07368	0.47758	36
21	Hudson	50.21	-92.31	0.07913	0.50727	33
22	Lac Seul	50.42	-92.10	0.08848	0.51021	33
23	Fort Hope	51.52	-88.03	0.14390	0.57162	31
24	Weenusk	55.29	-85.26	0.30873	0.59896	28
25	Long Lake	49.75	-86.54	0.07577	0.60076	31
26	Ogoki	51.60	-86.01	0.15431	0.60227	31
27	Gogama	47.42	-82.29	0.00000	0.68062	35
28	Moose Factory	51.25	-80.52	0.16751	0.68777	29
29	Temagami	47.10	-80.00	0.00155	0.72076	36
30	La Sarre	48.73	-79.31	0.07305	0.72191	33
31	Senneterre	48.43	-77.26	0.07612	0.75681	31
32	Pointe Bleue	48.72	-72.32	0.13118	0.83255	32
33	Aklavik	68.24	-135.16	1.00000	0.10706	21
34	Arctic Red River	67.41	-133.64	0.95789	0.10760	23
35	Fort Nelson	58.79	-122.62	0.54688	0.11675	27
36	Fort St. John	56.14	-120.53	0.42782	0.11766	27
37	Fort Liard	60.19	-123.49	0.60732	0.12062	30
38	Fort Good Hope	66.24	-128.53	0.87339	0.13588	25
39	Fort Simpson	61.76	-121.38	0.65033	0.15890	28

Post	HBC post name	Latitude	Longitude	northing	easting	Richness
40	Upper Hay	58.78	-118.32	0.51293	0.16789	28
41	Fort Vermillion	58.22	-116.34	0.47743	0.18775	30
42	Fort Providence	61.35	-117.56	0.60816	0.19747	28
43	Little Red River	58.37	-114.69	0.47294	0.20932	30
44	Hay River	60.80	-115.73	0.57541	0.21404	30
45	Fort McMurray	56.70	-111.35	0.38703	0.24158	30
46	Fort Resolution	61.20	-113.54	0.57876	0.24202	29
47	Fort Fitzgerald	59.83	-111.63	0.51430	0.25604	30
48	Fort Chipewyan	58.79	-111.07	0.46973	0.25698	31
49	Wabowden	54.91	-98.59	0.27350	0.41122	30
50	Norway House	53.96	-97.80	0.23347	0.42185	32
51	Split Lake House	56.33	-95.72	0.33101	0.45196	29
52	Oxford House	54.99	-95.36	0.27577	0.45726	30
53	Little Grand Rapids	52.26	-95.36	0.16215	0.45788	34
54	Minaki	50.03	-94.77	0.06912	0.46786	37
55	Churchill	58.70	-94.30	0.42951	0.46993	26
56	God's Lake	54.68	-94.13	0.26320	0.47490	30
57	York Factory	57.02	-92.39	0.36173	0.49673	27
58	Cat Lake	51.46	-92.42	0.13117	0.50373	31
59	Osnaburgh House	51.12	-90.40	0.12089	0.53575	31
60	Nipigon House	50.08	-88.93	0.08115	0.56150	32
61	Severn	56.07	-87.75	0.33235	0.56180	28
62	Attawapiskat	52.97	-82.38	0.22707	0.65075	28
63	Mattice	49.54	-83.29	0.08186	0.65372	31
64	Albany	52.19	-81.51	0.20003	0.66766	28
65	Fort George	53.82	-78.92	0.28122	0.69571	23
66	Rupert's House	51.42	-78.81	0.18537	0.71274	29
67	Eastmain	52.27	-78.36	0.22269	0.71373	28
68	Nemaska	51.43	-76.89	0.19944	0.74129	28
69	Woswonaby	49.69	-76.57	0.13217	0.75874	29
70	Barriere	47.53	-76.64	0.04449	0.77336	33
71	Obijuan	48.69	-74.98	0.10545	0.79120	32
72	Mistassini	50.43	-73.84	0.18451	0.79472	31
73	Manowan	47.50	-74.25	0.06450	0.81245	34
74	Bersimis	48.92	-68.74	0.17668	0.88551	30
75	Great Whale River	55.31	-77.74	0.34821	0.70231	21
76	Fort Chimo	58.15	-68.26	0.53234	0.79909	19
77	Seven Islands	50.15	-66.53	0.24847	0.90535	28
78	North West River	53.60	-60.22	0.45243	0.95006	26
79	Rigolet	54.15	-58.58	0.49311	0.96327	22
80	Cartwright	53.67	-57.01	0.49763	0.98893	22
81	Romaine	50.26	-60.14	0.33418	0.99409	21
82	St. Augustine	51.28	-58.70	0.39078	1.00000	22

APPENDIX D: List of 35 mink collection sites and associated data acquired from cross-Canada mink diet study. Collection sites are sorted by easting and the variable values used in modelling percent muskrat in mink diet are recorded (refer to Table 2-2 for variable details).

#	Prov	northing	easting	# mink	weight	preyrichness	isrich	ssrich
1	BC	0.47221	0.00000	21	806.5	21	6	5
2	BC	0.43646	0.02937	2	619.3	27	2	6
3	BC	0.42704	0.06029	5	545.4	25	4	3
4	YK	0.66235	0.09794	25	606.6	27	13	11
5	NT	1.00000	0.14226	119	976.7	22	20	21
6	BC	0.41875	0.14686	2	418.0	27	1	1
7	NT	0.82940	0.16571	5	595.2	26	8	7
8	AB	0.27229	0.17741	6	744.1	27	5	3
9	NT	0.65919	0.18932	20	618.7	28	12	11
11	NT	0.62582	0.22842	7	828.3	28	3	4
12	NT	0.57686	0.23006	27	714.5	30	13	11
15	AB	0.30003	0.26244	4	940.4	33	3	2
16	AB	0.40931	0.27172	3	458.8	30	1	2
17	NT	0.64121	0.27179	5	807.8	25	1	1
18	NT	0.54624	0.28332	22	712.2	30	13	12
19	AB	0.48845	0.28829	3	590.4	31	5	5
21	SK	0.32679	0.35190	2	1053.7	31	2	3
23	SK	0.24034	0.36814	2	567.5	33	2	5
24	SK	0.18578	0.37974	5	893.6	32	5	6
25	MB	0.28597	0.40278	2	902.7	31	1	1
26	MB	0.35560	0.41893	15	726.5	29	10	8
27	MB	0.30695	0.43621	5	560.4	29	5	9
28	MB	0.31077	0.47104	41	762.4	29	21	17
29	MB	0.07490	0.47168	12	793.0	42	14	10
30	MB	0.10367	0.47846	34	725.7	38	16	11
31	MB	0.08549	0.49474	7	764.0	38	8	5
32	MB	0.13249	0.49483	9	588.6	36	7	5
33	MB	0.27312	0.49901	8	578.9	30	9	7
34	MB	0.35127	0.50780	9	755.7	27	8	9
35	ON	0.00000	0.76589	51	535.2	36	22	22
36	QB	0.10458	0.78575	102	497.2	31	32	32
37	QB	0.05303	0.78577	30	552.4	35	15	17
38	QB	0.18488	0.84068	48	467.9	32	25	18
39	QC	0.09834	0.88339	57	484.0	36	24	20
40	NL	0.46512	1.00000	36	406.2	26	16	14

APPENDIX E: List of 90 Canadian temperature stations acquired from the Climate Monitoring and Data Interpretation Division, Meteorological Service of Canada. Stations are sorted by Longitude and the length of time (# years) that was used in the correlation analysis is recorded.

#	ID	Station Name	Prov	Latitude	Longitude	# years
1	2100402	Dawson Airport	YK	64.1	-139.1	83
2	2100631	Haines Junction YT	YK	60.8	-137.5	58
3	2100700	Mayo A	YK	63.6	-135.9	79
4	2101300	Whitehorse A	YK	60.7	-135.1	61
5	2202570	Inuvik A	NT	68.3	-133.5	77
6	2101100	Teslin A	YK	60.2	-132.8	59
7	1192340	Dease Lake	BC	58.4	-130.0	58
8	2101200	Watson Lake A	YK	60.1	-128.8	65
9	2202800	Norman Wells A	NT	65.3	-126.8	60
10	1192940	Fort Nelson A	BC	58.8	-122.6	66
11	2202101	Fort Simpson A	NT	61.8	-121.2	83
12	1183000	Fort St John A	BC	56.2	-120.7	72
13	3070560	Beaverlodge CDA	AB	55.2	-119.4	83
14	3072920	Grande Prairie A	AB	55.2	-118.9	81
15	3062440	Entrance	AB	53.4	-117.7	83
16	3075040	Peace River A	AB	56.2	-117.4	72
17	3073146	High Level A	AB	58.6	-117.2	83
18	3062244	Edson A	AB	53.6	-116.5	83
19	2202400	Hay River A	NT	60.8	-115.8	83
20	3050520	Banff	AB	51.2	-115.6	83
21	2300902	Kugluktuk	NU	67.8	-115.1	73
22	3015522	Rocky Moutain House A	AB	52.4	-114.9	83
23	3065999	Slave Lake A	AB	55.3	-114.8	81
24	3061200	Campsie	AB	54.1	-114.7	83
25	2204100	Yellowknife A	NT	62.5	-114.5	61
26	3031093	Calgary Int'l A	AB	51.1	-114.0	83
27	3023720	Lacombe CDA	AB	52.5	-113.8	83
28	3012205	Edmonton Int'l A	AB	53.3	-113.6	66
29	2202200	Fort Smith A	NT	60.0	-112.0	83
30	3062693	Fort McMurray A	AB	56.7	-111.2	83
31	3072658	Fort Chipewyan A	AB	58.8	-111.1	83
32	3081680	Cold Lake A	AB	54.4	-110.3	78
33	4048520	Waseca	SK	53.1	-109.5	83
34	2201900	Fort Reliance	NT	62.7	-109.2	44
35	4057120	Saskatoon	SK	52.2	-106.6	83

#	ID	Station Name	Prov	Latitude	Longitude	# years
36	4056240	Prince Alberta A	SK	53.2	-105.7	83
37	4056120	Pilger	SK	52.4	-105.2	83
38	4063560	Island Falls	SK	55.5	-102.4	74
39	5060520	Brochet A	MB	57.9	-101.7	55
40	5052880	The Pas A	MB	54.0	-101.1	83
41	5010240	Birtle	MB	50.4	-100.8	81
42	5040680	Dauphin	MB	51.2	-100.0	83
43	5023222	Winnipeg Int'l A	MB	49.9	-97.2	83
44	2300500	Baker Lake A	NU	64.3	-96.1	57
45	5031200	Great Falls	MB	50.5	-96.0	79
46	5022760	Sprague	MB	49.0	-95.6	83
47	5061001	Gillam A	MB	56.4	-94.7	60
48	6034075	Kenora A	ON	49.8	-94.4	83
49	5060600	Churchill A	MB	58.7	-94.1	74
50	6022475	Fort Frances	ON	48.6	-93.4	83
51	6025203	Mine Centre	ON	48.8	-92.6	83
52	6037775	Sioux Lookout A	ON	50.1	-91.9	73
53	2300707	Chesterfield Inlet	NU	63.3	-90.7	82
54	6016527	Pickle Lake A	ON	51.5	-90.2	73
55	6010738	Big Trout Lake	ON	53.8	-89.9	63
56	6048261	Thunder Bay A	ON	48.4	-89.3	83
57	6041109	Cameron Falls	ON	49.2	-88.4	79
58	6014353	Lansdowne House (A	ON	52.2	-87.9	62
59	unknown	Wawa A	ON	48.0	-84.8	63
60	6057592	Sault Ste Marie A	ON	46.5	-84.5	58
61	6092925	Gore Bay A	ON	45.9	-82.6	83
62	6073975	Kapuskasing A	ON	49.4	-82.5	66
63	6073960	Kapuskasing CDA	ON	49.4	-82.4	82
64	6075425	Moosonee	ON	51.3	-80.7	83
65	6072225	Earlton A	ON	47.7	-79.9	65
66	6085700	North Bay A	ON	46.4	-79.4	64
67	6163171	Haliburton 3	ON	45.0	-78.5	83
68	7090120	Amos	QB	48.6	-78.1	80
69	7103282	Inujuak	QB	58.5	-78.1	82
70	7103536	Kuujjuarapik A	QB	55.3	-77.8	78
71	7034480	Maniwaki	QB	46.4	-76.0	83
72	6105976	Ottawa CDA	ON	45.4	-75.7	83
73	6106000	Ottawa MDonaldCart	ON	45.3	-75.7	64
74	7091399	Chibougamau Chapai	QB	49.8	-74.5	82
75	7074240	La Tuque	QB	47.4	-72.8	80
76	7060400	Bagotville A	QB	48.3	-71.0	83
77	7113534	Kuujjuaq A	QB	58.1	-68.4	56
78	7117825	Schefferville A	QB	54.8	-66.8	55
79	7047910	Sept-Iles A	QB	50.2	-66.3	58

#	ID	Station Name	Prov	Latitude	Longitude	# years
80	7045400	Natashquan	QB	50.2	-61.8	83
81	8501900	Goose A	NL	53.3	-60.4	62
82	8502400	Hopedale (Aut)	NL	55.5	-60.2	60
83	8402975	Port Aux Basques	NL	47.6	-59.2	60
84	8403800	Stephenville A	NL	48.5	-58.6	61
85	8401500	Deer Lake	NL	49.2	-57.4	69
86	8501100	Cartwright	NL	53.7	-57.0	69
87	8403401	St Anthony	NL	51.4	-55.6	83
88	8401700	Gander A	NL	49.0	-54.6	66
89	8403605	St John's West CDA	NL	47.5	-52.8	52
90	8403506	St John's A	NL	47.6	-52.7	83