INVESTIGATING THE POTENTIAL CAUSES OF MUSKRAT (ONDATRA ZIBETHICUS) DENSITY DECLINE ON PRINCE EDWARD ISLAND

BY

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MASTER OF SCIENCE

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ABSTRACT

Muskrats (*Ondatra zibethicus*) are the most abundant furbearer on Prince Edward Island (PEI). For this reason, they have long been considered a cornerstone of the trapping industry in the province. In the past decade, muskrat harvests have been decreasing throughout the province, and trappers are reporting substantial declines in muskrat density in areas that have traditionally been more productive.

To determine if muskrat harvests are indeed a function of abundance, multiple linear regression was used with predictor variables including weather, pelt prices, and the number of trappers. The number of trappers was found to be the strongest predictor of muskrat harvests, which suggests that declining muskrat harvests are most strongly related to reduced trapper effort.

Data were gathered on a number of important population parameters through both field and laboratory studies conducted in 2008 and 2009. Mark-recapture studies found that growth and survival from summer to trapping season were both within the ranges reported in previous studies from PEI and elsewhere in North America. Similarly, laboratory analysis of muskrat carcasses determined that sex and age ratios of PEI muskrats have not changed significantly since the late 1960’s, when a baseline study of the province’s muskrat population was conducted. Weight and body condition of individual muskrat carcasses did not suggest poor population health, although Tyzzer’s disease was diagnosed in a carcass recovered in the field, the first record of this disease in PEI. Productivity, as estimated from placental scar counts, was found to be significantly lower than in the late 1960’s, although the inclusion of data from different study sites may have introduced a bias into this analysis.

Field studies using remote-triggered cameras found raccoons (*Procyon lotor*) to be frequent visitors to muskrat houses during the summer months, although direct predation impacts could not be determined.

Although this study was not able to conclusively determine the causes of the apparent decline in density of PEI’s muskrat population, important information was gained nonetheless. This information will be useful in focusing future studies of the issue, which should include investigations into the roles of predation and Tyzzer’s disease in the density decline.
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CHAPTER ONE: LITERATURE REVIEW

1.1 Systematics

The muskrat (Ondatra zibethicus) is the largest of the microtine rodents, a group which also includes voles and lemmings. This species' place in the mammalian hierarchy is as follows: Class Mammalia, Order Rodentia, Suborder Myomorpha, Superfamily Muroidea, Family Cricetidae, Subfamily Arvicolinae, Genus Ondatra. Muskrats on PEI are of the Ondatra zibethicus zibethicus subspecies.

1.2 The Place of Muskrats in Wetland Ecosystems

Muskrats (Ondatra zibethicus) play key roles in wetland ecosystems, and their activities can exert strong influences on floral and faunal communities. Due to both their herbivorous foraging and use of plant materials in lodge building activities, muskrats alter the plant communities in their habitats. At times of high densities, muskrat use of emergent plant vegetation may be so heavy as to destroy large tracts of marsh vegetation, areas referred to as “eat-outs” (Lynch et al. 1947; Dozier et al. 1948; Errington 1963; Kadlec et al. 2007). Higgins and Mitsch (2001) found that in the growing season following muskrat incursion into new habitat, the biomass of emergent vegetation did not recover to the same degree in eat-out areas compared to control areas with little muskrat activity. Furthermore, increases in muskrat density three years after colonization of the two study wetlands corresponded to decreases in macrophyte cover of 17.4% and 17.3%, respectively. A similar effect was observed in Sweden (Danell 1979). In a summer preceded by two winters of high muskrat densities, the area covered
by emergent horsetail beds (*Equisetum* sp.) was reduced by 3% compared to summers following winters of low muskrat density. In this instance, the reduction in the dominant *Equisetum* sp. was accompanied by an overall increase in plant diversity, as several species of submerged plants colonized the new open water areas (Danell 1977). Connors et al. (2000) also detected a reduction in overall plant biomass and biomass of dominant cattail species (*Typha* sp.) in areas of muskrat activity, with this reduction being greatest closest to the lodges. However, they did not observe a subsequent increase in species diversity coinciding with the newly created open water areas. After expansion into previously unoccupied habitat in Russia, muskrat foraging has led to substantial changes in the macrophyte communities (Smirnov and Tretyakov 1998). Specifically, species such as bubble sedge (*Carex vesicaria*) have disappeared entirely in the study area since the arrival of muskrats, and a once dominant reed species has been reduced by 11.2% in this time. Overall, these authors detected a decline in the biodiversity of wetland plants in their study area which they attributed directly to the activities of the muskrat population.

Muskrat lodges themselves provide a unique habitat for plants within the marsh. Kangas and Hannan (1985) found that abandoned muskrat houses harboured a biomass of non-dominant marsh plants (those other than cattail and burr-reed (*Sparganium* sp.)) that was more than 30 times greater than the surrounding habitat. Furthermore, it was determined that significantly more plant species colonized abandoned as opposed to active muskrat houses, meaning that the effects of the muskrat alteration of habitat can persist long after the muskrat have moved on.
Changes in habitat structure can coincide with equally important changes in the invertebrate communities as well. As with other ecosystems, invertebrates in wetlands are key food sources for a variety of wildlife species, so changes in community composition can have significant effects at higher trophic levels. In Finland, researchers noted a change in the size distribution among the most abundant invertebrates coinciding with muskrat foraging (Nummi et al. 2006). The largest individuals tended to be found in the undisturbed *Equisetum* stands, whereas open water areas affected by muskrat foraging contained smaller species. In addition, invertebrate diversity was found to be lowest in these open water areas. Furthermore, only the open water areas created by muskrat grazing were found to have fish depredating the invertebrates. de Szalay and Cassidy (2001) found differences in the invertebrate community structures and diversity levels in the denuded areas around muskrat houses when compared to those found in intact cattail stands. Diversity was higher in cattail stands, and the open water around muskrat lodges had proportionally more gathering collector invertebrates, such as chironomid midges, and less scrapers, such as gammarid scuds. These invertebrate community responses were attributed to altered habitat characteristics such as changing the physical habitat through the removal of emergent vegetation, disturbance to sediments, and the enrichment of sediments through muskrat fecal deposition. In addition, the muskrat lodges themselves provide habitat for a variety of invertebrate species. Upon investigating an abandoned muskrat house, Judd (1970) noted 158 invertebrates representing 20 different species present in the house material.

The presence of muskrats in a wetland has numerous direct and indirect effects on other wildlife species as well. By opening up dense stands of emergent vegetation, muskrats
can create foraging habitat for dabbling ducks (Danell 1979). Muskrat lodges can function as islands in the marsh, and as such are used extensively by a variety of species, as reviewed by Kiviat (1978). This review noted more than 60 vertebrate species known to make use of muskrat lodges and/or burrows for such purposes as shelter, nesting, foraging, and resting. In fact, muskrat lodges can provide important nesting habitat for wetland birds such as common terns (Nickell 1966), common loons (Munro 1945), and trumpeter swans (Monnie 1966). Williams and Marshall (1937) found that muskrat houses were critical to breeding success of Canada geese in their study area in Utah, as 80% of all goose nests were associated with these structures. Spotted turtles use muskrat burrows as refuge areas at night and during times of exceptionally warm weather (Ernst 1976), and in Lake Erie, 89% of radio-tagged raccoons used muskrat houses as dens, particularly during warm weather (Urban 1970). Gas-bubbles associated with muskrat dens can provide enough oxygen to enable the survival of central mudminnows during times of winter anoxia (Klinger et al. 1982).

1.3 Muskrat Reproduction

Much is known about the breeding biology of the muskrat across much of its range. Movement data of adult muskrats suggest that they are monogamous during the breeding season (Sather 1958; also Caley et al. 1988). There is some variability in the reports of the onset of muskrat breeding. It was determined from year round observations of muskrat reproductive tracts that male sperm production begins in mid-December, while corpora lutea (temporary endocrine structures) begin to appear in significant numbers in females in late February in Maryland muskrats (Forbes 1942) and that the seasonal gonadal activity in both sexes terminates in late October. Olsen (1959)
determined from the examinations of muskrats trapped in Manitoba in early April that animals would not be in breeding condition for another month, and that the beginning of breeding was associated with a warm night with a light rain in early May. Danell (1978) found a close relationship between the date when 25% of muskrat copulations had occurred and a period of at least two days with a mean air temperature above 5°C. This link between the onset of breeding activity and weather conditions appears to be supported by the findings of Simpson and Boutin (1993) who compared muskrat populations in the Yukon and in southern Ontario. They found that in Ontario, muskrats began breeding in late April or early May, but in the Yukon breeding did not begin until mid-late June. Parker and Maxwell (1984) reported that the first breeding by muskrats in eastern New Brunswick varies with the year and is likely dependent on snow depths and the onset of warm weather in late February or early March. Errington (1937) stated that the main breeding season for muskrat in Iowa was May, June, and July, but that the first young were born in late April and some late litters were born well into August. Beer (1950) found a similar breeding season in the muskrats of Wisconsin, with breeding beginning in the first ten days of April and continuing until the middle of June. Those born of late summer and or fall litters represented 4.4% of over 23,000 muskrats examined by Dozier et al. (1948) in Maryland, and Lay (1945) found that in his Texas study areas muskrats bred throughout the winter when the weather was mild. The evidence is clear in support of a latitudinal gradient in muskrat breeding seasons.

While in more northern climates the breeding season does not appear to extend into the winter, Sather (1958) did detect noticeable patterns in the production of litters throughout the summer in Nebraska. In particular, he observed three peaks of litter
production; the first in late April/May, the second in the beginning of June, and the third in early August. Gashwiler (1950), meanwhile, observed just two such peaks of litter production in Maine muskrats: during the first week of June and in the second week of July.

The number of young produced per litter (litter size), as well as the number of litters produced per female per year, can vary widely across the muskrat’s range. Gashwiler (1950) hypothesized that the number of litters per year decreased with increasing latitude, but the number of young produced per litter increased. Consistent with this assertion, Simpson and Boutin (1993) found that female muskrats in the Yukon produced just one litter per year on average, whereas muskrats in their Ontario study area produced two litters. This is due to the fact that the Yukon muskrats commenced breeding so late in the season (mid-June), and while the investigators did not observe any differences in mean litter size, the Ontario muskrats produced significantly more young per year by virtue of having more litters. Parker and Maxwell (1984) found muskrats in New Brunswick to have an average of 2.36 litters per breeding season, and Proulx and Gilbert (1983) reported that most females in their study marsh in Ontario had two litters per breeding season. During the course of their study, Proulx and Gilbert (1983) observed that muskrats in the second year, which featured more favourable habitat conditions, produced on average four more young in their second litters compared to the previous year. Olsen (1959) observed changes in the average litter size as the breeding season progressed, with litter sizes increasing from small early-season to above average mid-season litters, with a corresponding reduction in average litter sizes from mid- to late-season. Average litter sizes reported from field observations include
5.4 (Gashwiler 1950), 7.1 and 7.3 (Olsen 1959), 6.0 and 6.5 (Sather 1958), and 7.12 and 6.7 (Simpson and Boutin). Using placental scar counts as an indicator of litter sizes, Arata (1959) determined the average litter size of muskrats from strip mine ponds in Illinois to be just 3.4. He attributed this low measure to the adverse environmental conditions in this habitat type, including scarce food available in winter, a limited number of burrowing sites, and a lack of streams to aid in dispersal. Similarly, Hjältén (1991) found a mean litter size of 3.9 in his study of the muskrat populations in Sweden, and determined that adult muskrats building houses in high quality habitat (surrounded by deep water, far from shore, and having adequate cover) produced significantly more young than those that built houses in poorer habitat. Conversely, Maxwell and Parker (1984) reported high productivity in New Brunswick muskrats, with a mean placental scar count of 19.8 (representing up to three litters) and a mean embryo count in pregnant females of 8.4. Using placental scar counts, Proulx and Buckland (1986) compared the productivity of muskrats in creeks, rivers, and ponds, and found no significant differences between these habitat types (6.0, 6.5, and 6.7 young per/litter, respectively).

Interestingly, the water level does not appear to affect muskrat reproduction. Errington (1937) observed no significant difference in the breeding of muskrats between an unusually wet summer and a drought summer in his Iowa study areas. Donohoe (1966) compared muskrat reproduction in areas of controlled and uncontrolled water levels, and found no significant difference in the mean placental scar counts of adult females from both habitat types.

In some cases, young muskrats born early in the breeding season can breed the same year, which is known as precocial breeding. Sather (1958) found evidence of precocial
breeding in muskrats in Nebraska, and noted that these individuals produced litters that were considerably smaller than those from adult females. Parker and Maxwell (1984) documented precocial breeding in New Brunswick, as 5% of all females removed from one impoundment were young-of-the-year that were pregnant or had previously given birth. These researchers suspected that this precocial breeding was initiated by reduced muskrat densities due to experimental harvest in this area, meaning that precocial breeding in this case functioned as a compensatory response. This result was not supported by the findings of Simpson and Boutin (1989), however, who found no evidence of precocial breeding in a harvested population of muskrats in the Yukon. The mean litter size of the precocial breeders reported by Parker and Maxwell (1984) was 7.5, less than the 8.4 mean litter size for adult females. In Ontario, Proulx and Buckland (1985) identified precocial breeding in three of 594 juvenile females examined, and these individuals had a mean litter size that was slightly larger than that from adult females from the same area (7.7 compared to 6.3 and 6.1). It was hypothesized that mild conditions in the previous winter allowed females to successfully rear their first litter unusually early, giving the young of that litter sufficient time to develop and produce their own litters the same year. Even if precocial breeding occurs in an area, it may not be common. Errington (1937), for example, saw no evidence of precocial breeding in Iowa, with even the oldest juveniles of the year still being obviously immature at seven months of age. However, more than two decades later, Errington (1961) reported precocial breeding in a small percentage of the muskrats in his Iowa study marshes.
1.4 Economic Value of the Muskrat

Muskrats have long been among the most economically valuable furbearers. While the muskrat pelt is not the most profitable, muskrat trapping remains lucrative by virtue of the large numbers that are harvested relative to other species. Numerous reports covering a large period of time, prepared by state and provincial wildlife agencies, list the muskrat among the most heavily harvested furbearer in their jurisdiction (Hubert Jr. 1981; Peck et al. 1985; Landholt and Genoways 2000, and Frawley 2007). According to Statistics Canada (2007), the muskrat ranked either first or second in terms of number of wild furs harvested every year between 1999 and 2007, with only the beaver exceeding it in certain years. A report by the United States International Trade Commission (2004) lists the muskrat, along with the raccoon and the beaver, as the principal species harvested in America based on monetary value. This report states that in 1997-1998 trapping season, 2,183,000 muskrats were harvested in the continental United States, worth over $6 million U.S. In 1925, Ashbrook listed the muskrat as the most valuable fur producer in the United States, and regarded the species as a staple of the American fur market. In fact, this author cited fur buyers of the time who suggested “as goes the muskrat, so goes the market”. Bailey (1937) called muskrat trapping one of Maryland’s most important industries, worth about $2 million annually at that time. Elton and Nicholson (1942), while studying muskrat population fluctuations, determined that 2,731,490 muskrats were trapped in Canada during the year of heaviest harvest, and that muskrat pelts were the most valuable wild fur crop in Canada at that time. Muskrat trapping can be of great importance to local economies. Schindler and Smol (2006) reported that in the period between 1960 and 1968, muskrat trapping accounted for
almost all of the disposable income of the native peoples of the Peace-Athabasca Delta in northern Canada. Muskrats in habitats other than natural marshes, such as those inhabiting farm ponds, can provide a secondary source of income for those owning the land (Beshears and Haugen 1953).

1.5 Predation

Muskrats are prey to many predators in and around wetland habitats. The degree of predation pressure on muskrat populations is usually a function of both the density of the population and the availability of alternate prey. However, the diversity of predators means that although no species feeds exclusively on muskrats, the cumulative effect of predation may in fact be severe when local predator populations are high. Predation pressure can also vary according to season, as changes in both local conditions and muskrat behaviour can alter the availability of this species to predators.

1.5.1 Mink

The predator most closely associated with muskrats is the mink (*Mustela vison*). The muskrat is indeed a preferred prey item of this species, and the mink is the predator best suited to pursuing and killing muskrats in North America (Errington 1954; Erb et al. 2001). Mink are capable of killing, skinning, and eating muskrats of all ages, although mature muskrats in healthy condition may present such a formidable defence as to deter predation attempts (Errington 1943). Field data show that mink consumption rates of muskrats range from two per day to two to three per week among individuals preying exclusively on muskrats (Errington 1943), but in some cases, mink have been known to kill thousands of muskrats on a local scale (Errington 1954). The effect of mink
predation on muskrats at the population level can be significant. In the northern regions of Poland, muskrat harvests have declined 170-fold since the early 1980's, coinciding with increased densities of mink in this region (Brzezinski et al. 2010).

Much has been written on the mink-muskrat relationship, particularly from the perspective of statistical analyses of population cycles. From historical harvest records, there is evidence of a distinct predator-prey relationship in some regions of Canada, most notably a lag in the population response of the mink to changes in the muskrat population. This trend was strongest in western and central Canada, where mink populations lagged one to three years behind those of muskrats (Erb et al. 2001), and the periodicity of the cycle was eight to nine years (Viljugrein et al. 2001). In eastern Canada, however, mink and muskrat populations fluctuated in synchrony, suggesting that the predator-prey relationship is weaker in this region (Erb et al. 2001; Haydon et al. 2001; Holmengen et al. 2008). Although it seems logical that this lesser dependence of mink on muskrats is due to increased availability of alternative prey items (greater prey diversity), this hypothesis was not supported by Shier and Boyce (2009), who found that mink prey diversity was actually lowest in eastern Canada. These researchers attributed the weak predator-prey relationship in eastern Canada to the high number of coastal trading posts from which the data were derived, areas where mink do not encounter muskrats.

The susceptibility of muskrats to mink predation and the severity of the impacts of this predation depend on many factors. Certain habitat conditions may predispose muskrats to mink predation. In Newfoundland, cattails (the preferred food and building material for muskrats) are scarce, so muskrats are forced to occupy habitat of poorer quality. In
this marginal habitat, it has been suggested that mink predation may lead to greatly
depressed muskrat populations, most likely because the habitat lacks adequate plant
materials for muskrats to build houses to supplement their burrows (Soper and Payne
1997). Similarly, drought conditions can increase the vulnerability of muskrats to mink
predation (Errington 1939, 1954), to the point of complete exploitation in some areas. In
Ontario, Proulx et al. (1987) found that during times with low water conditions, mink
travelled deeper into the marsh and muskrats became a more important part of the mink
diet. These areas were not accessible to mink during high water periods, and at these
times the mink fed primarily on other prey found at the marsh borders. In Iowa,
investigations by Errington (1939) revealed that exposure of bank burrows during times
of low water resulted in the killing of almost all adult muskrats by mink in a defined
section of marsh. Those that did gain refuge from mink predation during this period
were situated in lodges away from shore in deeper water, although records from Sweden
indicate that mink predation there is independent of water depth or distance of the lodge
from shore (Hjalten 1991). Errington’s work shows that the period of increased
predation pressure corresponding to drought can be quite acute, with mink focusing on
vulnerable muskrats for a week or two before switching to alternative prey.

Intrinsic characteristics of the muskrat population itself can influence the severity of
mink predation. Most notably, when the muskrat population is high, young muskrats and
some adults are forced to more upland and marsh edge habitat through conflicts with
those muskrats with established territories (Errington 1954). These areas are intensively
hunted by mink, and the muskrats pushed into these areas can be subject to heavy
predation. Errington (1954) also found that when the muskrat population is at a stable
level and suitable habitat is available for all individuals, mink predation on young muskrats is very low, and even non-existent despite a high density of mink in the marsh area. In this sense, Errington found that muskrat populations in his area were largely self-regulating and corresponded closely to the carrying capacity of the environment, as opposed to being controlled by mink predation. Even when the toll of mink predation was high, the mortality was largely of a compensatory nature, meaning that those losses were offset by less mortality from other factors (starvation, disease, etc) (Errington 1954). In times of high density, muskrats can be vulnerable to disease outbreaks, times during which mink can be very opportunistic in their exploitation of muskrat populations. In particular, it appears that mink are active scavengers of muskrats succumbing to disease outbreaks. In Iowa, Errington (1954) found that 65-70% of mink scats containing muskrat remains were associated with either scavenging or predation upon muskrats afflicted with hemorrhagic disease (now known as Tyzzer’s disease).

The importance of muskrats to the mink diet appears to vary with season and with region. In North Carolina, Wilson (1954) found muskrat remains in 5% of mink digestive tracts taken in the fall and winter. Similarly, Korschgen (1958) found muskrat remains in less than 2% of winter mink stomachs examined from Missouri. Conversely, Sealander (1943) identified muskrats as the most important prey item in the diet of Michigan mink in the winter, with remains occurring in 36% of mink stomachs and 24% of mink intestines. In the summer months, Hamilton Jr. (1940) identified muskrat as the most important food item of New York mink. In the most comprehensive and rigorous study of muskrat-mink interactions, Errington (1954) found that in the absence of adverse environmental conditions, mink predation on muskrat is low or negligible.
during the summer, fall, and early winter months, and that in the late-winter and spring
mink predation can be severe when muskrats become restless and travel on the snow or
ice. However, it is important to exercise caution when interpreting dietary data,
particularly when muskrat remains are poorly represented in the stomach contents and
scat. Low frequency of muskrats remains in the digestive tract or feces of mink may be
more a reflection of the level of the local muskrat population than of the minks’
preference for muskrats. As Errington (1954) said, “a marsh one year...may not have any
muskrats or so few that they would not comprise any significant proportion of the diet of
the minks if they were all eaten”.

1.5.2 Raccoon

Due to the fact that raccoons (*Procyon lotor*) make use of a variety of habitat types and
are not always associated with wetlands, only the food habit studies of raccoons in
marshes are relevant to a review of muskrats as prey items. In New York marshes,
Hamilton (1940) found the muskrat to be a relatively minor component of the summer
diet of raccoons. Similarly, Sather (1958) found only scant evidence of raccoon
predation upon muskrats. However, other research suggests that raccoons can be
important predators of muskrats. Lay (1945), for instance, listed raccoons and marsh
hawks as the most common winter predators of muskrats in Texas marshes.

An in-depth study of raccoon-muskrat relationships in a managed marsh was conducted
by Dorney (1954). This research found muskrat kits to be the second most important
food item of marsh raccoons in the summer, constituting approximately one third of
their total diet. In particular, kits less than 20 days of age were subject to the most severe
raccoon predation. In some instances, losses of this type were so high as to alter the age ratio of fall trapped muskrats. Similar raccoon depredation upon litters was determined to be the main factor accounting for depressed muskrat productivity and, ultimately, decreased fur yields in the marshes of North Carolina (Wilson 1953). This study found that in the spring and early summer months, when muskrat breeding was at its peak, almost 70% of muskrat houses were damaged by raccoons. Similar to the findings of Dorney (1954), analysis of the age structure of the fall trapped muskrats from this area showed a strong bias towards adults in the sample, suggesting poor survival of muskrat young as a result of raccoon predation. Conversely, significant predation on adult muskrats occurred only in late spring and late fall, times when the muskrats are known to be preoccupied with breeding and winter-house building activities, respectively (Dorney 1954). It is important to note, however, that the presence of adult muskrats in the fall diet of raccoons may well represent scavenging of trapped muskrats.

An important insight gained from these works is that muskrats that make use of bank burrows instead of houses gained refuge from raccoon predation. No instance of raccoon molestation of muskrat bank burrows was recorded by Dorney (1954), and Wilson (1953) noted that in nearby areas where muskrats predominantly occupied bank burrows instead of houses, production and fur yields appeared normal.

1.5.3 Red Fox

Like raccoons, red foxes (Vulpes vulpes) are opportunistic predators so the severity of the predation pressure they exert on muskrat populations is a function of the availability of muskrats as a food source. In some areas, such as in central Newfoundland (Dodds
and Missouri (Korschgen 1959) muskrats appear to be a relatively unimportant food item for red foxes. However, red foxes can be efficient predators of muskrats, particularly vulnerable individuals less than two weeks of age which are blind and unable to escape when foxes dig into their houses (Hjalten 1991). On Isle Royale, the muskrat is the second most common mammalian prey of red foxes, with only snowshoe hare being a more important food source (Johnson 1970). Upon investigating food habits of red foxes in Maryland, Heit (1944) concluded that this species constitutes a menace to the muskrat population, and went so far as to speculate that the foxes changed their denning habits to coincide with concentrations of muskrat. Danell (1978) found that the predation pressure exerted by red foxes on muskrat litters varied with year and was inversely related to the vole population in the area. In years when the vole population (the foxes’ main prey) was low, as high as 33% of muskrat litters within the study area were taken by foxes. Conversely, Dell’Arte et al. (2007) found no such correlation between the density of main prey and the level of predation on muskrats in Finland.

When habitat conditions place additional stressors on the muskrats, red foxes can increase their exploitation of this food source. Such was the case identified by Errington (1937), who found that the percentage of muskrat remains at red fox den sites and in fecal samples was elevated in a summer of drought when compared to a normal summer the previous year. In a subsequent summer of drought, Errington (1945) observed that foxes hunting systematically in family groups caught all but the adult muskrats on a 20 acre area of marsh. In this case, the foxes adopted a hunting system in which some foxes investigated muskrat feeding grounds and lodges while others waited beside well-
defined muskrat trails. Errington (1945) suggested that while the total number of muskrats killed by red foxes in this Iowa study area was far outnumbered by those killed by mink, the impact of fox predation in terms of muskrat production was in fact of more significance. He stressed that while mink usually exploited muskrats that would have otherwise died from some other mortality factor, the red fox predation targeted muskrats that would likely have otherwise survived drought conditions. It was estimated that a reduction of 25% in harvestable pelts resulted from this red fox predation.

Habitat characteristics and seasonal factors can also play a role in red fox predation on muskrats. Research by Hjalten (1991) showed that all red fox predation attempts occurred in houses built in shallow water within 40 meters of shore, whereas those in deeper water seemed to be inaccessible to the foxes. Danell (1978) suggested that fox predation is highest in summer and early autumn when water levels drop, leaving houses more vulnerable. A similar pattern was found by Heit (1944) in the marshes of Maryland, where fox predation upon muskrats was most severe in June and July. In these months, muskrat remains were present in about 68% of fox scats examined, and Heit attributed this increased predation to two factors: (1) the marsh became drier in summer, concentrating muskrats in wetter areas and leaving those in drier areas more vulnerable, and (2) the first muskrat litters were independent enough to wander and become an easy and energetically efficient food source. Danell (1978) also noted that during an early thaw, red foxes could access all houses because of the ice-cover, and could easily dig out thawed houses. This appears to be supported by the findings of Johnson (1970), who found that the percent of fox scats containing muskrat remains was highest in June (20%), while only 5.8% of winter scats contained muskrat remains.
Conversely, Eadie (1943) found that the percentage of red fox scats containing muskrat remains was higher in the winter months (6.3%) than in the summer months (0.9%).

### 1.5.4 Coyote

Coyotes (*Canis latrans*) are known to prey on muskrats, but the importance of muskrats to the coyote diet appears to range widely. In Texas, coyotes ate virtually no muskrats in any season (Best et al. 1981). Similar results were described in Montana and British Columbia (Murie 1945) and Missouri (Korschgen 1957), although the data in both studies were not necessarily obtained from coyotes frequently using wetlands as hunting grounds. Conversely, Sather (1958) determined the muskrat to be the second most common food item of the coyote in Nebraska. Furthermore, it was observed that coyotes exploited muskrats most heavily in the spring, during times of muskrat dispersal and movements across upland habitat (Fichter et al. 1955). In the winter, coyotes appeared to increase their focus on digging into muskrat houses in response to disease outbreaks in the muskrat populations, apparently in search of dead muskrats within the houses (Fichter et al. 1955). In the absence of such outbreaks, the researchers suggested that winter predation of coyotes on muskrats was minor. This conclusion is supported by the findings of Tiemeier (1955), who identified the remains of just one muskrat in a winter sample of 871 coyote stomachs.

### 1.5.5 Avian Predators

Predatory birds foraging in wetlands will prey on muskrats when conditions are favourable to do so. Errington et al. (1963) noted that when winter habitat conditions had deteriorated, birds of prey took advantage by feeding on desperate muskrats forced
to alter their normal behaviours. One of the more commonly listed predators in this
guild is the bald eagle (*Haliaeetus leucocephalus*). In Maryland, the consumption of
muskrats by bald eagles was a chief complaint among trappers (Smith 1936). While
analysis of nest remains did reveal that the muskrat was the most commonly found item,
it was suspected that stealing trapped muskrats and scavenging dead carcasses of
diseased individuals accounted for more than half of the total muskrats eaten by bald
eagles in this study marsh. In deeper water, tidal areas, muskrats appear to be a minor
component of bald eagle diets (Watson et al. 1991; Thompson et al. 2005), probably
reflecting low muskrat densities in these habitats. Although muskrat was the second
most common mammal recovered from bald eagle nests in Cape Breton, Nova Scotia,
the species accounted for only 1% of the total prey items found (Cash et al. 1985).
Similarly, a study of bald eagle food habits in Minnesota determined that the muskrat
was the most common mammalian prey, but that it comprised only 1.3% of the total
prey items and it was unknown if these individuals were actually killed by the eagles or
were scavenged (Dunstan and Harper 1975). Low levels of muskrat representation in
bald eagle diets were also documented in studies in Maine (Todd et al. 1982) and
Nebraska (Stalmaster and Plettner 1992).

Another avian predator known to take muskrats is the great-homed owl (*Bubo
virginianus*). Errington (1938) noted that when the extent of muskrat cover decreased,
great-homed owls responded with increased predation pressure on the muskrats despite
the fact that the muskrat population was much lower than in the previous year. Muskrats
were also noted in the diets of great-homed owls in Maine, with remains present in 8%
of the 86 stomachs examined (Mendall 1944). This same study mentioned that during
times of migratory influx, snowy owls (*Bubo scandiacus*) preyed extensively on muskrats in New England. This claim appears to be substantiated by the work of Keith (1963) in Pennsylvania, who determined muskrats to be a staple food of snowy owls in the winter. In cold weather, muskrats with houses in shallow water were particularly vulnerable due to freeze-outs, events in which the water freezes to the bottom forcing muskrats to the ice surface, making them easy prey for avian predators.

### 1.6 Disease

Muskrats are subject to outbreaks of highly pathogenic diseases. The wide range of disease conditions and endo-and ectoparasites known to affect muskrats are described in Erb and Perry (2003). This discussion will focus on those diseases of muskrats which are most important from a population perspective.

One of the most widely discussed diseases of muskrats is Tyzzer’s disease, caused by infection with the bacterium *Clostridium piliforme*. Long referred to as Errington’s disease, it was strongly suggested from work by Wobeser et al (1979) that Tyzzer’s disease and Errington’s disease were in fact the same. Outbreaks of Tyzzer’s disease among the muskrats of Iowa were described in detail by Errington (1954, 1961, 1967) who simply referred to it as hemorrhagic disease. The gross lesions of this disease usually consist of multifocal hepatic necrosis and hemorrhage into the walls of the cecum and colon (Karstad et al. 1971). Errington calculated that during ten years of observation, about 7,500 muskrats died as a result of this hemorrhagic disease, and suggested that this disease was present in muskrat populations over most of their range. The most serious outbreaks, those that can depopulate entire tracts of marsh, occur
during the cold weather months of late fall and winter. On such occasions, the widespread mortality may be almost imperceptible to observers, as the vast majority of mortalities occur in the lodges, and the muskrats are suddenly absent from the marsh. This pattern was also detected in Nebraska (Sather 1958), where muskrats affected by hemorrhagic disease were found dead in their houses associated with areas of high population density. In this case, the researcher correlated outbreaks of this disease with over-population stemming from non-harvest. Furthermore, Errington observed that localized areas of disease outbreak can retain their infectious properties for at least five years in the absence of any muskrats at all. This allows the disease to persist even at times of low populations, as new muskrats move into these areas (referred to by Errington as hotspots) and die within a few weeks. This notion of hotspots of infection appears to be supported by Wobeser et al. (1978), who found four muskrats dead in a single house in Saskatchewan with no observed mortality elsewhere in the marsh. A review of the records of the Canadian Cooperative Wildlife Health Centre by Wobeser et al. (2009) revealed that Tyzzer's disease has been diagnosed in muskrats in Ontario, Québec, Saskatchewan, and British Columbia.

Another important disease of muskrats is tularaemia, caused by infection with the bacterium *Francisella tularensis*. Recognized as a zoonotic disease (Sjöstedt 2007), tularaemia in muskrats is characterized by enlarged and necrotic spleens and multifocal hepatic necrosis (Langford 1954). Significant die-offs of muskrats have occurred as a result of infection with this organism. Danell (1996) reported an outbreak of tularaemia among the muskrats of northern Sweden in the early 1970s, and tularaemia was implicated in the deaths of hundreds of muskrats in Montana in the 1940's (Parker
In Ontario, Fyvie et al. (1959) reported severe, local muskrat mortality resulting from tularaemia on Wadpole Island. From area searches and interviews with locals, the investigators estimated that 70-80% of the area's muskrat population had been killed during the outbreak, and that this epizootic occurred following a year of very high muskrat abundance. At Loon Lake, Saskatchewan, an outbreak of tularaemia was responsible for the deaths of many muskrats, with carcasses prevalent in sloughs and in houses (Harris 1956). Ditchfield et al. (1960) concluded that an epizootic of tularaemia was responsible for the mortality of many muskrats in eastern Ontario during a period of peak abundance, and that many sick muskrats were easily caught by trappers. A die-off in which tularaemia was suspected, though not confirmed, was reported in Michigan by Lawrence et al. (1956). A review by Wobeser et al. (2009) found that tularaemia has been diagnosed in muskrats in British Columbia, Alberta, Saskatchewan, Manitoba, and Ontario.

Errington (1939, 1942, 1967) also described a fungal disease of the skin caused by the ringworm *Trichophyton mentagrophytes* that was the source of significant mortality and growth retardation in muskrat kits. Errington described the skin lesions as including a corrugated appearance of skin folds on ventral surfaces, bald spots on the top of the head and back, and patchy hairlessness on the extremities, face, and ventral thorax and abdomen. Diseased individuals less than two weeks of age succumbed to the infection without exception, and 92% of all infected animals apparently died as a result. Infected young were also subject to much heavier predation by mink as well, a pattern which Errington suggested could have been due to the audible whimpering of diseased, suffering litters. Errington determined that ultimately, mink predation upon these young
muskrats was compensatory, as the disease was so deadly that lesions appearing in one individual usually ensured the loss of the entire litter. This disease was also noted in the young of muskrats in Nebraska, and was most prevalent in those litters that had been disturbed and moved to new, wet nests (Sather 1958). When experimentally live-trapping muskrats in Iowa, Snead (1950) noted similar skin lesions in some young individuals, and he speculated that they were afflicted with the same skin disease described by Errington.

Other disease conditions have been implicated in large-scale die-offs of muskrats. In Oregon, severe infections of the cestode *Hymenolepis ondatrae* leading to occlusion of the small intestine were suspected to be the cause of a major die-off of muskrats over most of their range (Macy and Biggs 1953). In this case, up to fourteen muskrats were found dead in a single house. Shillinger (1938) reported that at times of low water levels or drought, massive infections with coccidial oocytes (coccidiosis) could occur among muskrat populations. Lesions included enteritis and hepatic necrosis, and mortality could be so heavy as to remove 75% of an area's muskrats. Shillinger suggested that such severe infestations resulted from a reduced ability to avoid fecal contamination among the muskrats because low water levels prevented the dilution and removal of waste from well-travelled areas. Severe hepatic infections with the larval stage of the cestode *Taenia (=Hydatigera) taeniaformis* were determined to be the cause of mass mortality of muskrats in Czechoslovakia in the early 1980's (Dvořáková and Prokopič 1984). Examined carcasses in this case revealed infections of 10-20 strobilocerci of this cestode covering the entire liver surface, rendering the liver unable to function and leading to the death of the animals. In Siberia, vast epizootics in muskrats occurring in
the 1940's were attributed to outbreaks of Omsk hemorrhagic fever (Fedorova and Sizemova 1964), a disease characterized by abundant hemorrhage in the internal organs. Indeed, a mixed outbreak of tularaemia and Omsk hemorrhagic fever was diagnosed as the causative factor of large-scale muskrat die-offs in Siberia in 1960-61 (Egorova et al. 1964).

1.7 Potential Effects of Environmental Contamination on Muskrat Populations

Wetland habitats can be vulnerable to contamination with substances from a variety of sources. Muskrats have long been recognized as a hardy species capable of existing in polluted environments (Ortmann 1909). Nonetheless, analyzing muskrat tissues and other samples for contaminants can be a useful indicator of this type of habitat pollution, and it has been suggested that muskrats have potential to function as pollution monitors (Everett and Anthony 1976; Parker 2004). Much of the work in this regard relates to muskrats inhabiting wetlands in the vicinity of known sources of pollution. Pascoe et al. (1996), for example, determined that in a wetland contaminated by mining operations, muskrats received the highest daily dose of all metals that were analyzed, including arsenic (As), cadmium (Cd), copper (Cu), and zinc (Zn), among the animals sampled including mice, voles, muskrats, beavers, waterfowl, osprey, bald eagles, and deer. These researchers suggested that this was due to this species' high intake of aquatic vegetation. This conclusion that muskrats are exposed to contaminants via the plant materials they consume appears to be supported by the findings of Erickson and Lindzey (1983). These researchers found that the site with the highest mean levels of lead (Pb) in cattail (*Typha angustifolia*) tissues also had the highest levels of Pb in muskrat livers. Furthermore, it was determined from this study that adult muskrats had significantly
higher levels of Pb and Cd in their livers and kidneys then did juveniles, meaning that these contaminants most likely accumulated in muskrat tissues over time. Everett and Anthony (1976) found similar positive correlations between concentrations of Cd, Zn, and Cu in plant tissues and muskrat tissues, and from this suggested that muskrats are valid indicators of pollution with these metals in aquatic ecosystems. Blus et al. (1987) reported low concentrations of Pb, Cu, mercury (Hg), and Cd in liver, kidney, and stomach content from muskrats trapped about 70 km downstream from a major mining and smelting operation in Idaho. Similarly, low levels of Hg were detected in muskrats in Wisconsin (Sheffy and St. Amant 1982), with mean concentrations being below 0.06 ppm in all tissues sampled (including liver, kidney, muscle, brain, and fur). Stevens et al. (1997) detected Hg in 75% of muskrat hair samples, and found that Hg levels were highest in muskrats from a stream known to have been subject to historical Hg contamination. Parker (2004) found significantly higher levels of Cd and nickel (Ni), but not Cu, Pb, or Zn, in muskrat livers and kidneys from a marsh highly impacted by industrial ore-smelting compared to those from a control site. This author suspected that Cd and Ni accumulated in the emergent cattail (Typha latifolia) stands used extensively as food for muskrats, and that this food chain transfer accounted for the elevated Cd and Ni levels detected in the muskrats from these areas.

Few studies have demonstrated an association between accumulation of environmental contaminants and reduced health of muskrats, although Halbrook et al. (1993) were able to relate elevated levels of aluminum (Al), Cd, Cu, Ni, and Zn with reduced weights and increased incidence of liver parasitism in muskrats from a contaminated site compared to those from an un-impacted control site. It is important to note, however, that no
differences in muskrat density or reproductive output were detected between the contaminated and control sites. So although individual health appears to have been impaired as a result of metal contamination, the net effects in terms of overall population health appeared to have been negligible.

Studies have examined the effects on muskrats of contaminants other than metals, although literature in this area is limited. For example, polychlorinated biphenyl (PCB) concentrations were determined in liver samples obtained from muskrats from the Hudson River, New York (Mayack and Loukmas 2001). Low levels of PCB were reported in the muskrats sampled, despite the fact that the authors cited this river as having the highest PCB loadings of any major river in the United States. The authors concluded that the low levels of PCB were a reflection of the herbivorous foraging patterns and short lifespan of the muskrat, resulting in a low potential for accumulation. Similarly, low levels of PCB, DDT, and chlordane were detected in muskrat liver and muscle samples from the Northwest Territories (Kennedy 1999 and Snowshoe 2003 in Gamberg et al. 2005). In these studies, the levels detected were considered normal for terrestrial wildlife.

Post (1951) and Hanson (1952) reported finding dead muskrats following application of the herbicide chlordane, although the cause of death in either case was not definitively determined to be the chemical. Scott et al. (1959) reported severe losses of muskrats almost immediately following application of the insecticide dieldrin to nearby agricultural fields. PCB and DDE, a major metabolite and breakdown product of the organochlorine insecticide DDT, were detected in the hind leg muscle of a single
muskrat in Finland, but no mention was made of toxic effects in this individual (Koivusaari 1976).

Greer et al. (2005) discussed the mortality of muskrats due to contamination with oil of wetland habitat in Maryland resulting from the rupture of an underground pipeline. Estimated mortality in the most densely populated area was 315 of an estimated population of 795 individuals. After observing precipitous muskrat decline in a marsh in Hamilton, Ontario following application of a fuel oil/DDT mixture for the purposes of mosquito control, Wragg (1954) determined that the oil had more detrimental effects on muskrats then did the DDT. He showed experimentally that the oil had serious effects on the waterproofing and buoyancy of muskrats, and that muskrats swimming in oil polluted water suffered from exposure. Beatty (1948) also discussed heavy mortality of muskrats due to oil pollution in Michigan, resulting in completely saturated hair coats and possibly causing internal toxicity. This report also noted markedly reduced quality of muskrats harvested from a stream contaminated by gold dredging wastes in Oregon, and that coal mining wastes had made certain streams uninhabitable for muskrats in Pennsylvania. In a watershed receiving uranium tailings from mining and milling activities, Mirka et al. (1996) found a highly significant positive correlation between radium-226 concentrations in muskrat bones and in the waters of their habitat. They also found that radium-226 concentrations were highest in the root tissues of cattails, the part of the plant used most extensively for food by the muskrat. This study concluded that muskrats were useful indicators of radium-226 pollution in aquatic habitats. This notion is supported by the findings of Pendleton et al. (1964), who associated relatively high
radium levels in muskrats with an accidental release of wastes from a uranium refining plant in Utah.

CHAPTER TWO: ESTABLISHING EVIDENCE TO CONFIRM A POTENTIAL DECLINE IN MUSKRAT DENSITY

2.1 INTRODUCTION

In the past decade, trappers on Prince Edward Island (PEI), Canada, have regularly reported declining harvests of muskrat (Ondatra zibethicus). Muskrat trapping is an important source of income for many trappers on PEI, and the muskrat is the most heavily harvested furbearer in the province (Dibblee, unpublished). Aside from the total annual harvest figures maintained by the PEI Department of Environment, Energy, and Forestry, no population monitoring for this species has occurred in the past forty years.

Overall harvest can be influenced by such external factors as pelt prices, the number of trappers (Poole and Mowat 2001), and weather (Clark 1986), and as a result, the number of muskrats harvested may not be indicative of actual population declines (Wlosinski and Wlosinski 1998). However, anecdotal reports by trappers of localized declines in muskrat harvest constitute the primary evidence a decline in muskrat populations, particularly in the absence of additional demographic monitoring. This type of local ecological knowledge can be a useful tool in wildlife management (Huntington 2000; Moller et al. 2004), but is sometimes difficult to collect, quantify, and validate.

Other localities in eastern and central North America have also been experiencing reduced harvest of muskrats, and trappers in these regions have been making similar claims of population decline (Landholt and Genoways 2000; Roberts and Crimmins 2004).
Although muskrat populations are known to fluctuate widely (Errington 1951, 1954), the current trend of recurring low returns appears to be abnormal, particularly from the perspective of those who have trapped the same areas over a long period of time.

Studies in this chapter had four main objectives; (1) to collect and quantify local ecological knowledge with regards to muskrat decline on PEI in the form of trapper beliefs and opinions, (2) to determine if declines in muskrat harvest are indicative of actual population declines by establishing the influence of external variables, (3) to evaluate growth and survival of various age classes of muskrats during the late summer (a period of suspected high mortality), and (4) to determine if the apparent decline in muskrat abundance has coincided with changes in important population parameters.

2.2 METHODS

2.2.1 Trapper Questionnaire

To evaluate the opinions of PEI trappers in relation to the apparent muskrat decline, a short questionnaire was delivered to all registered trappers in the province (Appendix A). This questionnaire was designed to gather data on muskrat trappers’ experiences in the field. The names and addresses of all trappers were obtained from license books provided by the PEI Department of Environment, Energy, and Forestry. The questionnaire was mailed to trappers, along with a postage-paid return envelope. There was no subsequent mail-out, and no attempt was made to contact trappers who did not respond to the initial mail-out.
2.2.2 Muskrat Harvest and the Influence of External Variables

Annual muskrat harvest totals, the average price per muskrat pelt, and the number of registered trappers were obtained for the period 1973-2008 from the PEI Department of Environment, Energy, and Forestry. Using the Bank of Canada Inflation Calculator (http://www.bankofcanada.ca/en/rates/inflation_calc.html) historical average pelt prices were adjusted to account for inflation, so that past prices were comparable to current prices (e.g. $1.00 Cdn in 1970 is equivalent to $5.75 Cdn in 2010). Air temperatures and rainfall amounts were obtained for the same time period from the Environment Canada website (http://www.climate.weatheroffice.gc.ca). These data were collected at station Charlottetown A, PEI (46° 17' 19.020” N, 63°07'43.070” W, Climate ID # 8300300, WMO ID# 71706), and were considered to be representative of conditions across the province.

A correlation matrix was constructed to check for significant correlations between muskrat harvest (the dependent variable) and average pelt price (PELT), the previous year’s average pelt price (PELT1), the number of registered trappers (TRAPPERS), the mean November air temperature (NOVTEMP), the number of days in November with a minimum air temperature below the freezing point (FREEZEDAYS), and the total November rainfall (RAIN) (predictor variables). This matrix also examined for co-linearity between the predictor variables. The assumption of normality for muskrat harvest was tested using the Shapiro-Wilk test and by examining the frequency histogram.
Two methods were used to determine the best model to predict muskrat harvest on PEI. A multiple regression analysis was conducted with muskrat harvest as the dependent variable and including all predictor variables. Starting with the factor that explained the least variability, predictors having no significant effects (p > 0.05) were removed one at a time, until all remaining variables had significant effects on the model. Changes in the partial regression coefficients of the remaining predictor variables and amount of variation explained by the model were examined at each step. The model used for the multiple regression was as follows:

\[ \text{Muskrat harvest} = \beta_0 + \beta_1 x_1 + \ldots \beta_n x_k, \text{ where } 1 \text{ through } k \text{ represent predictor variables} \]

In addition, a stepwise multiple regression model was used which included all predictor variables. Alpha to enter and alpha to remove were both set at 0.15. The results of this stepwise regression were compared with those obtained from the standard multiple regression analyses to determine the best model to predict muskrat harvest on PEI.

2.2.3 Growth and Survival of Muskrats

*Study Sites*

Trapping was conducted at three sites: (1) Larkin’s Pond in the north-eastern part of the province, (2) Doc’s Marsh in the south-eastern part of the province, and (3) Indian River Impoundment in the north-west part of the province (Figure 1). Larkin’s Pond (\(-62.4195556^\circ N, 46.4281230^\circ W\)) is an approximately 63 hectare wetland, established by the PEI Department of Environment, Energy, and Forestry and Ducks Unlimited Canada. At its mouth, Larkin’s Pond is bordered by a narrow strip of cattail (*Typha*)
lattifolia), with grey alder (Alnus incana) giving way to stands of black spruce (Picea mariana) and white spruce (Picea glauca) directly behind the cattail stand. Towards the head of the Pond, the open water is bordered by extensive cattail stands, with a network of open-water pockets distributed throughout the cattails (Figure 2). Other emergent vegetation includes bulrush (Scirpus species) and sweet gale (Myrica gale).

Figure 1. Locations of the study areas for growth and survival of muskrats in PEI

Doc’s Marsh (-62.5256605°N, 46.3638153°W) is an approximately 101 hectare wetland owned and maintained by the PEI Department of Environment, Energy, and Forestry and currently designated as a Wildlife Management Area. In the 1980’s, extensive ditching created numerous channels radiating from the main open body of water. The western shore of Doc’s Marsh features small, intermittent cattail stands, and large tracts of sweet gale. The northern and eastern shores have extensive stands of cattail, with many pockets of open water distributed among the cattail stands. Much standing,
wood lines the northern shore, and the main open water area is dotted with small islands vegetated by sweet gale and cattail (Figure 3).

Indian River Impoundment (-63.669728°N, 46.4601640°W) is an approximately 25 hectare wetland created by the PEI Department of Environment, Energy, and Forestry, and is currently designated as a Wildlife Sanctuary. As such, no hunting or trapping is permitted without a permit granted by the Provincial Government. The entirety of the open water area is bordered by extensive cattail stands, with a few open water pockets present throughout the stands. In some areas, the cattail stands are narrow and are bordered closely by alder/softwood tree cover (Figure 4).

Muskrats were trapped using Tomahawk double-door livetraps (Model #202) set on runs and houses and baited with apple. Captured muskrats were anaesthetized using the inhalant anesthetic isoflurane (Belant 1995), administered either by placing the muskrat into an enclosed space in close proximity to a jar containing cotton balls wetted with the anesthetic (for large muskrats), or by holding a cone containing cotton balls wetted with the anesthetic over the nose of the animal (for small muskrats) (Figure 5). Once subdued to allow handling, all muskrats were weighed to the nearest gram (Sartorius TE12000) and measured from the tip of the tail to the end of the snout using a conventional fish measuring board (measurements were to the nearest centimeter). Field measurements of weights were used as a means to separate age classes (Ahlers et al. 2010; Ahlers 2010). Those weighing <1000 grams were considered to be born that spring, and those weighing >1000 grams were considered to be at least one year old (Errington 1939). Each muskrat received a 12.5mm Passive Integrated Transponder (PIT) tag, injected subcutaneously on the back between the scapulae using a 12-gauge injector (Biomark,
Boise, Idaho) (Figure 6). These tags lay dormant in the animal until activated by an
electromagnetic field generated by a handheld scanning device, at which time a unique
identification number is displayed for each tag. In addition, muskrats litters (< 1 month
of age) located in nests were collected for tagging. These young animals did not require
anaesthesia in order to be handled safely. All other procedures were identical to those
used for live-trapped muskrats.
Figure 2. Larkin's Pond cover vegetation profile
Figure 3. Doc's Marsh cover vegetation profile
Figure 4. Indian River Impoundment cover vegetation profile
Figure 5. Live-trapped muskrat receiving isoflurane anaesthetic

Figure 6. Live-trapped muskrat receiving PIT tag
Live-trapping, as well as the handling and tagging of muskrat litters, took place in June, July, and August, 2009. Prior to November 1st (the beginning of the fall furbearer trapping season on PEI) trappers from each study area were notified of the presence of tagged muskrats in their trapping areas. Each trapper was provided with a map detailing the capture locations of all muskrats tagged in their trapping area (Figure 7), and were offered an incentive of $15 Cdn for every tagged muskrat that was returned in their harvest. Each trapper was visited on a daily basis while they were active in a study area to examine their harvest, and each trapped muskrat was scanned for the presence of a PIT tag. Tagged muskrats were weighed and measured using the same equipment as at time of tagging, and were transported to the Atlantic Veterinary College (AVC) for further examination. In addition, the total number of muskrats trapped from each study area was recorded. Daily weight gain was determined for each recovered muskrat by dividing the change in weight between tagging and recapture by the number of days elapsed since tagging.

The abundance in each study area was estimated using the Lincoln-Petersen index;

\[ N = \frac{MC}{R}, \]

where, \( N \) = the estimated population size, \( M \) = the number of muskrats captured and marked in the summer of 2009, \( C \) = the total number of muskrat captured in the fall 2009 trapping season, and \( R \) = the number of marked muskrats recaptured in the fall 2009 trapping season. Only recoveries made in the 2009 trapping season were included in the calculations, because additional recoveries were not associated with counts of unmarked individuals captured.
Figure 7. Example of capture location map provided to trappers for each study area
2.2.4 Examining Changes in Muskrat Population Structure

In the fall trapping seasons of 2008 and 2009, muskrat carcasses were obtained from registered trappers. Carcasses were obtained from wetlands distributed across the province and were stored in freezers (-20°C) at the AVC before examination in the laboratory. A total of 967 carcasses were examined, of which the capture locations were known for 957.

Sex and age data on all muskrat carcasses were obtained by examination of the internal sex organs (Errington 1939). Muskrats were classified as either juveniles (young of the year) or adults (at least one year old). Juvenile males had testes which were turgid and pink/cream-colored while adult males had testes which were greyish and flaccid (Figure 8). Juvenile females had uterine horns which were thin, flimsy, and transparent while adult females had uterine horns which were thickened and opaque (Figure 9). This method is considered accurate for ageing fall trapped muskrats (Errington 1939; Sather 1958; Dibblee 1971).

![Figure 8. Testes of an adult muskrat (left), which are greyish and flaccid, and of a juvenile muskrat (right), which are pinkish and turgid](image)

Figure 9. Uterine horns of an adult muskrat (left), which are thickened and opaque, and of a juvenile muskrat (right), which are thin and translucent

Age and sex ratios of muskrat samples were compared among areas having at least twenty-five observations using chi-squared tests of independence to examine for local differences in these parameters. Pooled data on age and sex ratios in the muskrat population were compared to those obtained in a similar study conducted on PEI in the 1968/69 (Dibblee 1971). Adult sex ratios in both samples were examined for differences from a 1:1 ratio of males to females using a chi-square goodness of fit test. Only those data from carcasses from known capture locations were included in the analysis. Overall proportions of each sex and age in the two samples were compared using chi-squared tests of independence (MiniTab 16), and $\alpha = 0.05$ for all analyses.

2.3 RESULTS

2.3.1 Trapper Questionnaire

A total of 105 questionnaires were distributed, of which 45 (42.8%) were completed and returned. Of these respondents, 31 (68.8%) indicated that they were active muskrat trappers on PEI, with each region of the province being represented (Figure 10). The
mean number of years of experience for muskrat trappers on PEI was 33.6 (range 2-69 years; Figure 11). The majority of respondents (74.1%) indicated that the abundance of muskrats in their trapping areas was one of the biggest determinants of their muskrat harvest, followed by time availability (22.5%) and the price obtained for muskrat pelts (9.6%) (respondents could choose more than one option).
A total of 19 (61.2%) of the active muskrat trappers said that their muskrat harvest has decreased since they began trapping on PEI. Most (78.8%) of these respondents trapped within Kings or Queens Counties, while 10.5% trapped in Western Prince County or in areas of all counties. Ten trappers (32.1%) responded that their harvest has stayed the same or increased since they began trapping in the province. Of these ten trappers, four trap in western Prince County, while six trap in Queens or Kings Counties (or both).

From an experience perspective, all 19 of the trappers who reported decreased harvests had been trapping on PEI for at least 10 years, and 84% have at least 20 years of trapping experience in the province. Four of the trappers who indicated steady or increasing muskrat harvests had been trapping for less than five years, while five had been trapping for 30 years or more.

Trappers reporting decreases in their harvest were asked to recall when they first noticed a decline of muskrats in their trapping areas, and their responses ranged from 20 years
ago to within the last two years (Figure 12). In addition, these trappers were asked to identify the factors they felt were responsible for this decline (respondents could select more than one option). Of the 19 respondents, 13 (68.4%) felt that the decline was related to increased numbers of predators, while habitat degradation and disease were chosen less frequently (26.3% and 21%, respectively). In addition, those implicating increased numbers of predators in the decline of muskrat were asked to specify which predators were most significant. Once again, respondents could select multiple options. All 13 eligible respondents for this question indicated that they felt bald eagles (*Haliaeetus leucocephalus*) were important, followed by coyotes (*Canis latrans*, 61.5%), owls (30.7%), and hawks (30.7%).

Figure 12. Time elapsed since a decline in muskrat populations was first noticed by trappers
Seven of 23 respondents (30.4%) indicated that they had previously found muskrat carcasses in their trapping areas, with five of these trappers having done so on more than one occasion. Only one of these seven trappers answered that he had submitted the carcass to the AVC for necropsy. The others either collected, skinned, and discarded the carcass, or simply left it.

Lastly, trappers suggesting declining muskrat populations were asked what they felt should be done to increase muskrat abundance in their areas. Seven (36.8%) of these respondents felt that predator populations should be controlled, whereas 15.8% felt that nothing should be done.

2.3.2 Muskrat Harvest and the Influence of External Variables

Muskrat harvest on PEI has declined by approximately 46% since 1973 (Figure 13). However, the harvest of 1718 muskrats from the 2009 trapping season represents the lowest total in the data set, and is 82.6% lower than the highest harvest number of 9886 muskrats from the 1984 trapping season. For the period between 1980-1989, muskrat harvests never fell below 5700. Since 1990, no trapping season has produced more than 5000 pelts.

The correlation matrix showed that both lagged and current average pelt prices, and the number of trappers were significantly correlated with muskrat harvest at a significance level of 0.05 (Table 1). The previous year’s pelt price was more strongly correlated with muskrat harvest than was that of the current year (r = 0.635 vs. r = 0.482). The strongest correlation with muskrat harvest was with the number of trappers (r = 0.848) (Figure 14). A number of the predictor variables were significantly correlated with each other.
PELT and PELT1 have an obvious relationship and were thus found to be strongly correlated with one another \((r = 0.838)\). In addition, TRAPPERS was strongly correlated with both PELT and PELT1 \((r = 0.743 \text{ and } 0.820, \text{ respectively})\). Two weather variables, NOVTEMP and FREEZEDAYS, were also strongly, negatively correlated with one another \((r = -0.856)\).
Table 1. Correlation matrix for muskrat harvest and predictor variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PELT</th>
<th>PELT1</th>
<th>TRAPPERS</th>
<th>NOVTEMP</th>
<th>FREEZEDAYS</th>
<th>RAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muskrat Harvest</td>
<td>r = 0.482</td>
<td>r = 0.635</td>
<td>r = 0.848</td>
<td>r = 0.003</td>
<td>r = 0.014</td>
<td>r = -0.054</td>
</tr>
<tr>
<td></td>
<td>p = 0.003</td>
<td>p = 0.000</td>
<td>p = 0.000</td>
<td>p = 0.984</td>
<td>p = 0.935</td>
<td>p = 0.754</td>
</tr>
<tr>
<td>PELT</td>
<td>r = 0.838</td>
<td>r = 0.743</td>
<td>r = -0.067</td>
<td>r = 0.023</td>
<td>r = 0.076</td>
<td></td>
</tr>
<tr>
<td></td>
<td>p = 0.000</td>
<td>p = 0.000</td>
<td>p = 0.699</td>
<td>p = 0.896</td>
<td>p = 0.658</td>
<td></td>
</tr>
<tr>
<td>PELT1</td>
<td>r = 0.820</td>
<td>r = -0.133</td>
<td>r = 0.108</td>
<td>r = 0.069</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p = 0.000</td>
<td>p = 0.439</td>
<td>p = 0.532</td>
<td>p = 0.690</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRAPPERS</td>
<td>r = -0.123</td>
<td>r = 0.081</td>
<td>r = 0.138</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p = 0.476</td>
<td>p = 0.641</td>
<td>p = 0.423</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOVTEMP</td>
<td>r = -0.856</td>
<td>r = 0.172</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p = 0.000</td>
<td>p = 0.317</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FREEZEDAYS</td>
<td>r = -0.325</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p = 0.053</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Because PELT and PELT1 were highly correlated (collinear) and both are a measure of the same factor, only PELT1 was included in multiple regression model because it was more strongly correlated with muskrat harvest. The multiple regression analysis including all predictor variables explained 78.3% of the variation in muskrat harvest and was significant \[ F(5,30)= 21.63, p< 0.000 \]. Only RAIN \( t= -2.22, p= 0.034 \) and TRAPPERS \( t= 7.04, p< 0.000 \) contributed significant variability to the model. The resulting regression equation was as follows:

\[
\text{Muskrat Harvest} = 2387 - 84.5(\text{PELT1}) + 242(\text{NOVTEMP}) + 8(\text{FREEZEDAYS}) - 13.2(\text{RAIN}) + 12.9(\text{TRAPPERS})
\]
Figure 14. Scatterplots of variables significantly correlated with muskrat harvest.
FREEZEDAYS did not contribute significant variability to the model (t= 0.10, p= 0.921) and was removed. The resulting model explained 78.3% of the variation in muskrat harvest and was significant [F(4,31)= 27.92, p< 0.000]. TRAPPERS (t= 7.15, p< 0.000), and RAIN (t=-2.44, p= 0.021 contributed statistically significant variability to the model. The resulting regression equation was as follows:

Muskrat Harvest = 2601 - 84.4(PELT1) + 220(NOVTEMP) - 13.4(RAIN) + 12.9(TRAPPERS)

PELT1 (t= -1.35, p= 0.187) did not contribute significant variability to the model and was removed. The resulting model explained 77% of the variation in muskrat harvest, and was significant [F(3,32)= 35.71, p< 0.000]. RAIN (t= -2.32, p= 0.027) and TRAPPERS (t= 10.33, p< 0.000) contributed significant variability to the model. The resulting regression equation was as follows:

Muskrat Harvest = 2324 + 228(NOVTEMP) - 12.9(RAIN) + 10.9(TRAPPERS)

NOVTEMP (t= 1.70, p= 0.099) was the only remaining predictor variable which did not contribute significant variability to the model and was removed. The resulting model explained 74.9% of the variation in muskrat harvest, and was significant [F(2,33)= 49.29, p< 0.000). Only TRAPPERS (t= 9.91, p< 0.000) contributed significant variability to the model. The resulting regression equation was as follows:

Muskrat Harvest = 2827 - 11.1 (RAIN) + 10.7(TRAPPERS)

Since RAIN (t= -1.98, p= 0.056) no longer contributed significant variability to the model, it was removed leaving TRAPPERS as the only significant predictor variable.
This model explained 71.9% of the variation in muskrat harvest, and was significant [F(1,34)= 87.19, p< 0.000). The resulting regression equation was as follows:

\[ \text{Muskrat Harvest} = 1913 + 10.4(\text{TRAPPERS}) \]

The forward stepwise regression model with alpha to enter and alpha to remove set at 0.15 agreed with one of the intermediate models in the standard regression. TRAPPERS (t= 10.33, p< 0.000), RAIN (t= -2.32, p= 0.027), and NOVTEMP (t= 1.70, p= 0.099) were included as predictors, and this model explained 77% of the variation in muskrat harvest.

2.3.3 Growth and Survival of Muskrats

A total of 324 trap nights were employed between June 29th and August 20th, 2009. Trapping success was 19.1%, with a total of 62 captures made. These captures represented 56 individual muskrats, of which 18 (32.1%) were from Larkin’s Pond, 22 (39.3%) were from Doc’s Marsh, and 16 (28.6%) were from the Indian River Impoundment. Three of the muskrats captured and tagged in Doc’s Marsh were later found dead either in traps in subsequent days, or in the general trapping area. All of these were young individuals with weights under 250 grams. In addition, two of the muskrats captured from the Indian River Impoundment were not tagged; one was a large individual found dead in the trap and the other was a young muskrat in poor condition which was immediately released. Thus, a total of 51 muskrats were tagged through live-trapping.

A total of ten muskrats were captured and tagged while searching for litters in houses. These included a single litter of nine very young muskrats (each weighing <50 grams) in
Larkin’s Pond and a single juvenile muskrat in Doc’s Marsh. The total number of tagged muskrats available for harvest in the fall of 2009 was 61. Thirty-nine (63.9%) of these tagged muskrats were juveniles (young-of-the-year), while the remaining 22 (36.1%) were at least one year old at time of capture (adults) (Table 2).

Table 2. PIT tagged muskrats available for harvest in the fall trapping season.

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Juveniles</th>
<th>Adults</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larkin’s Pond</td>
<td>20</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>Doc’s Marsh</td>
<td>9</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>Indian River</td>
<td>10</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Impoundment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>39</strong></td>
<td><strong>22</strong></td>
<td><strong>61</strong></td>
</tr>
</tbody>
</table>

A total of 20 tagged muskrats (32.8%) were recovered in the 2009 fall harvest of which 14 were juveniles and six were adults. Two additional tagged muskrats were recovered after the fall harvest of 2009. One was captured in August 2010 during live-trapping exercises in Larkin’s Pond, 377 days after tagging. This individual was an adult at the time of tagging, although no measurements were taken upon recapture to establish growth rates. A second adult muskrat was recovered from Doc’s Marsh during the 2010 fall trapping season. This gives a total of 22 tagged muskrats that were recovered (36.1%) (Table 3).

Table 3. PIT tagged muskrats recovered since fall 2009

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Juveniles</th>
<th>Adults</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larkin’s Pond</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Doc’s Marsh</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Indian River</td>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Impoundment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14</strong></td>
<td><strong>8</strong></td>
<td><strong>22</strong></td>
</tr>
</tbody>
</table>
Juvenile survival from summer to trapping season was thus estimated to be 35.9%, while adult survival was estimated to be 36.4%. The minimum number of days elapsed between the original date of capture and tagging and the recapture date in the fall harvest was 81, while the maximum was 141. Mean growth rate (rate of weight gain) was $7.38 \pm 1.02$ (mean ± 95% confidence interval) grams/day for juvenile muskrats and $2.43 \pm 0.63$ grams/day for adult muskrats.

The mean growth rate for juveniles (mean ± 95% confidence interval) in each of the study areas was $6.19 \pm 1.58$, $6.76 \pm 0.035$, and $8.23 \pm 1.45$ grams/day for Larkin's Pond, Doc's Marsh, and the Indian River Impoundment, respectively. The mean rate of weight gain for adults was $2.48 \pm 0.98$ and $2.31 \pm 0.82$ grams/day for Larkin's Pond and Doc's Marsh, respectively. Indian River Impoundment had no adult muskrats recovered in the fall harvest.

Abundance estimates for the three study areas were 34 in Indian River Impoundment, 135 in Doc's Marsh, and 315 in Larkin's Pond (Table 4).

Table 4. Estimated population sizes and densities of the three study areas

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of PIT Tagged Muskrats</th>
<th>Total Captures in the Fall Harvest</th>
<th>Number of PIT Tagged Muskrats Captured in the Fall Harvest</th>
<th>Estimated Population Size</th>
<th>Estimated Density (muskrats/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indian River Impoundment</td>
<td>14</td>
<td>17</td>
<td>7</td>
<td>34</td>
<td>1.36</td>
</tr>
<tr>
<td>Doc's Marsh</td>
<td>20</td>
<td>27</td>
<td>4</td>
<td>135</td>
<td>1.23</td>
</tr>
<tr>
<td>Larkin's Pond</td>
<td>27</td>
<td>105</td>
<td>9</td>
<td>315</td>
<td>5.00</td>
</tr>
</tbody>
</table>
2.3.4 Examining Changes in Muskrat Population Structure

The proportion of males in the sample from each site in 2008/2009 ranged from 37.5% to 67.1%, but the overall sex ratio did not differ significantly between sites ($\chi^2 = 5.958, p = 0.744$; Table 5). The proportion of juveniles in the sample from each site in 2008/2009 ranged from 60% to 92.9%, and the overall age ratio differed significantly between sites ($\chi^2 = 17.036, p = 0.048$; Table 5).

**Table 5. Age and sex ratios of muskrats from selected areas on PEI, fall 2008/2009**

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample Size</th>
<th>Proportion of Males (%)</th>
<th>Proportion of Juveniles (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larkin’s Pond</td>
<td>158</td>
<td>55.1</td>
<td>78.5</td>
</tr>
<tr>
<td>Whitlock’s Pond</td>
<td>146</td>
<td>54.8</td>
<td>76.7</td>
</tr>
<tr>
<td>Doc’s Marsh</td>
<td>82</td>
<td>67.1</td>
<td>73.2</td>
</tr>
<tr>
<td>Pisquid Impoundment</td>
<td>78</td>
<td>65.4</td>
<td>82.5</td>
</tr>
<tr>
<td>Allisary Creek</td>
<td>63</td>
<td>55.6</td>
<td>69.2</td>
</tr>
<tr>
<td>Saddle Hill Marsh</td>
<td>45</td>
<td>57.8</td>
<td>80.0</td>
</tr>
<tr>
<td>Indian River Impoundment</td>
<td>41</td>
<td>56.1</td>
<td>87.8</td>
</tr>
<tr>
<td>MacDonald’s Pond</td>
<td>38</td>
<td>57.9</td>
<td>81.6</td>
</tr>
<tr>
<td>Montague Area Road Crossings</td>
<td>30</td>
<td>60.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Locke’s Dam</td>
<td>28</td>
<td>57.1</td>
<td>92.9</td>
</tr>
</tbody>
</table>

The overall proportion of juveniles among all muskrats from known capture locations was 76.9%, compared to 79.7% in the 1968-69 study (Figure 15). This difference was not significant ($\chi^2 = 3.395, p = 0.065$). Juvenile females comprised 31.6% of the 2008/09 sample, a slight decrease from the 34.7% juvenile female component found in 1968-69. This difference was not significant ($\chi^2 = 3.238, p = 0.072$). Juvenile males comprised 45.4% of the 2008/09 sample, while this age/sex class represented 45% of the 1968/69
sample. This difference was not significant ($\chi^2 = 0.042, p = 0.838$). In the 2008/09 sample, adult females and adult males accounted for 11.3% and 11.8%, respectively, compared to 10.2% and 10.1% in the 1968/69 sample. The differences in the proportions of these age/sex classes in the samples were not significant ($\chi^2 = 0.846, p = 0.358$ and $\chi^2 = 2.336, p = 0.126$). The proportion of each age/sex class in the 1968/69 and 2008/2009 samples are summarized in Table 6 and Figure 16.

Figure 15. Age ratios of 1968/69 and 2008/09 muskrat samples from PEI
Table 6. Counts and contributions to total sample of each age/sex class in 1968/69 and 2008/09 samples

<table>
<thead>
<tr>
<th>Year</th>
<th>Juvenile Males</th>
<th>Juvenile Females</th>
<th>Adult Males</th>
<th>Adult Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968/1969</td>
<td>1292 (45.0)</td>
<td>998 (34.7)</td>
<td>289 (10.1)</td>
<td>294 (10.2)</td>
</tr>
<tr>
<td>2008/2009</td>
<td>434 (45.4)</td>
<td>302 (31.6)</td>
<td>113 (11.8)</td>
<td>108 (11.3)</td>
</tr>
</tbody>
</table>
The overall proportion of males among all muskrats from known capture locations was 57.2%, compared to 55% in the 1968-69 study (Figure 17) and there was no significant difference in the overall sex ratio between the two studies ($\chi^2 = 1.317, p = 0.251$). Within the juvenile age class, males comprised 59% compared to 56.4% in the 1968-69 study. This difference was not significant ($\chi^2 = 1.476, p = 0.224$). Within the adult age class, males comprised 51.1% compared to 49.6% in the 1968-69 study, and this difference was not significant ($\chi^2 = 0.156, p = 0.693$). In both the 2008/09 and 1968-69 samples, the adult sex ratios were not significantly different from 1:1 ($\chi^2 = 0.113, p = 0.737$ and $\chi^2 = 0.043, p = 0.836$, respectively).

Figure 16. Proportions of each age/sex class in the 1968/69 and 2008/09 muskrat samples from PEI
2.4 DISCUSSION

2.4.1 Trapper Questionnaire

While the response rate of 42.8% was lower than would have been desired it is nonetheless comparable to those observed for questionnaires mailed to furbearer harvesters in other jurisdictions (Hamrick et al. 1986; Lipe 1997), although higher response rates have been reported for questionnaires with multiple mail-outs (Frawley et al. 2005). Thus, the response rate for this questionnaire would likely have been improved by sending follow up correspondence to the trappers to either remind them to complete the questionnaire or provide them with another copy.
Despite the relatively low sample size, the results of the trapper questionnaire mirror closely the opinions expressed to the researcher while interacting with trappers during the study. Furthermore, responses were received from the majority of the well-established, full-time trappers in the province. Therefore, it is believed that the results of this questionnaire are representative of the PEI trapping community's opinions.

The majority of active muskrat trappers felt that the abundance of muskrats in their trapping area was one of the biggest factors determining their harvest. This result suggests that muskrat harvest on PEI can be used as an approximate index for population size in the absence of a species-specific monitoring program, particularly when trapper effort (i.e. the number of trappers) is considered as well (Poole and Mowat 2001; DeVink et al. 2011). Total harvest is often used as a means to estimate furbearer abundance and establish population trends for a variety of furbearer species (Landholt and Genoways 2000; Brodie and Post 2010). However, the correlation between harvest and actual abundance is usually unknown (Poole and Mowat 2001) and indices should be verified with actual abundance estimates (Smith et al. 1984). For these reasons, the use of harvest data as a population monitoring technique has been criticized (Winterhalder 1980). The results of the trapper questionnaire indicate that the muskrat harvest of most trappers is a function of the abundance of muskrats in their trapping areas, which suggests that harvest trends should at least provide an approximation of actual population fluctuations.

Most trappers felt that their muskrat harvest had decreased over the years they have been trapping on PEI. Trappers within the same trapping region reported conflicting trends with respect to their harvests. For example, of the six respondents who trap exclusively...
in Western Prince County, four reported stable or increased harvests while two reported decreased harvests. This may be a reflection of trapping methods employed and the types of habitats trapped. Anecdotal evidence suggests that density of muskrats in large marshes is decreasing, so it may be that those reporting declining harvests focus their trapping efforts on this type of habitat. In addition, some trappers in this region may focus their trapping effort on one or two traditional trapping areas, whereas others may travel more extensively throughout the region in search of areas of muskrat concentration. The issues regarding the specifics of trapping effort, including types of habitats trapped and the variability in areas trapped from year to year, were beyond the scope of this questionnaire to provide answers, but warrant further investigation.

One trend that is very clear from the questionnaire results is that the vast majority of muskrat trappers who have experienced a decline in their harvests trap in the central and eastern portions of PEI. This is in accordance with evidence gathered from discussions with individual trappers from across the province. Once again, this may be a reflection of differences in the way trapping is conducted in these regions compared to western PEI. Furthermore, all trappers who reported a decline in their harvest, with the exception of one individual, had at least 20 years of experience trapping on PEI. On the contrary, those reporting stable or increasing harvests showed a wide range of trapping experience, from less than five years to more than 30 years. This has important implications when interpreting the results of this questionnaire. Those who are relatively inexperienced would not necessarily be as aware of historical muskrat population sizes, meaning that they would be less likely to consider current abundance levels as abnormally low. This is supported by the fact that most of the trappers who reported a
decline in their harvest indicated that they first noticed the decrease more than 10 years ago. Thus, those who began trapping on PEI within the last 10 years would not necessarily recognize the current muskrat densities as low because they were not actively trapping when higher densities were available for comparison. In addition, those with many years of trapping experience on PEI are likely to have trapped the same wetlands annually, so these individuals would be more aware of population trends on a local scale over a long period of time and could better compare current and historical densities in these specific wetlands.

In the questionnaire, factors implicated in decreased muskrat harvests included predation, habitat degradation, and disease. That such emphasis was placed on bald eagle predation was an interesting, but not unexpected, result. This was in accordance with evidence gathered from many informal discussions with trappers across the Province. While this species is known to occasionally prey on muskrats (Dunstan and Harper 1975; Todd et al. 1982; Stalmaster and Plettner 1992) the proportion of the diet comprised by muskrats is usually quite low. There are two related reasons why trappers on PEI may believe that bald eagles are responsible for muskrat decline. Firstly, this species has made a dramatic recovery in the Province in recent decades, growing from one known nest in the early 1980’s (MacDougall 1999) to the current estimate of at least 30 active nests (MacDougall, PEI Department of Environment, Energy, and Forestry, personal communication). Secondly, unlike many other predatory species, bald eagles are highly visible to trappers in their trapping areas. Trappers therefore may equate increased sightings of bald eagles in and around wetlands with increased predation pressure on muskrat populations.
Another predator frequently chosen in the questionnaire by trappers was the coyote. This species arrived in PEI in 1983 (Thomas and Dibblee 1986), and populations increased rapidly (Prince Edward Island Environmental Advisory Council 2001). This arrival added to the roster of potential muskrat predators in the Province, and it appears that trappers have linked current high coyote densities to declining muskrat populations even though research on this topic has yielded varied results (Sather 1958; Best et al. 1981).

Clearly, the majority of muskrat trappers on PEI feel that increased predation pressure is responsible for current low population levels. This is demonstrated by the fact that many questionnaire respondents indicated that controlling predator populations would be the best way to increase muskrat abundance in their trapping areas. A smaller group of trappers, however, thought that nothing should be done, which suggests that these individuals feel that current low muskrat abundances are part of a natural cycle not requiring management intervention.

2.4.2 Muskrat Harvest and the Influence of External Variables

The magnitude and pattern of decline in muskrat harvest found in this study are similar to those reported by Roberts and Crimmins (2010), who analyzed harvest data from many jurisdictions in northeastern North America. These researchers found that harvest declines in these areas occurred between 1986 and 1990, which corresponds approximately with the sharp decreases in the PEI muskrat harvest. Contrary to their findings, however, the current study found that lagged pelt prices were more strongly correlated with muskrat harvest than were current pelt prices when other predictors of
harvest were not included. In addition, the correlations of both current and lagged pelt prices and muskrat harvest are stronger in the current study than those found for recent harvests in Roberts and Crimmins (2010). It should be pointed out that part of the data set used for analysis in the current study falls out of the range of that explored by Roberts and Crimmins (2010) and represents an intermediate time frame in the context of their analyses. They used values from 1948-1968 as a historical data set and values from 1986-2006 as a contemporary data set, while this study incorporated data from the years 1973-2008. Interestingly, the correlations found in the current study also appear to be of intermediate strength, weaker than those found by Roberts and Crimmins (2010) for historical muskrat harvest but stronger than those found by these authors for recent harvest.

The results of the current study suggest that the number of trappers is a stronger determinant of muskrat harvest than are pelt prices. The number of registered trappers was the variable most strongly correlated with muskrat harvest, and had the strongest effects on all models. On PEI, the number of trappers can vary considerably from year to year, as a small but consistent group of full-time trappers is inflated by varying numbers of recreational trappers. It is likely that the harvest accounted for by the group of full-time trappers remains relatively consistent from year to year, as they devote the time and effort necessary to ensure that their muskrat harvest reaches a level needed to gain a certain income. For example, if yields are low in one wetland, this group of trappers will spread their trapping effort to other more productive areas. Thus, it is likely that variations in total muskrat harvest are driven strongly by the varying efforts of those
recreational trappers who pursue trapping as a hobby and do not need to reach specific harvest levels.

It is in recognition of this pattern that a potential issue in the multiple regression analyses must be addressed. The number of trappers and the pelt price were strongly correlated with one another, meaning that collinearity could have affected the reliability of the model. Worldwide market factors determine the prices paid for muskrat pelts, and changes in these values can increase or decrease incentive for trappers to catch muskrats (Miller 1975). This is probably most true for the recreational/hobby segment of the trapper population who view muskrat trapping as a means to supplement their income. High pelt prices, therefore, will provide incentive for more recreational trappers to harvest muskrats, whereas low prices will have the opposite effect. Siemer et al. (1994) observed this pattern among the trappers of New York, who cited low pelt prices as the most important reason for inactivity.

An interesting result was the fact that average pelt price lagged one year, rather than average pelt price, was a more important predictor of muskrat harvest. Due to the fact that the number of trappers probably changes as a result of varying participation from recreational trappers, and that this level of participation is probably related to the expected financial return from muskrat trapping, one would expect that pelt prices from the previous trapping season would be a more important determinant of muskrat harvest than would current prices. For example, high prices obtained for muskrat pelts in the previous season may provide incentive for more recreational trappers to harvest muskrats in the next season in anticipation of similar returns. The models arrived at by both the standard multiple regression and the forward stepwise regression did not
include a measure of pelt prices, despite the strong correlation shown between these individual variables and muskrat harvest. This is likely due to an overlap in the variation of muskrat harvest shared by these market factors and the number of trappers, as discussed. Average pelt price was excluded from all regressions because of collinearity with average pelt price lagged one year, and it was decided to include only the variable more strongly correlated with muskrat harvest.

Regression modelling determined that weather is another type of external factor that is an important predictor of muskrat harvest on PEI. On PEI, most muskrats are trapped in the month of November before wetlands freeze and the focus of trappers turns to other furbearer species. The results of the stepwise regression analysis show that air temperature in November is a significant predictor of muskrat harvest on PEI. Warmer conditions in November are conducive to larger muskrat harvests, both because freeze-up is delayed and muskrats are more active when it is warmer (Stewart and Bider 1977). In contrast, muskrats spend more time in their lodges during periods of cold air temperatures (MacArthur and Aleksiuk 1979), reducing their likelihood of being trapped.

Muskrats have also been shown to travel, explore, and forage farther on rainy days (Bélanger 1981), which would be expected to translate into higher harvests due to increased activity. However, the results of the current study suggest that total rainfall in the month of November is negatively correlated with muskrat harvest on PEI, and that this negative effect is in fact significant. This negative relationship is difficult to reconcile.
The role of weather factors in determining muskrat harvest has not been explored in
detail, although Clark (1986) showed that cold weather reduced trapper effectiveness
and suggested that the opening date of muskrat trapping seasons relative to weather
conditions may be the most influential factor in determining harvest rate. The results of
the current study suggest that air temperatures in November should be incorporated into
modelling scenarios of muskrat harvest on PEI and should be considered when
developing management strategies, and that rainfall in November is negatively
correlated with muskrat harvest in the province.

The muskrat harvest on PEI appears to be determined by a combination of trapper effort
and weather factors, with the number of trappers being the most important predictor.
Due to the fact that such a high proportion of the variation in muskrat harvest is
explained by the models arrived at through the multiple regression analyses, it is
difficult to recommend using harvest as a means to monitor muskrat population trends.
In their review, Poole and Mowat (2001) acknowledged that one of the central issues
with using furbearer harvest data to monitor population size or trends is that it is
unknown in most cases if the harvest values actually correlate with population size.
Thus, if overall harvest is to continue to be used as an index of population trends, actual
population estimates should be developed using other methods for comparison and
validation of the harvest models.

2.4.3 Growth and Survival of Muskrats

One of the main objectives of this study was to evaluate anecdotal reports from trappers
who claimed that muskrat mortality was high between the building of lodges in the late
summer/early fall and the onset of trapping season. For a variety of reasons, the return rate of tagged muskrats in this study was lower than expected. Trappers were provided with maps of the approximate locations of the muskrats and were offered a significant financial incentive to capture them, which should have increased the probability of recapture. In addition, time between tagging and the fall trapping season was relatively short and the sample included both juvenile and adult muskrats, which should have led to higher returns. However, calculated survival rates from summer to trapping season are conservative because they do not account for muskrats which may have lost their tags, moved from the study area, or eluded capture in the fall harvest (Simpson and Boutin 1993). In addition, trapper effort in the Doc's Marsh study site was limited by time and weather constraints, so the return of tagged muskrats from this site is probably not indicative of actual survival. Thus, the minimum survival rate of 36% for all age classes as calculated from this study is undoubtedly lower than the actual survival rate. Other studies have used marking methods to estimate the survival of various age classes of muskrats. Boutin et al. (1988), for example, estimated survival of juvenile muskrats from litters of different sizes to both weaning and adulthood (breeding), with values ranging from 100% to 25% to weaning and 86% to 25% to adulthood. In a study of over-wintering survival, Simpson and Boutin (1993) found juvenile survival to range from 22% to 26.8% and adult survival to range from 14.73% to 17%. On PEI, survival rates of muskrat kits to trapping season was estimated to be at least 46% from the recoveries of toe-clipped individuals in the fall harvest (Dibblee 1971). Thus, although the survival rates of juveniles were lower than those previously reported from PEI, they nonetheless fall within a reasonably expected range, especially when considering that
trapper effort was greatly reduced in one study site. Claims of excessive mortality between summer and the fall trapping season are therefore not supported, at least in the three areas studied.

This conclusion could have been strengthened by having a greater sample size. Mortalities of muskrats in traps early in the field season, with subsequent adjustments to the trapping regime, were at least partly responsible for the relatively low numbers. Trapping focused on areas of muskrat habitation, and initially an effort was made to capture and tag all of the muskrats from within a particular dwelling. This involved resetting traps in the same area on consecutive nights. However, it was found that some muskrats trapped on consecutive days, particularly juveniles weighing less than 250 grams trapped on rainy nights, were in poor condition or were dead when traps were checked on the second day. Three tagged individuals died in such a way, presumably due to exposure, after which an effort was made to avoid capturing muskrats on consecutive days by moving traps to other areas. In addition, an adult male muskrat found dead in a trap was found at necropsy to have a large area of necrosis in its left testicle, although its cause of death could not be conclusively determined.

The Lincoln-Petersen estimates of abundance supported the belief that the three study areas represented different population levels (i.e. low, medium, high). However, this index is intended for use in closed populations with no immigration/emigration and no births/deaths within the population. Dispersal in muskrat populations usually occurs in the spring (Sather 1958) and movements of muskrats between areas during the summer months have been shown to be negligible (Parker and Maxwell 1980; Clay and Clark 1985). Some movements of muskrats occur in the fall when drought conditions persist
(Mathiak 1966), but water levels in the current study were sufficient to support muskrats in all seasons. For these reasons, the no immigration/emigration assumption of the Lincoln-Petersen model is not believed to have been violated to a significant degree. However, births and deaths of muskrats may have occurred between tagging and harvest in all study sites. In fact, the main objective of the mark-recapture technique was to estimate survival assuming that muskrats would die in each study area. Therefore, while the Lincoln-Petersen abundance estimates are useful for comparing population levels at individual sites, the estimates derived should not be considered rigorous counts of local muskrat populations.

Using PIT tags to mark individuals is an increasingly common tool in wildlife biology because it offers advantages such as being internal and permanent (Gibbons and Andrews 2004). Tag loss can occur through the injection site, but this is uncommon, and research has shown that using PIT tags can decrease bias in mark-recapture studies (Morley 2002). To date, using PIT tags to study muskrat demographics has been limited (Ahlers et al. 2010), but the results of the current study support expanding their use for studying this species. Muskrats weighing as little as 44 grams (estimated to be less than 8 days old) were tagged without any obvious impairment to growth, as two individuals of this age were recovered 26 days post-tagging and both had weights within the expected range (Dorney and Rusch 1953).

Juvenile males have been shown to have a higher daily rate of weight gain than females during the summer months (Parker and Maxwell 1980). In the current study, the sex of live-trapped animals was not determined in the field, so sex differences in growth rates could not be determined. In addition, it is important to note that those muskrats
classified as juveniles actually represented individuals of varying ages (i.e. it was assumed those born early in the season were larger than those born later in the season, but this hypothesis could not be confirmed). It is known that muskrats grow at a faster rate in the first month after birth (Errington 1939; Virgl and Messier 1995), so differences in the observed growth rates between study sites may be due to some sites having had younger individuals at the time of tagging. However, the rationale for this approach was to permit the evaluation of overall growth rates of juvenile muskrats to determine if they were lower than those reported in the literature, possibly suggesting poor nutritional quality of food in their habitat. The results show that even the lowest observed growth rates of juveniles fall within the range of those reported for muskrats (Parker and Maxwell 1980, 1984; Simpson and Boutin 1993).

The fact that juvenile muskrats grew at a faster rate in the Indian River Impoundment compared to the other study sites may be attributable to differences in food availability and quality between the habitats (Dozier et al. 1948; Simpson and Boutin 1993). Dibblee (1971) stated that eutrophic conditions and relatively stable water levels resulted in high quality muskrat habitat on PEI. Sampling conducted in the watersheds of each study area showed that Indian River had nitrate concentrations at least ten times greater than those in the watersheds of Larkin’s Pond and Doc’s Marsh (M. Heuvel, University of Prince Edward Island, unpublished). These eutrophic conditions apparently support increased rates of weight gain in juvenile muskrats in Indian River Impoundment. Differences in rate of weight gain may also reflect differences in the density of muskrats between the study sites. The estimated density at Indian River Impoundment was quite low, so the decreased intraspecific competition may have
allowed juvenile muskrats more access to higher quality food resources than those from Larkin's Pond, although Scheffer (1955) presented evidence against density-dependant growth in muskrat populations. Nevertheless, growth rates of juveniles in the three study sites were within the expected range so it appears that muskrat habitat is providing food of sufficient nutritional quality to ensure normal development.

2.4.4 Examining Potential Changes in Muskrat Population Structure

Examining for changes in population parameters is important in the context of a potential decline because such changes can provide clues about differential mortality patterns due to age/sex class structure. Furthermore, evidence shows that during declines of microtine rodents, a group which includes muskrats, the age structure shifts substantially towards older animals (Boonstra 1994). In the current study, this exercise was particularly advantageous because there was an extensive data set representing a period of healthy muskrat populations available for comparison.

The results indicate that in the interval between Dibblee's (1971) study of PEI's muskrat population and the current study, there have been no significant changes in the age or sex structure that could reflect an apparent decline in overall abundance. Slight decreases in the proportion of juveniles, specifically the proportion of juvenile females, were detected, but these differences were not significant and are likely a product of differences in sample size between the historical and current studies. The ratio of juveniles to adults fell within the range reported for muskrat populations in other jurisdictions (Gashwiler 1950; Sather 1958; Errington et al. 1963). In addition, Sather (1958) noted that the proportion of juveniles in the fall harvest varied by up to 12%
between successive years. A very high proportion (38.5%) of adults in the fall population was linked to reduced productivity and population decline by Errington et al. (1963), but this ratio for the current study is far below that value. Younger age classes are usually dominant in increasing populations (Alexander and Radway 1951), and juveniles currently account for over 75% of the fall harvested muskrats. The lack of significant differences between the age ratios of the historical and current studies suggests that mortality in any particular age group has not increased, and as a result, the age ratio data of the PEI muskrat population should not be considered abnormal.

The overall sex ratios of both the historical and current muskrat populations show a clear male bias, in agreement with the findings of previous studies (Dozier and Allen 1942; Dozier 1945; Anderson 1947; Heit 1949; Gashwiler 1950). This bias may be either a reflection of a true disparity in the sexes in the fall trapping season, or of differences between the sexes in the probability of being trapped. Male muskrats tend to be taken more frequently than females in the first few weeks of the trapping season (Marshall 1937; Dozier and Allen 1942; Heit 1949), and since the majority of muskrat trapping on PEI occurs early in the month of November the samples of both the historical and current studies may not be representative of actual sex ratios in the population. In both the historical and current studies, the adult male:female ratio was not significantly different from 1:1. Muskrats are generally considered seasonally monogamous (Sather 1958; Caley 1987; Caley et al. 1988), although polygynous breeding does occur (Marinelli et al. 1997). The breeding strategy of muskrats on PEI is largely unknown but if seasonal monogamy is assumed then a 1:1 ratio of males to females in the breeding population is desirable to maximize productivity. These findings
suggest that no significant changes have occurred in adult sex ratios to cause a decline in productivity.

Overall, the structure of the muskrat population has been remarkably stable since the late 1960’s. It should be noted, however, that most of the data used in the comparisons between the historical and current studies was obtained from different localities within the province. Although no significant changes were detected for any of the parameters examined, the conclusions would have been strengthened by increasing the number of shared sites between the historical and current studies. Indeed, age ratios were found to be different among the areas looked at in the current study, so population structure can vary locally. Data in the current study was gathered from areas actively trapped by participating trappers, and these areas did not necessarily coincide with those actively trapped during the historical study. Despite this study limitation, the results nonetheless strongly suggest that in the context of a perceived population decline, no age/sex class is being specifically subjected to increased mortality. It appears then that any factor(s) responsible for the apparent decline of muskrat populations on PEI has/have acted on all age/sex classes equally, resulting in simply less of each age/sex class currently than were present in the late 1960’s.
CHAPTER THREE: INVESTIGATING POSSIBLE CAUSES OF MUSKRAT DENSITY DECLINE

3.1 INTRODUCTION

Anecdotal reports from trappers and furbearer harvest records suggest that muskrat (Ondatra zibethicus) populations in Prince Edward Island (PEI), Canada, have declined substantially from historical levels. Declines in the size of a wildlife population can be due to decreased recruitment and/or survival of adults (Schaefer et al. 1999).

Furthermore, recruitment is a function of both fecundity of breeders and survival of the offspring. Both recruitment and adult survival can be influenced by a number of biotic and abiotic factors, including predation (Seip and Cichowski 1994; Wittmer et al. 2005; Moreno et al. 2007), disease (Muths et al. 2003; Hawkins et al. 2006; Moreno et al. 2007), habitat loss (Dessecker and McAuley 2001; Rode et al. 2010), and environmental contamination by pollutants (Williams 1989).

In wetland ecosystems, the muskrat is prey for a variety of predatory species including red foxes (Errington and Scott 1945; Hjältén 1991), raccoons (Lay 1945; Wilson 1953), mink (Errington 1943; Proulx et al. 1987; Brzeziński et al. 2009), and predatory birds (Smith 1936; Lay 1945). On PEI, predator populations are generally considered to be at healthy levels, but the predation pressure exerted on muskrat populations is unknown. Similarly, the role of disease in structuring muskrat demographics on PEI has been largely unexplored, despite the fact that this species is vulnerable to outbreaks of such infectious diseases as tularemia (Langford 1954; Ditchfield et al. 1960) and Tyzzer's disease (Errington 1954; Wobeser et al. 1978). Furthermore, PEI’s landscape is
dominated by agricultural lands relying heavily on pesticides, and the province is one of the most intensive users of pesticides in Canada (Dunn 2004). Muskrats have been shown to be bioindicators of environmental contamination (Everett and Anthony 1976; Erickson and Lindzey 1983), but the accumulation and effects of contaminants on PEI muskrats have not been examined.

This study had four main objectives; (1) to investigate the activity of predators around muskrat houses in the summer months; (2) to evaluate the body condition and disease status of a sample of PEI muskrats; (3) to evaluate the degree of contamination of muskrat habitat by pollutants; and (4) to explore potential changes in muskrat recruitment by comparing it to a historical benchmark.

3.2 METHODS

3.2.1 Investigating Activity around Muskrat Houses in Summer

Seven active muskrat houses were monitored for varying periods of time in June-November 2010. House occupancy was confirmed either through opening in search of muskrat litters, signs of recent house maintenance, or by prior live-trapping. Two houses were located at Doc’s Marsh (Figure 18), three were located at Larkin’s Pond (Figure 19) and two were located at the Indian River Impoundment (Figure 20); Table 7 provides a site description of each house. Houses were monitored using infra-red remote cameras (HGO Scoutguard 560V) mounted on tripods approximately 1.5-3 meters from the house. Cameras were triggered by a change in the thermal signature within their range of view, and were equipped with an infra-red device for night vision observations. Cameras were set to capture three images each time they were triggered, with 30
seconds between successive triggers. These trigger events, instead of total images captured were used to determine activity patterns. This measure was taken because the time between successive images was greater in the dark than in the light, such that trigger events at night often resulted in only one image of the animal(s) whereas day trigger events almost always captured three images of the animal(s). Images were categorized based on time of day; morning (0500 – 1159 hrs), afternoon (1200 – 1659 hrs), evening (1700 – 2159 hrs), and night (2200 – 0459 hrs). Images were stored on standard SD memory cards ranging in storage capacity from one to four gigabytes. When a house appeared inactive for an extended period of time, the camera was removed and placed at another active house if the location of one was known. Cameras were checked periodically throughout the study to ensure that they were still in position, had sufficient battery power, and the memory cards were not full.
Figure 18. Camera locations at Doc's Marsh study area
Figure 19. Camera locations at Larkin’s Pond study area
Figure 20. Camera locations at Indian River Impoundment study area
Table 7. Description of camera sites at muskrat houses

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Camera Site</th>
<th>Site Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larkin’s Pond</td>
<td>N 46.42872°, W 062.42539°</td>
<td>34.6 meters to forest cover, 3 meters to main marsh area, house situated in cattail/sweet gale stand</td>
</tr>
<tr>
<td>Larkin’s Pond</td>
<td>N 46.43004°, W 062.42455°</td>
<td>26.15 meters to forest cover, 2 meters to main marsh area, house situated in cattail/sweet gale stand</td>
</tr>
<tr>
<td>Larkin’s Pond</td>
<td>N 46.42045°, W 062.43107°</td>
<td>&gt; 200 meters to forest cover, 50 meters from main marsh area, open water within 3 meters on each side of house, house situated in cattail stand interspersed with small pockets of open water</td>
</tr>
<tr>
<td>Doc’s Marsh</td>
<td>N 46.36349°, W 062.52209°</td>
<td>House situated on small island vegetated by sweet gale, cattail, and low grasses, with water depths of at least 1 meter on all sides. &lt; 10 meters from closest island, 73.9 meters to shore of main marsh.</td>
</tr>
<tr>
<td>Doc’s Marsh</td>
<td>N 46.36186°, W 062.52023°</td>
<td>40 meters to forest cover, 70.4 meters to main marsh area, house situated in stand of grey alder with small pockets of open water within 2 meters</td>
</tr>
<tr>
<td>Indian River Impoundment</td>
<td>N 46.46123°, W 063.67045°</td>
<td>33.53 meters to forest cover, 13.4 meters to main marsh area, house situated in cattail stand interspersed with small pockets of open water</td>
</tr>
<tr>
<td>Indian River Impoundment</td>
<td>N 46.46061°, W 063.66667°</td>
<td>&lt; 10 meters to forest cover, 2 meters to open water stream feeding main marsh area, house situated in dense cattail stand</td>
</tr>
</tbody>
</table>
3.2.2 Investigating Disease, Body Condition, and Environmental Contamination in Muskrat Populations

A total of 967 muskrat carcasses were collected from trappers across PEI in the fall trapping seasons of 2008 and 2009. Abbreviations used for selected areas from which carcasses were obtained are summarized in Table 8. Skinned carcasses were weighed to the nearest gram (Sartorius, 14 kg capacity) and tail length and total body length (length from the tip of the tail to the tip of the snout) were measured using a conventional fish measuring board. Although a rough estimation of stomach fullness was made during carcass examination, no correction was made for the weight of ingesta, so carcass weights reflect both body mass and ingesta mass. Abdominal adipose tissue stores were assessed on a scale of 0-3; 0 = no obvious adipose tissue stores, 1 = adipose tissue stores present but sparse, 2 = moderate adipose tissue stores, and 3 = abundant adipose tissue stores. Muskrats with a score of 0 or 1 were categorized as being in poor body condition, while those with a score of 2 or 3 were categorized as being in good body condition. Subcutaneous adipose tissue stores were disregarded because the amount of fat left on the carcass is a function of the skinning technique of individual trappers. This subjective assessment, while different from traditional body condition indices used for muskrats (Virgl and Messier 1993), was chosen based upon its expedition and the fact that the supervising pathologist had extensive experience using this method. Each carcass was assigned an age class (juvenile/adult) on the basis of the condition of the internal sex organs (Errington1939; Refer to Chapter 2). Overall proportions of each age/sex class in poor versus good body condition were compared using a chi-square test of independence ($\alpha= 0.05$). In addition, these proportions were compared among select areas for juvenile
males and females using a chi-square test and significant results were followed by Tukey’s honest significant difference test to elucidate differences between areas ($\alpha=0.05$). All analyses were conducted using MiniTab v.16. Sample sizes were too small to adequately compare proportions of body condition among areas for adult muskrats.

Weights of adult males and females, as well as juvenile males and females were compared using two sample t-tests. Weights of unskinned carcasses were excluded from the analysis. The weights of juvenile male muskrats were compared among select areas having at least ten observations using a fixed-effects, one-way ANOVA, as were the weights of juvenile females. Adult muskrat weights were compared among areas having at least five observations using fixed-effects, one-way ANOVAs. The restriction on the number of observations required was implemented to ensure comparability of results across the sexes. Significant differences in all cases were followed by unplanned multiple comparisons (Tukey’s method) to elucidate differences in weight between specific areas. Weights of muskrats in poor and good body condition were compared for each age/sex class using two sample t-tests. Whole-body (unskinned) weights were estimated from the mean skinned weights obtained for each age/sex class using the regression equations derived by Proulx (1997).
Table 8. Abbreviations for selected areas on PEI from which muskrat carcasses were obtained

<table>
<thead>
<tr>
<th>Area</th>
<th>Abbreviation</th>
<th>Area</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allisary Creek</td>
<td>AC</td>
<td>Locke's Dam</td>
<td>LOCK</td>
</tr>
<tr>
<td>Deroche Pond</td>
<td>DER</td>
<td>MacDonald Pond</td>
<td>MAC</td>
</tr>
<tr>
<td>Doc's Marsh</td>
<td>DOC</td>
<td>Pisquid Impoundment</td>
<td>PI</td>
</tr>
<tr>
<td>Indian River</td>
<td>IR</td>
<td>Saddle Hill Marsh</td>
<td>SH</td>
</tr>
<tr>
<td>Impoundment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johnston's River</td>
<td>JR</td>
<td>Whitlock's Pond</td>
<td>W</td>
</tr>
<tr>
<td>Larkin's Pond</td>
<td>LA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Carcasses were examined for lesions associated with known muskrat diseases. When abscesses or other lesions suggestive of bacterial infections were observed, samples were submitted for bacteriology, and the degree of liver parasitism was documented for all muskrats examined. In addition, muskrat habitats were intensively scanned for mortality in the process of completing other field work, and muskrat trappers were encouraged to look for mortalities in their trapping areas. Identified carcasses were submitted for necropsy at the Canadian Cooperative Wildlife Health Centre, Atlantic Region, (CCWHC) at the Atlantic Veterinary College (AVC).

The livers from 783 muskrats were excised and weighed (Sartorius TE12000). Liver weights were considered an index of body condition. Overall liver weights were compared between the age/sex classes using a one-way ANCOVA, with total body length (including tail) and total body weight included as covariates to control for their effects. Liver weights for each age/sex class were also compared among select areas of importance using a one-way ANCOVA. For juveniles, total body length (including tail
length) and total body weight were included as covariates, while for adults only total body weight was included because length had no significant effect on liver weight. Significant results were followed by Tukey’s multiple comparisons.

A liver somatic index (LSI) was derived from the liver weight data for each area (factor) within each age/sex class. This was calculated by dividing the least square mean for each area by the mean of the body weight covariate and multiplying by 100. In addition, log transformed liver weights were compared for each abdominal adipose tissue score using a fixed-effects, one-way ANOVA to determine the effects of this score on liver weight. This comparison was used to determine the effectiveness of using liver weights as an index of body condition.

Half of each liver was sealed in a WhirlPak bag and stored at -20°C for subsequent metal analysis. The other half of each liver was wrapped in tin-foil that had been baked at 450°C in a muffle furnace (Fisher Isotemp) to burn off organic materials, and then was stored in a WhirlPak bag at -20°C for subsequent pesticide analysis.

Adults were used exclusively for metal and pesticide analysis because it is believed that concentrations of contaminants in muskrat tissues are related to exposure duration and that comparisons between areas should consider muskrats of the same age class (Erickson and Lindzey 1983). Liver samples from sixty-four adult muskrats (thirty-one males and thirty-three females) were analysed for total mercury (Hg) at the Canadian Rivers Institute at the University of New Brunswick, Saint John campus, using the DMA-80 Direct Mercury Analyzer. This method involves heating freeze-dried tissue samples in an oxygenated decomposition furnace. Oxidation traps sulphur/nitrogen, and
mercury vapours are released from the resulting decomposition amalgamation via rapid heating. These vapours are carried by oxygen to absorbance cells set to absorb at a wavelength of 253.7 nm, and the absorbance gives a measure of total mercury in the sample. The limit of detection for this analysis was 3.42 µg/kg, dry weight. Samples analyzed were from DOC (n= 11), W (n= 19), LA (n= 16), IR (n= 4), MAC (n= 7), and DER (n= 7). These sites were selected based on geographic location and harvest levels. MAC and DER were also considered because field evidence suggested muskrats in these areas used freshwater mussels (*Pyganodon cataracta*) as a food source and these bivalves can accumulate contaminants (Bedford et al. 1968; Naimo 1995). Mercury concentrations were compared between the sexes and among the sites using a two-way, fixed-effects ANOVA.

Liver samples from twenty adult muskrats (ten males and ten females) were analyzed at Maxxam Analytics, Bedford, Nova Scotia, for the following metals: aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), strontium (Sr), thallium (Tl), uranium (U), vanadium (V), and zinc (Zn). Detection limits for the various elements are given in Table 9. Samples were analyzed using inductively coupled plasma mass spectrometry (ICP/MS). This method involves generating an aerosol using a nebulizer and forming ions by passing the droplets through high temperature plasma, causing atoms to release an electron. Ions are then focused by a positively charged electrostatic lens into an entrance aperture in the mass spectrometer. Ions are separated in the mass spectrometer by their mass-charge ratio and strike a detector which translates the
number of ion strikes into an electrical signal, giving a measure of the number of atoms of an element in the sample. Samples included in the analysis were from muskrats from LA (n= 6), DOC (n= 6), IR (n= 4), and DER (n= 4).

### Table 9. Detection limits for elements included in analysis of liver samples

<table>
<thead>
<tr>
<th>Element</th>
<th>Detection Limits for Individual Samples (mg/kg, dry weight)</th>
<th>Element</th>
<th>Detection Limits for Individual Samples (mg/kg, dry weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>10-20</td>
<td>Pb</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Sb</td>
<td>2-4</td>
<td>Mn</td>
<td>2-4</td>
</tr>
<tr>
<td>As</td>
<td>2-4</td>
<td>Mo</td>
<td>2-4</td>
</tr>
<tr>
<td>Ba</td>
<td>5-10</td>
<td>Ni</td>
<td>2-4</td>
</tr>
<tr>
<td>Be</td>
<td>2-4</td>
<td>Se</td>
<td>2-4</td>
</tr>
<tr>
<td>B</td>
<td>5-10</td>
<td>Ag</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Cd</td>
<td>0.3-0.7</td>
<td>Sr</td>
<td>5-10</td>
</tr>
<tr>
<td>Cr</td>
<td>2-4</td>
<td>Tl</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>Co</td>
<td>1-2</td>
<td>U</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>Cu</td>
<td>2-4</td>
<td>V</td>
<td>2-4</td>
</tr>
<tr>
<td>Fe</td>
<td>50-100</td>
<td>Zn</td>
<td>5-10</td>
</tr>
</tbody>
</table>

Liver samples from seventy-two adult muskrats (thirty-six males and thirty-six females) were pooled into twenty separate samples (pooled samples included tissues from muskrats of the same sex and from the same area) and were analyzed for the presence of pesticides at the Toxicology and Analytical Services Laboratory, AVC. Pesticides analyzed for included hexazinone, metribuzin, carbaryl, metalaxyl, carbofuran, linuron, atrazine, chlorothalonil, endosulfan 1, endosulfan 2, cis-permethrin, trans-permethrin, phorate, dimethoate, fonofos, diazinon, disulfoton, fenthion, phosmet, azinphos-methyl, and coumaphos. Approximately 1 g of liver was extracted using a 2:5 ratio of distilled
water:acetonitrile. Tissue was homogenized by sonic disruption and vortexed for 10 minutes. Samples were left at room temperature for 90 minutes and then placed in a shaking water bath at room temperature for 1 hour. Upon removal from the water bath, 1 g of potassium chloride was added to each test tube and vortexed for 20 seconds to separate the water phase from the acetonitrile phase. The samples were centrifuged for 10 minutes at 1,500 x g. A sub-sample of the upper acetonitrile phase was removed and placed in GC vials to be run on the GC/MS.

Samples were analyzed using a Hewlett-Packard 6890 Series GC/MS using a Zebron-50 column with a length of 27 mm, internal diameter of 0.25 mm and a film thickness of 0.25 μm (Phenomenex, Torrance, California). The analysis was conducted in full scan mode with an injection volume of 2μL and hydrogen carrier gas at an initial flow of 1.0 mL/min. The initial oven temperature of 60 °C was held for 0.50 min and subsequently increased by 45 °C/min to 105 °C followed by 40 °C/min to 165 °C, 30 °C/min to 300 °C, 20 °C/min to 310 °C and held for 5 min for a total run time of 13 min. Chromatographic data were compared against standard curves derived from pesticide mixtures (Chromatographic Specialties, Brockville, Ontario). The limit of quantification for this method ranged for the various pesticides between 0.5-2 mg/kg based on the standards used. Liver tissues analyzed were from DOC (n= 15), W (n= 21), LA (n= 18), IR (n= 4), MAC (n= 7), and DER (n= 7). These sites were selected based on geographic location, harvest levels, and agricultural land use in the respective watersheds.

3.2.3 Examining Potential Changes in Muskrat Productivity
The uteri of 106 adult female muskrats, obtained from trappers in fall trapping seasons of 2008 and 2009, were removed for placental scar counts. Placental scars are areas of hemorrhage resulting from separation of the fetal placenta from the uterine mucosa during parturition. Each uterine horn was stretched and placed over a strong light source, making the placental scars highly visible and allowing them to be differentiated (Gashwiler 1950). Counting these placental scars gives an estimate of the reproductive output of each breeding female during the current year because the scars fade prior to the onset of each breeding season (Parker and Maxwell 1984).

Mean placental scar counts were compared among areas having at least five observations using a one-way, fixed-effects ANOVAs (α= 0.05). Two separate comparisons were made; one using all placental scar counts, and another including only those placental scar counts greater than ten. These latter analyses were conducted to avoid the potential inclusion of precocial breeders, young-of-the-year that breed late in the breeding season. These individuals usually have only a single litter (Parker and Maxwell 1984; Proulx and Buckland 1985) and muskrat litter sizes rarely exceed ten young (Boutin et al. 1988). Since litter sizes decrease as the breeding season advances (Boutin et al. 1988) and precocial breeders have litters late in the season, excluding those with counts less than ten ensures that only one plus year-old adult females are considered. This approach is conservative because it likely excludes some adult females that had just one litter or two small litters. For both analyses, the assumptions of normality and homogeneity of variances were checked and satisfied by examining the normal probability plots and using Levene’s test for equal variances among groups, respectively. Significant results were followed by Tukey’s multiple comparisons. When
no significant result was detected, the power of the statistical test was determined using the maximum difference between means as the effect size.

Overall placental scar counts were compared between the current study and those obtained during a similar study of muskrat populations on PEI conducted in 1968/69 (Dibblee 1971) using a fixed-effects, one-way ANOVA. Once again, a separate analysis was conducted using only those counts greater than ten to avoid the inclusion of potential precocial breeders. Overall placental scar counts from Whitlock’s Pond, the only area shared by both the historical and current studies, were compared using both a Mann-Whitney test and a fixed-effects, one-way ANOVA because the data from 1969 showed a moderate departure from normality. Placental scar counts from Whitlock’s Pond with those less than ten excluded were compared using a fixed-effects, one-way ANOVA. When no significant result was detected, the power of the statistical test was determined.

To supplement the reproductive data obtained through carcass examinations, muskrat houses were searched in the field by opening them to count live litters. Houses were located either from a canoe or by intensively surveying the shoreline on foot. House investigations were conducted throughout the study in conjunction with other field work, but were emphasized primarily in the months of May, June, and July in Whitlock’s Pond, Doc’s Marsh, Indian River Impoundment, Deroche Pond, McEwen’s Pond, MacDonald’s Pond, and Pisquid Pond (Figure 21). Because other field work initiatives precluded disturbing muskrat houses (i.e. for live-trapping and trail camera observations), not all active houses encountered were searched for litters. Litters found were categorized as being complete or incomplete based upon whether or not the young
were found undisturbed in the nest cavity (Boutin et al. 1988). Placental scar counts, combined with information about the proportion of juveniles to adult females in a fall sample of trapped muskrats, can be used to give an additional measure of juvenile survival (Olsen 1959). The number of juveniles per adult female in the fall trapping seasons of 2008 and 2009 (see Population Structure section, p. 51) was divided by the overall mean placental scar count of adult females from these two seasons to give this index of juvenile survival. No correction was made for the potential contributions of precocial females because there is no way to separate the juveniles in the fall population which were produced by these individuals (Sather 1958). This index was compared to the same measure obtained by Dibblee (1971) in a previous study of PEI muskrat populations, although the nature of the data did not permit statistical comparisons.

Figure 21. Locations of field litter searches and muskrat house investigations on PEI
3.3 RESULTS

3.3.1 Investigating Activity around Muskrat Houses in Summer

A total of 1283 images of muskrat(s) were captured at the sites under observation, representing 512 separate trigger events. The vast majority of the images were captured at the Indian River Impoundment camera site #1 (Table 10), and muskrats were recorded at six of seven study sites. Muskrats were active around their houses at all times of the day, with most activity in the night and morning periods (29.7 and 28.9% of trigger events recorded, respectively) followed by evening (23.4%) and afternoon (18%). Activity was trimodal, with peaks between 1100-1200hrs, 1900-2100hrs, and 0100-0200hrs (Figure 22).

Table 10. Summary of muskrat images from camera sites

<table>
<thead>
<tr>
<th>Camera Site</th>
<th>Number of Images of Muskrat(s)</th>
<th>Number of Trigger Events with Muskrat(s)</th>
<th>Dates Observed (2010)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doc’s Marsh #1</td>
<td>12</td>
<td>4</td>
<td>June 10-23</td>
</tr>
<tr>
<td>Doc’s Marsh #2</td>
<td>6</td>
<td>2</td>
<td>June 14-August 30</td>
</tr>
<tr>
<td>Larkin’s Pond #1</td>
<td>0</td>
<td>0</td>
<td>June 29-July 20</td>
</tr>
<tr>
<td>Larkin’s Pond #2</td>
<td>52</td>
<td>29</td>
<td>June 29-August 30</td>
</tr>
<tr>
<td>Larkin’s Pond #3</td>
<td>1</td>
<td>1</td>
<td>August 13-August 30</td>
</tr>
<tr>
<td>Indian River Impoundment #1</td>
<td>1202</td>
<td>473</td>
<td>June 22-November 4</td>
</tr>
<tr>
<td>Indian River Impoundment #2</td>
<td>10</td>
<td>3</td>
<td>June 22-August 19</td>
</tr>
</tbody>
</table>

*These dates represent set-up and take-down of cameras. Within these periods cameras may have been inoperative at times due to being blown over, battery dying, etc.
Thirty-one images of raccoons (*Procyon lotor*) were captured, representing 14 separate trigger events (Figure 23). Raccoons were recorded at four of seven camera sites, and in all three study areas. 77.4% of the raccoon images were recorded at the Indian River Impoundment camera site #1. At this site, all images of raccoons were captured between 2050-0530 hrs. Five images of a mink (*Mustela vison*), representing two separate trigger events, were recorded at Larkin’s Pond camera site #3 (Figure 24).

![Graph](image)

**Figure 22.** Hourly occurrences of muskrat trigger events recorded on camera
Figure 23. Raccoon investigating a muskrat house at Indian River Impoundment

Figure 24. Mink on a muskrat house at Larkin’s Pond, showing hole dug into house (arrow)
Other species recorded at the camera sites included American robin (*Turdus migratorius*), wood duck (*Aix sponsa*), red-winged blackbird (*Agelaius phoeniceus*), common snipe (*Gallinago gallinago*), song sparrow (*Melospiza melodia*) and red squirrel (*Sciurus vulgaris*).

### 3.3.2 Investigating Disease, Body Condition, and Environmental Contamination in Muskrat Populations

Overall, there was no significant difference in the weights of male and female muskrats ($p=0.468$; Table 11). However, juvenile male muskrats weighed significantly more than their female counterparts ($p=0.001$; Table 11).

#### Table 11. Mean weights (g) of juvenile and adult muskrats from all areas

<table>
<thead>
<tr>
<th>Age/Sex</th>
<th>Sample Size (n)</th>
<th>Mean Weight (g)</th>
<th>SE (g)</th>
<th>Estimated Whole-Body Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult Males</td>
<td>110</td>
<td>1284.1</td>
<td>13.75</td>
<td>1638.5</td>
</tr>
<tr>
<td>Adult Females</td>
<td>107</td>
<td>1270.7</td>
<td>12.28</td>
<td>1668.5</td>
</tr>
<tr>
<td>Juvenile Males</td>
<td>423</td>
<td>931.9</td>
<td>7.60</td>
<td>1247.1</td>
</tr>
<tr>
<td>Juvenile Females</td>
<td>302</td>
<td>892.2</td>
<td>9.19</td>
<td>1187.9</td>
</tr>
</tbody>
</table>

Weights of juvenile female muskrats differed significantly between areas ($p=0.004$; Table 12). Post-hoc multiple comparisons showed significant differences in the weights of muskrats from Pisquid Impoundment as compared to those from Doc’s Marsh, Whitlock’s Pond, Allisary Creek, and Larkin’s Pond. A significant result was also found
when comparing weights of juvenile males among areas (p= 0.000; Table 12). Post-hoc multiple comparisons revealed significant differences in weights of juvenile male muskrats between Pisquid Impoundment and all other areas except Indian River Impoundment.

Weights of adult female muskrats differed significantly between areas (F= 3.31, p= 0.017; Table 12). Post-hoc multiple comparisons revealed that adult females from Doc’s Marsh weighed significantly more than those from Pisquid Impoundment. Adult male weights did not differ significantly among areas (F= 1.85, p= 0.133; Table 12).
Table 12. Mean weights (g) of juvenile and adult muskrats from selected areas on PEI

| Area | Juvenile Males | | | Adult Males | | | Adult Females | |
|------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|      | n | Mean | SE | n | Mean | SE | n | Mean | SE | n | Mean | SE | |
| AC   | 30 | 938.2 | 25.94 | 22 | 917.9 | 23.24 | 5 | 1252.6 | 61.18 | 6 | 1303.8 | 22.41 | |
| DOC  | 37 | 914.8 | 26.47 | 18 | 962.6 | 39.15 | 11 | 1297.0 | 43.63 | 9 | 1341.0 | 36.43 | |
| IR   | 15 | 940.1 | 58.53 | 14 | 781.6 | 71.76 | - | - | - | - | - | - | |
| LA   | 67 | 941.4 | 16.14 | 51 | 892.5 | 15.36 | 13 | 1297.0 | 40.33 | 17 | 1235.3 | 30.71 | |
| SH   | 21 | 966.7 | 25.62 | 15 | 891.0 | 46.79 | - | - | - | - | - | - | |
| W    | 64 | 955.4 | 17.98 | 48 | 921.8 | 18.39 | 16 | 1244.3 | 23.9 | 18 | 1286.8 | 33.94 | |
| PI   | 39 | 794.7 | 22.63 | 15 | 774.1 | 31.14 | 12 | 1174.1 | 37.44 | 12 | 1165.8 | 32.94 | |

* The means within an age/sex class that do not share a letter are significantly different.
The majority of muskrats within all age/sex classes were in good body condition (Figure 25), but the proportions differed among these groups ($\chi^2 = 16.150$, df= 3, p= 0.001). Both juvenile males and females had a significantly higher proportion of individuals in poor body condition than did adult males, and juvenile females also had a higher proportion of individuals in poor body condition than did adult females. There were significant differences in the proportions of juvenile male muskrats in poor body condition between areas ($\chi^2 = 23.136$, df= 6, p= 0.001). Specifically, the proportion of muskrats from Pisquid Impoundment in poor condition was significantly higher than in Doc’s Marsh, Larkin’s Pond, and Whitlock’s Pond. Significant differences were not detected for juvenile females ($\chi^2 = 9.284$, df= 6, p=0.158; Table 13).

Muskrats in poor body condition weighed significantly less than those in good body condition for juvenile males (p= 0.000), juvenile females (p= 0.000), and adult females (p= 0.008). The weights of adult male muskrats in poor body condition did not differ significantly from those in good body condition (p= 0.089; Figure 26) and a difference of 119.6 grams would have been required to generate a power of 0.8 for this group.
Figure 25. Overall proportions of each age/sex class in poor body condition

* Proportions within an age/sex class that do not share a letter are significantly different.
Table 13. Proportions of each age/sex class in poor body condition from selected areas on PEI

<table>
<thead>
<tr>
<th>Area</th>
<th>Juvenile Males (% in poor body condition)</th>
<th>Juvenile Females (% in poor body condition)</th>
<th>Adult Males (% in poor body condition)</th>
<th>Adult Females (% in poor body condition)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>30&lt;sup&gt;a&lt;/sup&gt;,&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>DOC</td>
<td>21.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>16.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.7</td>
<td>0</td>
</tr>
<tr>
<td>IR</td>
<td>25&lt;sup&gt;a&lt;/sup&gt;,&lt;sup&gt;b&lt;/sup&gt;</td>
<td>62.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LA</td>
<td>25.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0</td>
<td>16.7</td>
</tr>
<tr>
<td>PI</td>
<td>64.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>53.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.7</td>
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<td>33.3&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>-</td>
</tr>
<tr>
<td>W</td>
<td>28.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25</td>
<td>44.4</td>
</tr>
</tbody>
</table>

* Proportions within an age/sex class that do not share a letter are significantly different.
Figure 26. Mean weights (± SD) of muskrats in poor and good body condition. An asterisk denotes a significant difference within an age/sex class.

There was no significant difference in liver weights between the age/sex classes when body length and weight were controlled for ($p = 0.054$). For juvenile males, significant differences in liver weights were detected among areas ($p = 0.000$). Specifically, muskrats from Whitlock's Pond had greater liver weights than did those from Pisquid Impoundment and Allisary Creek. Significant differences in liver weights among areas were also found for juvenile females ($p = 0.003$). Specifically, muskrats from Whitlock's Pond had greater liver weights than did those from Allisary Creek.

Adult male muskrats from Whitlock's Pond had significantly greater liver weights than did those from Doc's Marsh, Pisquid Impoundment, and Allisary Creek ($p = 0.000$). Lastly, adult female muskrats from Larkin's Pond had significantly greater liver weights
than did those from Pisquid Impoundment and Allisary Creek. Liver somatic index values are given in Table 14.

Liver weights varied significantly with abdominal adipose tissue score ($F = 49.234$, $p = 0.000$). Muskrats with an abdominal adipose tissue score of 0 had a mean liver weight of $27.46 \pm 3.95$ g (mean ± 95% confidence interval), those with a score of 1 had a mean liver weight of $34.03 \pm 1.46$ g, those with a score of 2 had a mean liver weight of $38.22 \pm 1.12$ g, and those with a score of 3 had a mean liver weight of $41.62 \pm 1.11$ g.
<table>
<thead>
<tr>
<th>Area</th>
<th>Juvenile Males</th>
<th>Juvenile Females</th>
<th>Adult Males</th>
<th>Adult Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n LSI SE</td>
<td>n Mean SE</td>
<td>n Mean SE</td>
<td>n Mean SE</td>
</tr>
<tr>
<td>AC</td>
<td>29 3.59a 1.24</td>
<td>22 3.54a 1.26</td>
<td>5 3.36a 4.20</td>
<td>6 3.46a 2.47</td>
</tr>
<tr>
<td>DOC</td>
<td>37 3.84ab 1.29</td>
<td>18 3.83ab 2.11</td>
<td>10 3.66a 2.15</td>
<td>9 3.89ab 3.39</td>
</tr>
<tr>
<td>LA</td>
<td>47 3.88ab 1.03</td>
<td>37 3.83ab 1.10</td>
<td>9 4.03ab 2.20</td>
<td>11 4.33b 2.14</td>
</tr>
<tr>
<td>PI</td>
<td>34 3.74a 1.08</td>
<td>10 3.55ab 1.85</td>
<td>9 3.50a 1.99</td>
<td>10 3.48a 2.09</td>
</tr>
<tr>
<td>W</td>
<td>55 4.11b 0.97</td>
<td>41 4.12b 1.11</td>
<td>12 4.41b 2.76</td>
<td>15 4.13ab 3.54</td>
</tr>
</tbody>
</table>

* LSI values within an age/sex class that do not share a letter are significantly different.
Disease

Parasitic cysts were observed in the liver of 64 individuals, an overall prevalence of 6.7%. Four of six samples of liver parasites were identified as larval stages of the tapeworm *Taenia taeniaeformis*, while the metacestodes in the other two samples were too immature to be identified with certainty (identification by Dr. Gary Conboy, Department of Pathology and Microbiology, AVC). Intensity of infection ranged from a single cyst (in 80% of cases) to 16 cysts recovered from an adult male muskrat (Figure 27). Thirty-three of the infected muskrats were adults, and of these, 23 (69.7%) had one to two cysts, five (15.2%) had three to five cysts, and five (15.2%) had six or more cysts. Of the 31 infected juveniles, 29 (93.5%) had one to two cysts, two (6.5%) had three to five cysts, and none had six or more cysts. When considering only those areas from which more than 20 muskrats were examined, prevalence ranged from 0% in Larkin’s Pond, MacDonald’s Pond, and Indian River Impoundment, to 57.1% in Locke’s Dam (Table 15).
Figure 27. Larval tapeworm cyst in a muskrat liver

<table>
<thead>
<tr>
<th>Area</th>
<th># of Muskrats Examined</th>
<th># of Muskrats with Parasytic Cysts</th>
<th>Prevalence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>63</td>
<td>6</td>
<td>9.52</td>
</tr>
<tr>
<td>DOC</td>
<td>82</td>
<td>1</td>
<td>1.22</td>
</tr>
<tr>
<td>LA</td>
<td>158</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MAC</td>
<td>38</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>JR</td>
<td>21</td>
<td>3</td>
<td>14.3</td>
</tr>
<tr>
<td>LOCK</td>
<td>28</td>
<td>16</td>
<td>57.1</td>
</tr>
<tr>
<td>SH</td>
<td>45</td>
<td>1</td>
<td>2.22</td>
</tr>
<tr>
<td>PI</td>
<td>78</td>
<td>1</td>
<td>1.28</td>
</tr>
<tr>
<td>IR</td>
<td>41</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>W</td>
<td>146</td>
<td>1</td>
<td>0.68</td>
</tr>
</tbody>
</table>
No muskrat carcass obtained from trappers in the 2008 and 2009 fall trapping seasons had lesions suggestive of a clinically significant disease process. Abnormalities that were observed included a gastric abscess, an abdominal abscess from which the bacterium *Staphylococcus aureus* was isolated, and a chronic abdominal abscess/granuloma. A single muskrat carcass recovered from Indian River Impoundment during the course of field studies presented gross and microscopic lesions characteristic of Tyzzer’s disease, a fatal systemic infection caused by the bacterium *Clostridium piliforme*. These lesions included severe, acute hemorrhagic and necrotizing colitis, acute multifocal necrotizing hepatitis, and microscopically, the presence of typical bacterial rods positive on silver stain (diagnosis by Dr. Pierre-Yves Daoust at the CCWHC; Figure 28).

![Figure 28. Hemorrhagic and necrotizing colitis (left) and multifocal necrotizing hepatitis (right) associated with Tyzzer’s disease diagnosed in a muskrat from Indian River Impoundment](image)
Contamination by Pollutants

Mercury concentrations ranged from below the detection limit (< 0.00342 mg/kg) to 0.0985 mg/kg (dry weight). Mean mercury concentrations were slightly higher for males than for females and among the areas, Indian River Impoundment had the lowest mean mercury concentrations while Larkin’s Pond and Whitlock’s Pond had the highest mean mercury concentrations (Tables 16 and 17). Mercury concentrations did not differ significantly between the sexes or among the sites (p= 0.925 and p= 0.371, respectively).

Table 16. Mean liver mercury concentrations (dry weight) for adult male and female muskrats

<table>
<thead>
<tr>
<th>Sex</th>
<th>Sample Size</th>
<th>Mean mercury concentration (mg/kg)</th>
<th>SE</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>32</td>
<td>0.0213</td>
<td>0.0028</td>
<td>&lt;0.00342 - 0.0808</td>
</tr>
<tr>
<td>Females</td>
<td>33</td>
<td>0.0209</td>
<td>0.004</td>
<td>0.00515 - 0.0985</td>
</tr>
</tbody>
</table>

Table 17. Mean liver mercury concentrations (dry weight) for adult muskrats from selected areas on PEI

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample Size</th>
<th>Mean mercury concentration (mg/kg)</th>
<th>SE</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>DER</td>
<td>7</td>
<td>0.033</td>
<td>0.0148</td>
<td>0.00648 - 0.0985</td>
</tr>
<tr>
<td>DOC</td>
<td>11</td>
<td>0.0219</td>
<td>0.0024</td>
<td>0.0119 - 0.0355</td>
</tr>
<tr>
<td>IR</td>
<td>4</td>
<td>0.00916</td>
<td>0.0010</td>
<td>0.00654 - 0.0102</td>
</tr>
<tr>
<td>LA</td>
<td>17</td>
<td>0.0218</td>
<td>0.0026</td>
<td>0.0113 - 0.0541</td>
</tr>
<tr>
<td>MAC</td>
<td>7</td>
<td>0.0157</td>
<td>0.0051</td>
<td>&lt;0.00342 - 0.0380</td>
</tr>
<tr>
<td>W</td>
<td>19</td>
<td>0.0202</td>
<td>0.0040</td>
<td>0.00515 - 0.0758</td>
</tr>
</tbody>
</table>
Al, Sb, As, Ba, Be, Cd, Cr, Co, Pb, Ni, Ag, Sr, Tl, U, and V were not detected in any sample, with the exception of the detection of a very high concentration of lead in one sample most likely due to contamination during sample preparation. Molybdenum and Se were detected in single but different samples, both at concentrations of 2 mg/kg. Boron was detected in 85% of the samples, and the essential elements Cu, Fe, Mn, and Zn were detected in all samples (Table 18).
Table 18. Mean liver concentrations of select metals for adult muskrats from selected areas on PEI

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample Size</th>
<th>Boron</th>
<th>Copper</th>
<th>Zinc</th>
<th>Manganese</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOC</td>
<td>6</td>
<td>14.67*</td>
<td>6.67</td>
<td>76.5</td>
<td>11.2</td>
<td>870</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&lt;9-28)</td>
<td>(3-11)</td>
<td>(70-94)</td>
<td>(6-15)</td>
<td>(650-1100)</td>
</tr>
<tr>
<td>LA</td>
<td>6</td>
<td>14.2**</td>
<td>8.17</td>
<td>79.5</td>
<td>16.8</td>
<td>648.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&lt;6-20)</td>
<td>(7-10)</td>
<td>(64-97)</td>
<td>(10-34)</td>
<td>(420-920)</td>
</tr>
<tr>
<td>IR</td>
<td>4</td>
<td>14</td>
<td>6.25</td>
<td>74.8</td>
<td>8</td>
<td>777.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9-18)</td>
<td>(4-8)</td>
<td>(69-86)</td>
<td>(7-9)</td>
<td>(600-920)</td>
</tr>
<tr>
<td>DER</td>
<td>4</td>
<td>18</td>
<td>7.75</td>
<td>82.5</td>
<td>12</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7-45)</td>
<td>(5-9)</td>
<td>(52-120)</td>
<td>(10-14)</td>
<td>(640-1100)</td>
</tr>
</tbody>
</table>

* Boron only found in four of six samples
** Boron only found in five of six samples
No pesticides were detected in any of the samples analyzed.

3.3.3 Examining Potential Changes in Muskrat Productivity

Mean placental scar counts for the current study were significantly different among areas when all counts were included (F = 2.86, df = 5, p = 0.022). However, the post-hoc Tukey’s multiple comparison showed no significant differences between any of the areas (Table 19). When counts less than ten were excluded, there were no significant differences in mean placental scar count among areas (F = 0.75, df = 5, p = 0.592), although the power for all groups was less than 0.5. A sample size of 181 would have been required to generate a power of 0.8 for this statistical test.

The mean placental scar count from all areas over the two year study period was 15.24 with all counts included, and 16.45 when those with counts less than ten were excluded. These values compare with 17.22 and 17.72 for the historical study (Table 20). The overall mean placental scar count was significantly greater in the historical study than in the current study both with counts less than ten included (F = 12.76, p = 0.000) and excluded (F = 5.9, p = 0.016) (Figure 29).

For overall placental scar counts from Whitlock’s Pond, the Mann-Whitney (W = 835.5, p = 0.2117) and the one-way ANOVA (F = 0.73, df = 1, p = 0.398) showed that there were no significant differences between the historical and current studies. The power for the one-way ANOVA comparison was less than 0.2 for both groups, calculated using the maximum difference in the observed means. A sample size of 97 in both samples would have been required to generate a power of 0.8 for this statistical test. Similarly, there was no difference between the two study periods when counts less than ten were
excluded (F= 1.89, df= 1, p= 0.176). For this test, the power was less than 0.35 for both groups.
Table 19. Placental scar count data from breeding female muskrats from selected areas on PEI, 1968/69 and 2008/09

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample Size</th>
<th>Mean Placental Scar Count (St. Dev)</th>
<th>Sample Size</th>
<th>Mean Placental Scar Count (St. Dev)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>- All P. Scar Counts</td>
<td></td>
<td>- P. Scar Counts ≥ 10</td>
</tr>
<tr>
<td>Doc's Marsh</td>
<td>- 9</td>
<td>14.22 (6.44)</td>
<td>- 7</td>
<td>16.43 (5.44)</td>
</tr>
<tr>
<td>Allisary Creek</td>
<td>- 6</td>
<td>15.83 (1.47)</td>
<td>- 6</td>
<td>15.83 (1.47)</td>
</tr>
<tr>
<td>Larkin's Pond</td>
<td>- 17</td>
<td>15.53 (4.43)</td>
<td>- 16</td>
<td>16 (4.12)</td>
</tr>
<tr>
<td>Mt. Albion</td>
<td>- 5</td>
<td>17.6 (5.13)</td>
<td>- 5</td>
<td>17.6 (5.13)</td>
</tr>
<tr>
<td>Marsh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pisquid Impoundment</td>
<td>- 12</td>
<td>10.25 (5.26)</td>
<td>- 7</td>
<td>13.71 (3.68)</td>
</tr>
<tr>
<td>Whitlock's Pond</td>
<td>31 18</td>
<td>17.77 (4.53)</td>
<td>28 17</td>
<td>18.82 (3.29)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 20. Mean placental scar counts of breeding female muskrats in PEI, 1968/69 and 2008/09

<table>
<thead>
<tr>
<th>Year</th>
<th>Sample Size</th>
<th>All Counts</th>
<th>Sample Size</th>
<th>Counts ≥ 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968/69</td>
<td>317</td>
<td>17.22 (4.84)</td>
<td>301</td>
<td>17.72 (4.42)</td>
</tr>
<tr>
<td>2008/09</td>
<td>106</td>
<td>15.24 (5.22)</td>
<td>93</td>
<td>16.45 (4.31)</td>
</tr>
</tbody>
</table>

Figure 29. Mean placental scar counts (± SE) of breeding female muskrats in PEI, 1968/69 and 2008/09. An asterisk denotes a significant difference.

A total of fifty-nine muskrat houses were investigated during the course of the study. Of these, twenty-four were verified as being active muskrat houses on the basis of sign in the area (i.e. the presence of actively used trails, evidence of recent feeding, etc.) and the well maintained condition of the house (Table 21). At Whitlock’s Pond, only five active houses were located during the course of field investigations, compared to at least 29
found by Dibblee (1971) in the late 1960's. Only five muskrat litters were found, two in Doc's Marsh, one in McEwen's Pond, one in Indian River Impoundment, and one in Larkin's Pond. Two litters were incomplete (two young in each), while complete litters consisted of five, seven, and nine young, respectively.

**Table 21. Summary of litter search data**

<table>
<thead>
<tr>
<th>Area</th>
<th>Houses Opened</th>
<th>Litters Found*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Possibly Inactive</td>
<td>Verified as Active</td>
</tr>
<tr>
<td>Deroche Pond</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Larkin's Pond</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Doc's Marsh</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Pisquid Pond</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>McEwen's Pond</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>MacDonald's Pond</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Whitlock's Pond</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Indian River Impoundment</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

* Litters considered incomplete were found in nests that were in disarray and where it was obvious that the mother had moved one or more of the young, or when the young were large enough to leave the nest when it was disturbed. Complete litters were those that were located within a defined nest chamber having a covering of grasses.

The number of juveniles per adult female in the two year study period was 6.89. From this value juvenile survival from birth to trapping season was estimated to be 45.2%. This survival estimate is 1.45% lower than the two year average survival of 46.65% reported by Dibblee (1971).
3.4 DISCUSSION

3.4.1 Investigating Activity around Muskrat Houses in Summer

Muskrats in the study areas were active around their houses at all hours of the day, although the vast majority of the images were captured at just one site. Using the time of day categories described earlier, it is clear that muskrat activity around their houses is approximately equal in the morning, evening, and night, and is slightly reduced in the afternoon. Three distinct peaks of muskrat activity were found. Bimodal activity patterns of muskrats have been reported elsewhere in the literature (MacArthur 1980; Lyons et al. 1997), but these studies found that during ice-free periods, muskrats were active at night and almost inactive during the day. Stewart and Bider (1977) also noted bimodal activity patterns in muskrats, but found peak activity both prior to and after sunset, while Tanguay (1985) found that captive muskrats were more active in the evening hours than in the morning hours. Thus, the current finding of peak activity around midday is a surprising result that is unsupported by previous studies. Muskrat activity can be influenced by such factors as weather (Stewart and Bider 1977; Bélanger 1981), sex, and time of summer (Tanguay 1985). Increased activity around their houses during the daylight hours may mean that muskrats are more vulnerable to predation from diurnal predators such as raptorial birds (Lay 1945), but this increased daylight activity may reflect an avoidance of nocturnal predators such as raccoons.

The fact that the house at the Indian River Impoundment camera #1 site was actively maintained by muskrats for the entirety of the observation period, whereas the others were abandoned, may be related to the fact that this house was not disturbed in any
manner during the course of the investigations. Muskrats are known to move their litters in response to disturbance from researchers (Errington 1939; Dibblee 1970) so it is likely that those houses which were opened in search of litters were abandoned shortly thereafter. Although verifying the presence, age, and size of a litter may be important, it may be advantageous in future studies to avoid disturbing the houses to be monitored.

Known muskrat predators were recorded at four of seven houses under observation, and in all three study areas. In particular, raccoons were observed investigating muskrat houses most frequently, and they did so in locations with very different cover types. Raccoons were particularly persistent in their interest in the muskrat house at Indian River Impoundment camera site #1, probably because this house remained actively maintained by muskrats throughout the duration of the study. While it is impossible to determine from the images if the raccoon(s) were successful in preying on the muskrats at this site, the fact that they were observed on eleven separate occasions means that the resident muskrats were at least repeatedly harassed by these predators. Mink were recorded on two occasions at Larkin's Pond camera site #3, and on one such occasion, a hole consistent with mink invasion was present in the house. Subsequent visits to this site revealed mink scat containing what appeared to be muskrat fur, suggesting that this mink was successful in preying on a muskrat(s) at this location. In addition, mink scats containing what appeared to be muskrat fur were found on the house at Larkin's Pond camera site #1 after the camera had been removed, but it could not be conclusively determined if the remains were from muskrats dwelling within that house or from some other location. While the exact impact of predators on the muskrats under observation is difficult to determine, the results at least verify that raccoons and mink attempt to prey
on PEI muskrats, and that raccoons are disturbing (if not directly preying on) muskrats in all three study sites, representing a variety of cover types. These results mean that predation pressure cannot be ruled out as a limiting factor of PEI muskrat populations. However, without additional data, including year-round observations and exploring the impact of raptorial birds, predation cannot be determined conclusively to be the cause of the muskrat population decline. Until this additional work is completed, discussion about the exact role predation plays in this decline would be speculative.

Infra-red remote cameras have been used extensively to study wildlife ecology (Cutler and Swann 1999), particularly nest predation in birds (Heske et al. 1999; Purcell and Verner 1999; White et al. 2010) and activity patterns of mammal species (Séquin et al. 2003; Bridges 2004; McCain 2008). No previous study, however, has used this technology to study wildlife activity around muskrat houses. The results of the current study indicate that infra-red remote photography is a viable research tool to document activity around muskrat houses, including that of predators, but there are a suite of challenges associated with its use in muskrat habitat. Firstly, the lack of stable, woody vegetation in many locations means that the camera must be mounted on an artificial stand such as a tripod. This system worked well in the current study and was effective in ensuring that camera units were properly placed and aligned (Swann et al. 2004), but it is possible that the presence of this unnatural structure influenced the behaviour of the muskrats and/or deterred potential predators, thus biasing the results. In the current study, raccoons appeared to be unaffected by the presence of the tripod, but other more wary predators such as coyotes (Séquin et al. 2003) may have avoided muskrat houses because of its presence. It is also possible that the presence of the tripod actually
stimulated raccoons to investigate the area, as this species is known to be inquisitive. In addition, the density and movement of vegetation (primarily cattails) around many muskrat houses can cause the camera to trigger very frequently without an animal being present (known as false triggering and discussed by Swann et al. 2004). This can cause battery failure and cause memory cards to reach their storage capacity quickly, meaning that the site will not be monitored until the card can be replaced. Because in many habitats cattails are fast growing, ensuring that the camera’s view of the house under observation does not become obstructed requires frequent visits to the site and the alteration of site vegetation, intrusions which should ideally be minimized to reduce observer influence and biased results (Cutler and Swann 1999). Despite these drawbacks, the results of this study support the expanded use of infra-red remote photography to study predator activity at muskrat houses on PEI, ideally incorporating more camera sites and deploying cameras in all seasons to study year-round predation.

3.4.2 Investigating Disease, Body Condition, and Potential Contamination by Pollutants in Muskrat Populations

Weights and Body Condition

The fact that much of the established literature reports on the weights of unskinned carcasses, coupled with the fact that many historical studies did not separate adults from juveniles when reporting muskrat weights, makes it difficult to put the current results into context. Proulx (1997) reported skinned weights of 1120 and 1036 grams for adult males and females, respectively, and values of 779 and 735 for juvenile males and females, respectively. Weights in the current study were higher for all age/sex classes. Applying the regression equations derived by Proulx (1997) for each age-sex class
permits the estimation of whole body weights and enables the comparison of results to those from other studies. Errington (1939) reported average weights of adult and juvenile muskrats from Iowa of 1092 and 748 grams, respectively, values far exceeded in the current study. Similarly, Dozier and Allen (1942) reported average weights of adult male and female muskrats of 1043.2 and 983.3 grams, respectively. Using whole-body weight estimates, it appears that muskrats on Prince Edward Island are heavier than those in other regions.

Previous studies have shown no correlation between muskrat density and average weights (Dozier and Allen 1942). The results of the current study support this finding. Weights of muskrats from areas of varying densities (as determined by harvests over a two-year period) showed no discernible pattern. Larkin’s Pond, for example, had the highest two-year harvest of any area, and its adult male muskrats shared the highest average weight of all areas. Pisquid Impoundment, which had a moderate harvest over a two-year period, had the lowest average weights among all areas for all age/sex classes. Weights for juvenile males and females, as well as adult males, were significantly lower in Pisquid Impoundment than in areas of higher density. Furthermore, juvenile muskrats from Pisquid Impoundment had among the highest proportions of individuals in poor body condition, and juvenile males from this area had a significantly higher proportion of individuals in poor body condition than did Larkin’s Pond or Whitlock’s Pond (the areas with the highest densities). Muskrats from Pisquid Impoundment also had the lowest mean liver weights for all age/sex classes aside from adult males, providing further evidence of poorer body condition in the muskrats from this area, although other assessments of body condition in muskrats have not incorporated this measure (Virgl
and Messier 1993). It should be noted, however, that the use of harvests as a measure of density was not supplemented by other density estimates, and that the densities in even the areas supporting the largest harvests are considered to be low.

These results nonetheless suggest that weights of muskrats on PEI may be more influenced by habitat quality than by muskrat density. Muskrats from habitats having an abundance of food of good nutritional quality generally weigh more and have more fat accumulation than their counterparts from food poor habitats (Dozier and Allen 1942; Dozier 1945; Dozier et al. 1948). The current study showed that for three of four age/sex classes, muskrats in good body condition (moderate to extensive visceral adipose tissue stores) weighed significantly more than their counterparts in poor body condition. The observation that heavier muskrats tended to have more extensive abdominal fat deposits than did lighter muskrats agrees with the findings of Alexander (1955) and suggests that something in their habitat, likely diet quality, does influence body condition of PEI muskrats, although habitat condition was not directly measured in the current study. The combination of low mean body weights and high proportion of muskrats in poor body condition despite a relatively low population in Pisquid Impoundment suggests that this area provides poor quality diet for muskrats. It is possible that this area featured litter production late into the summer, which would account for a greater proportion of smaller individuals in the fall harvest and would reduce the mean weight of juveniles (Dozier et al. 1948). Indeed, several juveniles from this area weighed less than 600 grams, and they most likely fall into the category of a late litter. This would not account for the lower mean weights of adults, however. Adult females from Pisquid Impoundment were found to have the lowest reproductive output among adult females.
(Refer to Table 19, pg X), so it appears that the poor body condition of muskrats from this area has had an effect on their ability to reproduce.

Although muskrats in the current study were heavier on average than those previously reported, patterns in the weight data are consistent with past studies. Muskrats tend to exhibit slight sexual dimorphism with males being slightly larger and heavier than females. Dozier et al. (1948) found that males were distinctly heavier than females. In the current study, males were heavier than females for both juvenile and adult age classes, although the difference was only significant for juveniles. Previous studies have shown that weights of adult males and females are very similar (Sather 1958; Simpson and Boutin 1993) or that males are heavier than females (Sooter 1946). Similarly, juvenile males and females have been shown to have similar weights in late fall (Sooter 1946). In general, it appears the muskrats on PEI are in good body condition and that, for the most part, their habitats are providing adequate nutrition to attain body weights exceeding those of muskrats in other areas.

*Disease and Parasite Burden*

Lesions indicative of infectious diseases, such as Tyzzer’s disease and tularemia, were not observed in any of the muskrat carcasses obtained from trappers. Diseased individuals can restrict their movements and become more secretive in their behaviour (Wobeser 2007) and can therefore be under-represented in harvested samples (Conner et al. 2000). The diagnosis of Tyzzer’s disease from a single muskrat recovered from Indian River Impoundment, however, represents the first record of this disease in the PEI muskrat population. It is difficult to determine if Tyzzer’s disease has an effect at
the population level in PEI muskrats or its role in the apparent decline of muskrats in the province. Tyzzer’s disease can cause significant mortality in muskrat populations (Errington 1954, 1961, 1967; Mathiak 1966), and carcasses can be difficult to locate in muskrat habitat because diseased individuals die in their lodges (Sather 1958; Errington 1967). The recovery of just a single carcass, therefore, may not be indicative of significant disease related mortality in Indian River Impoundment. Outbreaks of this disease usually occur at times of high density, as bacterial shedding from diseased individuals plays a role in the transmission to healthy muskrats (Lord et al. 1956). Infection can persist in localized areas known as foci (Errington 1963; Wobeser et al. 1978) in muskrat habitat for long periods of time (Mathiak 1966), so it is probable that within such areas the disease constitutes a viable mortality factor for muskrats. Now that an area of infection has been identified in the field, the persistence of the disease can be assessed by field investigations in future years. However, there is no evidence to suggest that the sweeping epizootics reported in the literature have occurred on PEI. It is unlikely that Tyzzer’s disease alone explains the current trend of low muskrat densities both locally at Indian River Impoundment and throughout the province.

Although *Taenia taeniaeformis* was only conclusively identified in four individuals, it is likely that this species was the causative agent in the majority of the cysts observed in the liver during gross examination of muskrat carcasses. The muskrat acts as an intermediate host for the larval form of this cestode which has been reported in muskrats across their range in North America (Ameel 1942; Rausch 1946; Edwards 1949; Knight 1951; Byrd 1953; Gilford 1954), including PEI (Dibblee 1971), and in Europe (Dvořáková and Prokopič 1984 and references therein). In the current study, the overall
prevalence of parasitic cyst infection in livers was 6.7%, a proportion very similar to those reported by Rausch (1946) and Edwards (1949) but much lower than that observed by Byrd (1953). Prevalence was slightly higher in adults than in juveniles (Anderson and Beaudoin 1966) and adults tended to have more multiple infections, suggesting that the intensity of infection in PEI muskrats is positively related to the intermediate host’s age. Prevalence of this parasite in muskrats is also thought to be related to habitat type and has been shown to be higher in streams than in marshes (Anderson and Beaudoin 1966), which may explain the low prevalence or absence of parasitic cysts in muskrats from large marshes such as Larkin’s Pond, Whitlock’s Pond, and Doc’s Marsh. In some cases, infection with this parasite can be severe and between 10 and 20 cysts can be present in the liver of a single muskrat (Byrd 1953; Dvořáková and Prokopič 1984). In the current study, three individuals, all adults, had at least ten *Taenia taeniaeformis* cysts in their liver. Such intensity of infection was found to be the cause of mass deaths of muskrats in the former Czech Republic (Dvořáková and Prokopič 1984), but no harmful effects were observed in muskrats with severe infections of this parasite in Virginia (Byrd 1953). However, there is no evidence to suggest that even the highest parasite burdens observed in the current study had negative effects on muskrat health. All three individuals with more than 10 parasitic cysts in their liver were in good body condition and had body weights that were within the normal range. Considering that overall prevalence is consistent with other areas and that the infections of higher intensity did not appear to negatively affect muskrat health, it can be assumed that muskrat populations on PEI are not limited by liver parasitism.

*Contamination by Pollutants*
The concentrations of mercury found in the current study do not appear to warrant concern. All mean dry weight concentrations of mercury were below those reported by Everett and Anthony (1977) in a study in which no adverse effects on muskrat condition were observed. Plant tissues accumulate environmental mercury at lower levels than do aquatic animals, so carnivorous species such as mink usually have higher mercury burdens than do herbivorous species such as muskrats (Sheffy and St. Amant 1982; Blus et al. 1987; Stevens et al. 1997). Samples from MacDonald’s Pond and Deroche Pond were included in the analysis because the muskrats in these areas are known to prey on freshwater mussels, and mussels can accumulate metal contaminants in their tissues (Naimo 1995). The low burdens of mercury found in the current study are, therefore, an expected result, and represent levels that are not expected to have negative effects on PEI muskrat populations.

Other elemental contaminants, such as lead and cadmium, were not detected in any of the samples. For cadmium, the detection limits for individual samples ranged from 0.3-0.7 mg/kg (dry weight). Everett and Anthony (1977) reported mean liver cadmium concentrations that were higher than these detection limits in three of four groups, and Radvanyi and Shaw (1981) reported mean liver cadmium concentrations of 0.306 mg/kg. The detection limits in the current study therefore appear to have been sufficient to detect environmentally relevant levels of cadmium in muskrat liver tissue. The concentration of cadmium in muskrat tissues has been found to be correlated with concentrations in cattail (Typha spp.) tissue (Everett and Anthony 1977) and sediments from muskrat habitat (Halbrook et al. 1993). Halbrook et al. (1993) were able to demonstrate that muskrats from a contaminated reach of river had elevated cadmium
concentrations and were in poor body condition relative to those from uncontaminated areas, but cadmium concentrations were roughly 4.5 times that of the detection limits in the current study. It is clear that cadmium contamination is not a factor negatively impacting muskrats on PEI.

The detection limit for lead in the current study ranged from 0.5-1 mg/kg (dry weight). These concentrations are considerably higher than the mean liver lead concentrations reported by Everett and Anthony (1977) in a known polluted area in Pennsylvania, although the muskrats collected from this area were not in poor physical condition. The detection limits in the current study are lower than those reported by Erickson and Lindzey (1983) elsewhere in Pennsylvania. Halbrook et al. (1993) found no overt signs of toxicity in a group of muskrats with a mean kidney lead concentration of 1.2 mg/kg (dry weight). Erickson and Lindzey (1983) correlated elevated lead concentrations in Typha tissues and muskrat liver tissues and Niethammer et al. (1985) found significantly higher concentrations of lead downstream from a known pollution source than upstream, suggesting that muskrats function as bioindicators of lead contamination. The absence of lead in the samples analyzed is thus evidence that lead contamination is not currently an issue facing muskrats on PEI.

Boron was detected in 85% of the samples. Halbrook et al. (1993) found boron in less than 80% of muskrat kidney samples, although the concentrations were not reported. Boron is not considered an essential element for mammals (Eisler 1990), but it is naturally released into aquatic environments by such means as the weathering of sedimentary rocks (Howe 1998). It is difficult to determine if the concentrations observed are sufficient to elicit toxic effects in muskrats. In laboratory studies, rats fed a
diet of up to 525 mg boron/kg had no observable effects on fertility, litter size, weight, or appearance (Sprague 1972, reviewed in Eisler 1990). However, little is known about the relationship between boron in the diet and in tissue of free-living mammals and, therefore, studies examining the toxic effects of boron in the diet are not helpful in the interpretation of tissue concentrations. The concentration of boron in cattail tissues has been shown to be positively correlated with water concentration (Powell et al. 1997), but once again, little is known about the relationship between the concentration of boron in food plants and in muskrat tissue. Boron is essential for plant growth, so herbivorous species like the muskrat may ingest the element while foraging. At this point, the concentrations in PEI muskrat tissues appear to be lower than the documented levels affecting mammals as determined by laboratory studies, but further studies should be conducted to determine the relationship between concentrations of boron in plant and muskrat tissues and to establish background boron levels in PEI wetlands.

The muskrat is considered a good bioindicator of copper and zinc in semi-aquatic environments because tissue concentrations are positively correlated with concentrations in the tissues of food plants (Everett and Anthony 1977). These essential elements were not detected in concentrations suggesting toxicity. Copper concentrations were lower than those reported for livers (Everett and Anthony 1977; Radvanyi and Shaw 1981) and kidneys (Halbrook et al 1993) from muskrats associated with contaminated areas. In addition, copper concentrations detected in the current study were not so low as to suggest a deficiency (reviewed by Eisler 1997). Zinc concentrations were found to be similar to those reported by Radvanyi and Shaw (1981). However, mean zinc concentrations were roughly twice those found by Everett and Anthony (1977) in
muskrats from uncontaminated habitats, and were more comparable to those reported for
muskrats from a contaminated wetland. Despite this, zinc levels are well below those
reported to have negative effects on mammals and birds, and are above deficiency levels
(reviewed by Eisler 1993).

Little research has explored the effects of pesticides on muskrats. Juhlin and Halbrook
(1997) found only atrazine in quantifiable amounts in fat tissue from muskrats
inhabiting an agricultural area, while other pesticides were present in trace amounts or
were undetected. In addition, necropsies of muskrats from that agricultural area revealed
no adverse effects from exposure to pesticides (Thommes 1994, as cited in Juhlin and
Halbrook 1997). Juhlin and Halbrook (1997) concluded that, even in the worst case
scenario of increased application rates and heavy rainfall, muskrats in that area were not
at risk from pesticides. No pesticides were detected in any of the samples analyzed in
the current study. This is somewhat unexpected due to the intensive agricultural land use
on PEI. The analysis included 12 of the 31 highest ranked pesticides on PEI according to
risk, which incorporates hazard of the substance, exposure, and the environmental
loading of the substance (Dunn 2004). Detection limits were above the organochlorine
concentrations observed by Halbrook et al. (1993) in Virginia muskrats, so it is possible
that trace amounts of pesticides were present in the samples but went undetected.
Pesticide detection frequencies and concentrations are influenced by their environmental
persistence, and organochlorine insecticides are known to persist in the environment
longer than other classes of compounds (Wright and Welbourn 2001). However, even
the persistent organochlorines, such as endosulfan 1 and endosulfan 2, were not detected
in the current study. Pesticides can accumulate in the tissues of freshwater mussels as
well (Bedford et al. 1968), providing an alternate exposure route for muskrats known to prey on these molluscs, such as in Deroche Pond and MacDonald’s Pond. However, samples from these areas also failed to yield detectable concentrations of pesticide. While the results should be interpreted with caution because of the transient nature of pesticides in the environment and the annual variation in pesticide application in the vicinity of the study areas, it appears that pesticide contamination is not playing a role in the health of muskrat populations on PEI.

3.4.3 Examining Potential Changes in Muskrat Productivity

Placental scar counts have been used extensively to estimate muskrat productivity (Sooter 1946; Gashwiler 1950; Reeves and Williams 1956; Sather 1958; Arata 1959; Olsen 1959; Donohoe 1966; Mathiak 1966; Simpson and Boutin 1993), but issues have been identified with the technique. Studies with other rodent species have shown that while there is a general relationship between the number of young produced and the number of placental scars, the two values are rarely equal because resorbed fetuses also leave scars and scars can coalesce or become superimposed (Davis and Emlen Jr. 1948). In addition, the technique is subject to observer bias since investigators must exercise judgement to differentiate scars from one another (Mathiak 1966; Bray et al. 2003), particularly in multi-breeding season individuals, an issue which can make comparing results across studies difficult. This second issue is at least partially overcome in this study because the investigator in the historical study trained the current investigator in the use of the placental scar count technique, so the methodology was consistent across both studies.
Muskrat productivity on PEI, as estimated from placental scar counts, was significantly lower in the current study than in the late 1960’s. However, because the two studies used reproductive data from different areas, it cannot be definitely determined if this overall difference is due to an actual decrease in muskrat productivity or is a reflection of local differences in reproduction among these areas. Indeed, data from 2008/2009 showed a high degree of variation among sites. The overall mean placental scar count of all bred females was 15.24. This value is well within the range of those reported in muskrat populations elsewhere in North America (Gashwiler 1950; Donohoe 1966) but is lower than the value of 19.8 reported by Parker and Maxwell (1984) for adult female muskrats in the Tintamarre National Wildlife Area in southeastern New Brunswick. Removing potential precocial breeders to ensure that only adult females were included, mean placental scar count was increased to 16.45, but this value is still lower than that reported by Dibblee (1971) in PEI and considerably lower than that reported by Parker and Maxwell (1984) in New Brunswick. Muskrats in the temperate zones of eastern Canada usually have around two litters per year (Stewart and Bider 1974; Proulx and Gilbert 1983; Proulx and Buckland 1986), an average which was supported by the findings of Dibblee (1971) for PEI muskrats in the late 1960’s. If this average of two litters per year per breeding female is assumed to have remained consistent on PEI, then the average litter size as determined from mean placental scar counts is 7.62 for all bred females and 8.22 for those with counts of ten or more. This compares with values of 8.19 and 8.43 for PEI muskrats in the late 1960’s (Dibblee 1971). Productivity per adult female can be related to habitat type (Proulx and Buckland 1986), so the observed decrease in average litter size is likely due to the fact that the majority of the data from
the historical and current studies was gathered from different areas on PEI. It is also possible that muskrats on PEI now have fewer litters per year on average, and that this change accounts for the observed decrease in mean placental scar count. The onset of breeding in the muskrats of Atlantic Canada is related to snow depths and the arrival of warm weather during February and March (Parker and Maxwell 1984), and it is thought that early breeders give birth to more litters than late breeders (Parker and Maxwell 1980). Thus, environmental factors may be playing a role in delaying the onset of breeding activities in PEI muskrats and possibly reducing the number of litters produced. The number of litters produced per year has been shown to be a function of latitude (Boyce 1977), so it is reasonable to assume that this figure has not changed significantly in the time since the historical study was conducted.

Attempts to supplement reproductive data from carcasses with field data on litter sizes failed to yield any useable information due to the low density of active houses and the difficulty in finding litters. Only three complete litters were handled in the field despite intensive investigations. Muskrat houses in areas of low density can be widely scattered and difficult to find (Gashwiler 1950), but the complete lack of houses in large tracts of marsh is hard to explain. In Whitlock’s Pond, for example, Dibblee (1971) examined twenty-nine partial and complete litters by opening muskrat houses, whereas only five houses were found in the current study that could be considered active and none contained litters. The difference in productivity per adult female in that pond between the historical and current studies was not statistically significant. However, the power for this statistical comparison was quite low (−0.15), so the results should be interpreted with caution. From a biological perspective, annual productivity in Whitlock’s Pond
decreased by approximately 1.2 young per female, a reduction which could have meaningful implications in terms of overall muskrat abundance in this area. Whitlock’s Pond has undergone substantial alteration of habitat since the 1968/69 study. A significant amount of backwater area was trenched, resulting in channels radiating from the main, open water area. This change to the habitat increased the opportunities for bank denning for muskrats, an adaptation that may explain the drastic reduction in the number of houses observed in this pond. Muskrats have also been shown to select against building houses when populations are low (Messier and Virgl 1992), so low abundance may be exacerbating the shift to bank denning in Whitlock’s Pond.

Furthermore, in the time between the historical and current studies there have been substantial changes in the vegetative community at Whitlock’s Pond. Much of the wetland area is now dominated by sweet gale (*Myrica gale*), while in the late 1960’s there were extensive cattail stands and bulrush islands. Muskrats in habitats rich in cattails have been shown to produce more young per litter than those in other habitat types (Proulx and Gilbert 1983), so habitat changes may be responsible for the observed decrease in young per litter observed in Whitlock’s Pond. This habitat specific variation in productivity does not explain the overall decreases in mean placental scar counts observed, however, as many of the areas included in the current study are dominated by extensive cattail stands. This study could have been improved by examining carcasses from the same areas as those included in the 1968/69 study, but this was difficult because carcasses were provided by local trappers and areas trapped were dependant on trapper preferences.
If those females with placental scar counts of less than ten are considered precocial breeders, then 12.3% of bred females from all areas in the current study would fall into this category. It is likely, however, that removing those females with placental scar counts of less than ten excluded adult females who had only a single litter or had two small litters, so the actual proportion of precocial breeders in the breeding population is undoubtedly lower than 12.3%. Dibblee (1971) found sixteen bred females with placental scar counts of less than ten, of which just seven were confirmed to be juveniles based upon the molar fluting aging technique. This represented 2.4% of the breeding females in the study. Because a second aging technique was not employed in the current study, the proportion of bred females that were juveniles cannot be conclusively determined. It has been hypothesized that precocial breeding in muskrats is compensatory for high mortality rates and low densities (Parker and Maxwell 1984), but further research has disputed this suggestion (Simpson and Boutin 1989). In addition, the occurrence of precocial breeders in the population may be due to the early onset of the breeding season due to warm weather, such that the first born litter is able to reproduce by the end of the breeding season (Proulx and Buckland 1985). If precocial breeding does function as a compensatory mechanism in low density populations, it remains to be seen if this mechanism has been initiated in PEI muskrats.

Muskrats from Pisquid Impoundment had significantly less placental scars than those from all other areas except Doc's Marsh when all counts were included, and had the lowest mean placental scar count when counts less than ten were excluded. The ability to detect significant differences with counts less than ten excluded was greatly reduced due to the low power of the test, but the muskrats from Pisquid Impoundment clearly
produced fewer young than those in the other areas. The apparent reduced productivity of breeding females in Pisquid Impoundment may be related to poorer body condition of muskrats in this area (see Body Condition, Disease, and Contamination Section, page 97).

Errington (1963) reasoned that 50% survival of juveniles from birth to trapping season should be considered a good survival rate. The juvenile survival rate determined in the current study was 45.2%, which was slightly lower than the two year average observed for PEI muskrats by Dibblee (1971). However, Dibblee (1971) found a survival rate ranging from 44.6-48.7% during his two year study period, so the rate found in the current study falls within this range of variation. This juvenile survival rate is lower than those reported in New Brunswick (Parker and Maxwell 1984), Ontario (Proulx and Gilbert 1983) and Manitoba (Olsen 1959), but is higher than the rates found by other researchers (Baumgartner and Bellrose Jr. 1943; Clark 1987). This juvenile survival rate can be influenced by habitat type (Proulx and Buckland 1986), and juvenile survival has been shown to be density dependent (Clark 1987). Juvenile survival on PEI appears to be in the range of what is considered normal, or is at least unchanged from that in muskrat populations in the province in the late 1960’s when abundances were higher. Research has shown that there is no relationship between juvenile survival and litter sizes in muskrats (Boutin et al. 1988), so the apparent decrease in litter size along with no changes in juvenile survival is not surprising.

The number of juveniles per adult female in the fall samples over the duration of the current study was 6.89. This is considerably lower than the two year average of 7.98 juvenile/adult female ratio observed by Dibblee (1971) in the late 1960’s, although once
again this historical data was obtained from different sites. This result, in combination with the similar juvenile survival rates in the historical and current studies, lends further support to the idea of reduced litter sizes in the muskrats of PEI. Juveniles appear to be subjected to the same degree of mortality, but there are now fewer juveniles present in the fall population (see Population Structure Section).

In areas where reproductive output is low, juvenile survival is generally high leading to normal annual productivity (Clough 1987). The results of the current study suggest that reduced reproductive output of breeding females is not being offset by increased juvenile survival, which may explain the current trend of low muskrat populations. This assertion could be strengthened by examining the reproductive tracts of females from the same areas as those in the historical study by Dibblee (1971), which may require kill-trapping muskrats by the investigator.

CHAPTER FOUR: GENERAL SUMMARY AND FUTURE RECOMMENDATIONS

The apparent decline of muskrat populations on PEI is a complex issue with many potential contributing factors. The primary evidence of such a decline in the province is decreased harvest levels, but this study has shown that trapper effort explains much of the variation in muskrat harvest. Thus, it is difficult to conclude that decreased muskrat harvests are indicative of actual population declines. However, anecdotal evidence from trappers claiming that muskrat populations have been reduced should not be discounted because these individuals offer a unique perspective. In many cases, the same individual(s) have trapped the same locations for several decades, and as such they are
acutely aware of changes in the density and distribution of muskrats in these areas. The results of the questionnaire provide strong evidence that trappers have acknowledged a decrease in muskrat populations in the areas that they trap. Clearly resources need to be allocated to population monitoring programs to include actual abundance estimates as a predictor of muskrat harvest. Implementing these programs now will not provide further evidence of an actual population decline because there are no historical benchmark levels for comparison. However, it is essential that population indices be established and maintained in important areas, including Doc’s Marsh, Larkin’s Pond, and Indian River Impoundment to determine if the apparent decline is ongoing, or if population have stabilized at what are considered low levels. Ideally, a wetland in western PEI, such as Nail Pond, would be included in such a monitoring program.

This study made only a cursory exploration of the claims of muskrat population decline through density estimates, and the goal was not to validate or invalidate these assertions. Study objectives, incorporating the beliefs and opinions of trappers and wildlife biologists, were then formulated to explore various aspects of this decline. Much of the results are negative in nature, in that they detract support from potential contributing factors. A recurring observation from trappers was that muskrats were present in wetlands in the early fall to build houses for over-wintering, but the muskrats were no longer present in these areas upon the arrival of the trapping season in early November. Mark-recapture studies, however, showed that in Larkin’s Pond and Indian River Impoundments, survival from late-summer to trapping season was at least 0.37 of the tagged individuals. In Doc’s Marsh, low return rates were confounded by limited trapper effort, so it was difficult to determine survival rates at this location. Nevertheless, these
results provide evidence against the claims of high mortality from late-summer to trapping season, at least in the areas studied.

Several lines of evidence show that habitat is providing adequate nutrition to resident muskrats at most sites. Mean daily rates of weight gain for recaptured muskrats were similar to those reported elsewhere, including New Brunswick. Overall body weights were greater than those reported for muskrats in other jurisdictions and in the same range as those reported in New Brunswick (Parker and Maxwell 1984). Also, the majority of muskrats of all age/sex classes were in good body condition as determined by examining abdominal fat deposits. The one notable exception was in the muskrats from Pisquid Impoundment. This was not a main study area, but many carcasses were received from trappers there. For all age/sex classes, muskrats from this location had the lowest mean body weights and mean liver weights, and juvenile male muskrats from Pisquid Impoundment had a significantly higher proportion of individuals in poor body condition than did other areas. Interestingly, adult females from Pisquid Impoundment also had the lowest mean placental scar counts of all areas. It appears that the habitat at Pisquid Impoundment provides poorer quality nutrition than other areas, and future research should explore the population level effects in this wetland. In the perspective of overall population decline, however, the results of this study do not suggest that the nutritional quality of available habitat is a major limiting factor.

At the onset of this study, a key question was if the apparent decline in muskrat populations had coincided with changes in population structure. The study benefited from having a historical data set from PEI with which to compare, in the form of a master’s thesis project conducted by Randy Dibblee in 1968/69. This historical study
was conducted when muskrat populations in the province were considered healthy. No significant differences were found in any of the population parameters compared, including overall sex and age ratios, and the proportions of each age/sex class in the samples. These results are important in the context of an apparent population decline. Firstly, because there have not been significant changes in the age structure of the population it can be inferred that if a mortality factor(s) is/are responsible for the current low numbers, this/these factor(s) is not acting differentially on a particular age class. Also, this result shows that the population is not aging, a trend which can be linked to declines. Secondly, the sex ratio within the adult age class was found to have not changed significantly, and is still close to a 1:1 male:female ratio. Due to the fact that muskrats are largely considered seasonally monogamous, the adult sex ratio desired for optimal reproduction is 1:1. This study has shown that population declines of muskrats on PEI have not coincided with changes in population structure, although a potential study bias may limit the interpretation of these results. Study areas differed between the historical and current studies, meaning that the results could reflect local differences in population structure and not an overall pattern.

Because the muskrat is known to be vulnerable to outbreaks of infectious disease that can decimate local populations, it was important to assess the role of disease in PEI muskrats. However, clinically significant disease was not observed in any of the 967 carcasses examined in the laboratory. This may be due to the fact that the sample was from harvested muskrats, and diseased individuals may have had a lower capture probability due to reduced activity. A muskrat carcass found in the course of field investigations at Indian River Impoundment was diagnosed as having died of Tyzzer's
disease. This case was the first record of Tyzzer’s disease in PEI muskrats. Although this was a significant finding because it verifies the presence of another potential limiting factor for muskrat populations in the province, the role of this disease in the apparent decline of muskrats is unclear at this time. Further work should be undertaken to map the distribution of this disease in the province, which should include being more assertive in encouraging trappers to submit mortalities they find in the field to the CCWHC for necropsy. In addition, because muskrats with Tyzzer’s disease are known to die in their houses in the late fall, a field program should focus on opening houses in search of mortalities at this time. It may be that this disease is in fact partly responsible for the initial decline in muskrat populations, or it may be functioning to limit population recovery. Nonetheless, the current state of knowledge on the ecology of this disease on PEI means that additional information is needed before its role in the decline of muskrat populations can be elucidated.

The issue of recruitment is central to any investigation into population decline, and changes in recruitment can be due to reduced reproductive output or mortality of young. Reproduction was assessed by counting placental scars from breeding females. Once again, this study benefited from having a historical benchmark to compare to in the form of Randy Dibblee’s 1968/69 study. Mean placental scar counts were found to have decreased slightly but significantly since the late 1960’s, while juvenile survival (as measured by juveniles per adult female in the fall population) did not change substantially. It appears then that adult female muskrats are currently producing fewer young on average than in the late 1960’s. This conclusion, while of obvious importance from a management perspective, should be tempered by the fact that females examined
in the two studies came from different areas, and by the fact that the placental scar count is a technique subject to observer bias.

A key concern among trappers was habitat contamination, and its potential effects on muskrat populations. This concern was addressed by collecting tissues from muskrat carcasses and analyzing them for a variety of potential contaminants, including mercury, cadmium, lead, arsenic, and a suite of pesticides. The results demonstrate that these contaminants are not likely present at concentrations sufficient to elicit toxic effects in muskrats. This is particularly true of the metals analyzed because detection limits were generally below values reported in previous studies in which no harmful effects were observed in muskrats. Conclusions drawn from the results of the pesticide analysis, however, should be made with caution. Reportable detection limits were quite high, so the fact that no pesticide was detected does not necessarily mean that substances were not present in biologically relevant concentrations.

Lastly, because the muskrat is an important prey species for a variety of predators in and around wetland ecosystems, predation is an important factor to consider in the context of a population decline. Predation pressure is an inherently complicated topic because it involves multiple predators preying on muskrats in accordance with availability, which is in turn a function of the toll of the other predators. In addition, the predator communities can vary with season and local habitat conditions. This study used remote cameras to initiate the investigation into predator impacts on muskrats. The results did not rule out predation as a potential factor in the decline, as raccoons in particular were repeatedly observed harassing muskrats in their houses. This was observed in all three study areas and in different cover types. This study demonstrated that remote cameras
can be a valuable tool in exploring predator impacts on muskrats because they remove the investigator from the field and allow multiple areas to be monitored simultaneously. The expanded use of these cameras in all seasons could provide valuable insights.

In conclusion, the apparent decline of muskrats on PEI does not appear to have coincided with changes in population structure and is not likely related to habitat quality. Decreased reproduction was observed, but the precise causes of this finding remain unknown. Harmful levels of contaminants, reproductive disease, and an overall decline in body condition were not detected. However, unrelated to decreased reproduction, predation cannot be ruled out as a major factor contributing to the decline and lack of recovery of muskrat populations on PEI. Unfortunately, abundance estimates of several key predators on PEI, including mink, raccoon, and coyote, are derived from harvest data which have may not be indicative of actual population sizes. Anecdotally evidence suggests that these populations are relatively high, which may be exerting significant predation pressure on muskrat populations.
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