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Original Research

Declines in Muskrat (*Ondatra zibethicus*) Population Density in Prince Edward Island, Canada

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Abstract

Muskrats (*Ondatra zibethicus*) are the most abundant furbearer on Prince Edward Island (PEI) and a cornerstone of the trapping industry in the province. In the past 10-20 yrs, trappers have reported declines in muskrat density in areas that have traditionally been much more productive. In order to evaluate the validity of those concerns, a trapper survey was conducted, historic muskrat harvest data was evaluated, and population characteristics and demographics were directly estimated. Trapper surveys confirmed the general opinion of decreased muskrat density, though only in those trappers with 2 decades or more of experience. The number of trappers and pelt price were significantly positively related to annual harvest, and unemployment negatively related to annual harvest indicating that harvest is influenced by economic factors. Harvest was not significantly related to weather-related metrics during the harvest season. While age/sex ratios in the fall harvest have not changed since the 1960s, mark-recapture studies in 3 marshes found that current population densities ranged from 1 to 5 muskrats/ha, at the lower end of expected densities of muskrats based on studies from throughout North America. Furthermore, muskrat house density in 4 marshes was less than 0.12

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house/ha. Those values were generally lower than any reported in the literature, and comparison of house density with data from the 1960s from 1 marsh showed an almost 6-fold reduction in house counts. Overall, these data suggest evidence for low but stable populations of muskrats in the majority of PEI marshes examined, substantiating trapper opinions of low muskrat density.

Key Words: Canada, Decline, Harvest, Mark-recapture, Muskrat, Population, Prince Edward Island, Trapping.

INTRODUCTION

Localities in eastern and central North America have been experiencing reduced harvests of muskrat (*Ondatra zibethicus*), and depressed harvest levels have been suggested as evidence of population declines (Landholt and Genoways 2000; Roberts and Crimmins 2010; Ahlers and Heske 2017). Although muskrat populations are known to fluctuate widely (Errington 1951, 1954), the current trend of recurring low returns in these areas appears to be abnormal. Unfortunately, furbearer harvest information is often the only information with which to assess population status in most jurisdictions.

Inferring actual population declines from muskrat harvest in a geographic region can be problematic (Wlosinski and Wlosinski 1998). Harvest can be influenced by such external factors as pelt prices, the number of trappers (Poole and Mowat 2001), and weather (Clark 1986). In the absence of demographic monitoring, anecdotal reports by trappers of localized declines in harvest remain as primary indicators of declines in muskrat populations. This type of local ecological knowledge can be a useful tool in wildlife management (Huntington 2000; Moller *et al.* 2004), but can be difficult to collect and quantify.

Over the past 2 decades, trappers on Prince Edward Island (PEI), Canada, have regularly reported depressed harvests of muskrat. Muskrat trapping is an important source of income for many trappers on PEI, and the muskrat is the most heavily harvested furbearer in PEI. Aside from the total annual harvest data reported by trappers to the PEI Department of Communities, Land, and Environment, no formal population monitoring for this species has occurred in the past 40 yrs.

The central hypothesis of this study was that muskrat population declines have occurred in PEI on a decadal scale. Given the lack of consistent muskrat monitoring in PEI, this hypothesis was independently evaluated using 3 methods. Firstly, local trapper ecological knowledge with regard to muskrat decline on PEI was collated through the use of a survey. Secondly, historic muskrat harvest data for 46 yrs was examined to evaluate trends in harvest. Economic factors such as number of trappers, pelt prices and unemployment were examined as to their influence on annual harvest. Finally, muskrat population size was estimated with mark-recapture and house counts made in 4 PEI marshes. These latter demographic variables were compared to historic data from PEI where available, and also to estimates from different jurisdictions.

STUDY AREA

The study was conducted in the island province of Prince Edward Island, Canada (Figure 1). Surveys were mailed to trappers in 2008, and muskrat harvest data were collected from all registered trappers distributed throughout the entire province from 1971 until 2017. Live-trapping was conducted at 3 sites: (1) Larkin's Pond, a 63-ha shallow marsh designated as a Natural Protected Area in the north-eastern part of the province, (2) Doc's Marsh, a 101-ha shallow marsh designated as a Wildlife Management Area in the south-eastern part of the province, and (3) Indian River Impoundment, a 25-ha shallow marsh designated as a Wildlife Management Area in the north-western part of the province (Figure 1). Comprehensive house surveys were conducted at the above 3 marshes, in addition to Whitlock's Pond (70.5 ha). Less exhaustive house counts were conducted at 4 additional marshes (Figure 1): Deroche Pond (46 ha), Pisquid Pond (96 ha), MacEwen's Pond (17 ha), and MacDonald's Pond (86 ha). All marshes were dominated primarily by narrow-leaf cattail (*Typha lattifolia*) with internal areas of open water and multiple open water channels throughout the peripheral vegetation.

MATERIALS AND METHODS

Trapper questionnaire

To evaluate the opinions of PEI trappers with respect to the apparent muskrat population decline, a short questionnaire was delivered to all registered trappers in the province. 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 Department of Communities, Land and Environment. A total of 105 questionnaires were mailed to trappers in the fall of 2008 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. Trappers were asked if they were active trappers, the number of years of trapping experience, and whether or not muskrat abundance, available time, or pelt price was the primary

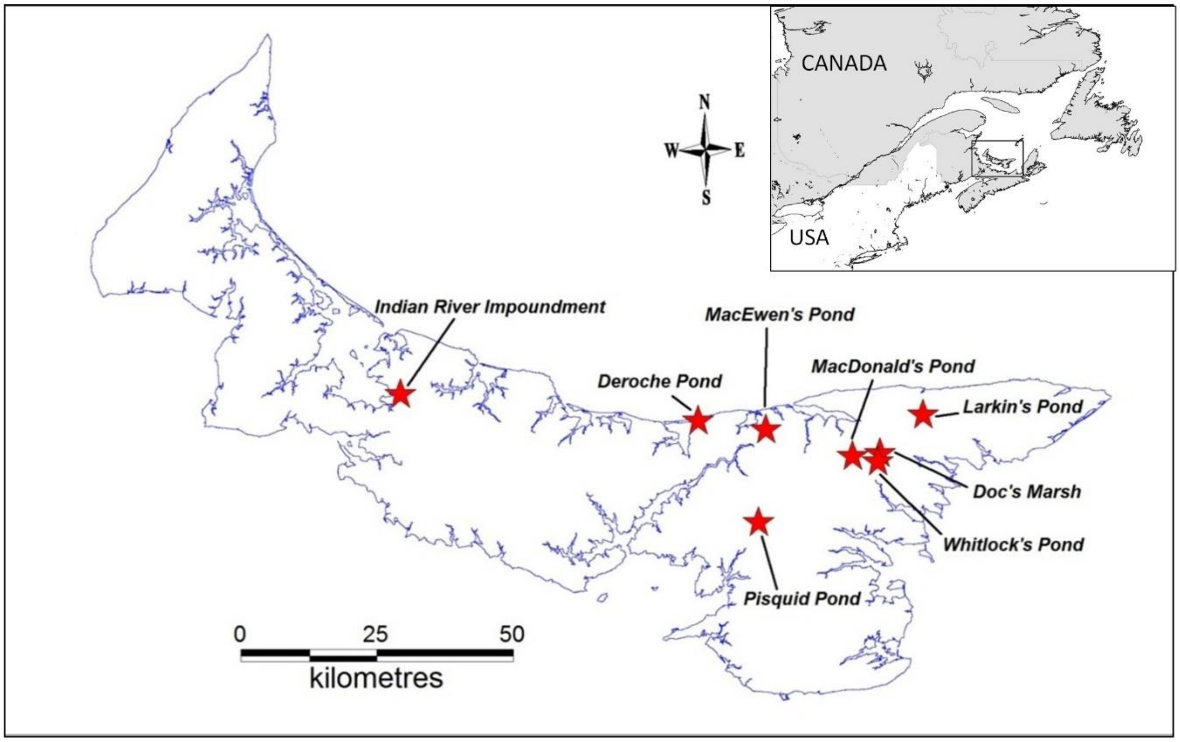

Figure. 1. Locations of the marshes studied in Prince Edward Island, Canada.

determinant of their harvest success. Trappers were asked to indicate if they thought muskrat had declined since they started trapping, and if so, what they thought the primary cause was.

Muskrat harvest and the influence of economic and weather variables

Annual muskrat harvest totals, the average price per muskrat pelt, and the number of registered trappers were obtained for the period 1971-2016 from the Department of Communities, Land and Environment. The use of muskrat harvest assumes that harvest is reflective of, or a reasonable sample of the overall population. Given that most harvest on PEI comes from marshes, almost all of which are trapped across PEI, and the marshes are relatively small, and thus intensively trapped, there is no reason to believe that this assumption would not hold. Examination of harvest data over time also assumes consistent harvest practice. There has been some change to harvest methods over the period examined. After 1997 when Canada became a signatory to the International Agreement on Humane Trapping Standards, leghold traps could only be used under water; however, the rotating-jaw (body-gripping) Conibear trap became available for trapping muskrats on land and is permitted on PEI. As muskrats could still be actively trapped on land and in water, any significant changes to trapping efficiency over this period are unlikely. Provincial unemployment rates for the range of years examined were obtained from Statistics Canada. Historical average pelt prices were adjusted to account for inflation using the Bank of Canada Inflation Calculator (http://www.bankofcanada.ca/en/rates/inflation_calc.html) so that past prices were comparable to current prices. Air temperatures and rainfall amounts were obtained for the same time period from the Environment Canada for station Charlottetown A, PEI (N 46°17'19.020", W 63°07'43.070", Climate ID # 8300300, WMO ID# 71706), and were assumed to be representative of conditions across PEI.

A Principal Components Analysis (PCA) was conducted using economic and weather variables with harvest as a supplemental variable as a preliminary visual examination of correlations between muskrat harvest and potential influencing variables. The assumption of normality for the supplemental and predictor variables were examined using visual examination of normal probability plots. Logarithmic transformations were applied to harvest, number of trappers, and all price variables to normalize those distributions. As variables exhibited significant collinearity, the first 3 principal components were used to examine their influence on harvest using a general linear model. All PCA and general linear model statistics were conducted with STATISTICA v.12 software.

Juvenile survival, growth, and density of muskrats

Live-trapping, as well as the handling and tagging of muskrat litters, took place in June, July, and August 2009. Muskrats were trapped using Tomahawk double-door livetraps (Model #202, Tomahawk Live Trap, Hazelhurst, Wisconsin) set on runs and houses and baited with apple. Captured muskrats were anaesthetized using the inhalational anesthetic isoflurane (Belant 1995), administered either by placing the individual 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). Once subdued to allow handling, all muskrats were weighed to the nearest gram (Sartorius TE12000, Bohemia, New York) 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 2010; Ahlers *et al.* 2010). Those weighing <1000 g were considered to be born that spring (young of the year), and those weighing >1000 g were considered to be at least 1 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). In addition, muskrat litters (< 1 month of age) located in nests were collected for tagging. Only active houses (2-7 houses depending on the marsh) discovered during the early part of the season (June), when nursing juveniles were likely to be present, were opened up. 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.

Prior to 1 November (the beginning of the fall muskrat 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 and were offered an incentive of $15 CAD for every tagged muskrat that was returned in their harvest. The provision of capture locations could be interpreted as providing a bias in capture effort; however, a number of factors make this potential bias negligible. Firstly, the size of the marshes examined was relatively small and the open water distance in the cattail-dominated areas ranged from 800-1000 m areas of the marsh. Muskrats were tagged over the full extent of each marsh where they were present. Given such small distances and the 5 months that had elapsed since tagging, some dispersal of tagged juvenile muskrats likely occurred. These relatively small areas also allow the marsh to be saturated with traps (e.g., only 20 traps would represent a trap every 50 m). Secondly, trappers had at least 10 yrs of experience in the marshes examined, and thus the provision of the capture locations did not alter the patterns of trapping that have led to harvest success in past years. The presence of signs of muskrat activity would have been the largest determinant of trapping effort and trappers would have sought to maximize harvest with the least possible effort.

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 using a portable tag reader. Tagged unskinned muskrats were weighed and measured using the same equipment as at the time of tagging, and were transported to the Atlantic Veterinary College, Charlottetown, PEI 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. Minimum survival estimates between summer and the onset of trapping season in November were calculated based on the proportion of tagged muskrats returned in the harvest. Locals trappers suggested that this period coincided with high levels of mortality, evidenced by the fact that marshes often had recently constructed muskrat houses but little to no muskrats available for trapping.

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

$$N = MC/R$$

where N= the estimated population size, M= the number of muskrats captured and marked in the summer of 2009, C= the total number of muskrats captured in the fall 2009 trapping season, and R= the number of marked muskrats recaptured in the fall 2009 trapping season. The Lincoln-Petersen method further assumes population closure, no mortality, immigration equals emigration in the duration between tagging and recapture. While the assumption of no mortality may not be entirely met in the months between tagging and capture, deviations from this assumption, would tend to overestimate the population size. The population at the time of tagging would be underestimated if emigration was greater than immigration.

Juvenile, adult and sex ratios

In the fall trapping seasons of 2008 and 2009, muskrat carcasses were obtained from registered trappers across PEI. Carcasses were obtained from wetlands distributed across the province and were stored at -20°C before examination in the laboratory. A total of 967 carcasses were examined, of which the capture locations were known for 957. Muskrat carcasses were from 10 different marshes with between 28 and 154 muskrats per marsh. 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 1 year old). Juvenile males had testes which were turgid and pink/cream-colored while adult males had testes which were greyish and flaccid. Juvenile females had uterine horns which were thin, flimsy, and transparent while adult females had uterine horns which were thickened and opaque. This method is considered accurate for ageing fall trapped muskrats (Errington 1939; Sather 1958; Dibblee 1971).

Age and sex ratios of muskrat samples were compared among areas having at least 25 samples using chi-square 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 late 1960s (Dibblee 1971). Adult sex ratios in both the current and late 1960 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 2 samples were compared using chi-square tests of independence (MiniTab v.16). Differences were considered statistically significant where $P \leq 0.05$.

Muskrat house counts

To supplement the reproductive data obtained through carcass examinations, muskrat houses were located either from a canoe or by intensively surveying the shoreline vegetation 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, and Indian River Impoundment. Seasonally, muskrat house counts may be elevated in summer as compared to winter as muskrats can use more than 1 house in summer. Searches for muskrat houses were aided by the presence of muskrat foraging on cattail clearly visible from the water, and by the presence of active muskrat runs increasing the probability of house discovery. Where activity was observed, searches were continued until a house was found. All houses discovered were categorized as active or inactive based on the presence of recent sign, including mud and vegetation on the house, nearby scat, and nearby floating vegetation consistent with muskrat foraging. Intensive efforts over multiple searches over several months and the relatively small size of the marshes minimized the probability of undiscovered houses. Historic muskrat house counts (Dibblee 1971) were also conducted in summer months. The author of that report participated in this study to ensure continuity in house counting methods.

RESULTS

Trapper questionnaire

A total of 105 questionnaires were distributed in the fall of 2008, of which 45 (42.8%) were completed and returned. Of these respondents, 31 (68.8%) indicated that they were currently active muskrat trappers. The mean number of years of experience for muskrat trappers on PEI was 33.6 (range 2-69 yrs). The majority of respondents (74.1%) indicated that the abundance of muskrats in their trapping areas was 1 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 1 option).

A total of 19 (61.2%) of the active muskrat trappers said that their muskrat harvest decreased since they began trapping. Ten (32.1%) trappers responded that their harvest had stayed the same or increased since they began trapping in the province. From an experience perspective, all 19 of the trappers who reported decreased harvests had been trapping on PEI for at least 10 yrs, and 84% had at least 20 yrs of trapping experience in the province. Four of the trappers who indicated stable or increasing muskrat harvests had been trapping for less than 5 yrs, while 5 had been trapping for 30 yrs 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 yrs ago to within the last 2 yrs. In addition, these trappers were asked to identify the factors they felt were responsible for this decline (respondents could select more than 1 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 muskrats 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%).

Seven of 23 respondents (30.4%) indicated that they had previously found muskrat carcasses in their trapping areas, with 5 of these trappers having done so on more than 1 occasion. Only 1 of these 7 trappers answered that he had submitted the carcass to the Atlantic Veterinary College for necropsy. The others 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.

Muskrat harvest and the influence of economic and weather variables

Muskrat harvest on PEI has declined by more than half when comparing the decade from 1977-1988 (mean of 7,483) to the average from 1988-2016 (mean of 3,371, Figure 2). Since 1990, no trapping season has produced more than 5,000 pelts. The muskrat harvest fell precipitously between 1988 and 1990. The trends in muskrat harvest closely followed the number of trappers (Figure 2A) with the number of trappers also dropping my more than 50% between 1988 and 1990. The inflation-adjusted pelt priced did not follow harvest as closely as the number of trappers (Figure 2B). There was an initial 3-fold drop in the pelt price

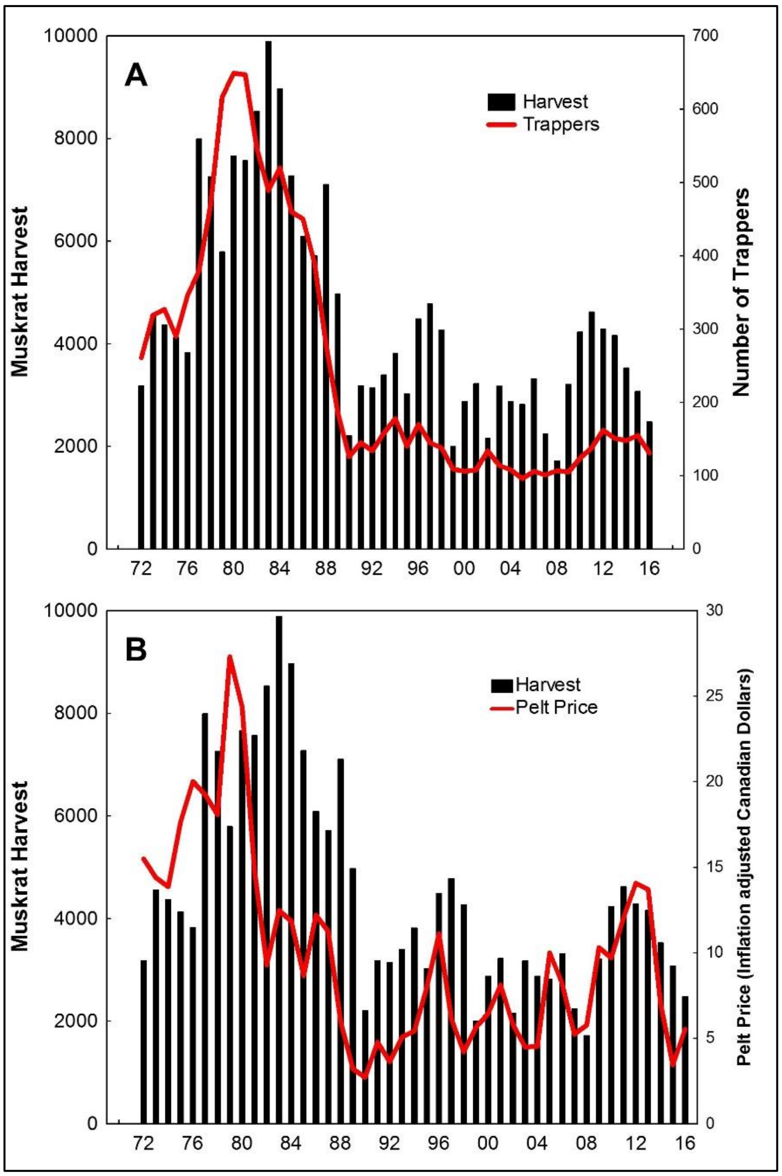

Figure. 2. A) Number of muskrats harvested and number of registered trappers on Prince Edward Island, 1973-2015; and B) number of muskrats harvested and inflation–adjusted pelt prices on Prince Edward Island.

from its peak in 1979 to 1982. This was followed by a second 3-fold drop starting in 1987 to the lowest recorded inflation-adjusted price in 1990.

The PCA showed 42.1%, 27.4%, and 13.6 % of variability in PC1, PC2, and PC3, respectively (Figure 3; total of 83.1%). Number of trappers, pelt price, lag pelt price and unemployment all loaded heavily into PC1 (loading of -0.82, -0.85, -0.93 and 0.55, respectively). The harvest supplemental variables also loaded strongly on PC1. The 2 temperature variables, mean November temperature and Novembers days below 0ºC were largely orthogonal to the economic variable and loaded mostly into PC2 (loading of 0.83 and -0.83, respectively). November rainfall was the dominant component loading to PC3 (loading -0.90). Correlation analysis also demonstrated the collinearity of the economic variables, number of trappers, and harvest. Number of trappers was found to be more strongly correlated with the harvest (Pearson's r = 0.85; Figure 4A) than was the inflation adjusted pelt price (Pearson's r = 0.5021; Figure 4B). There was also a statistically significant relationship between the inflation adjusted pelt price and the number of trappers (Pearson's r =0.70; Figure 4C). A general linear model was utilized using harvest as the dependent variable and the first 3 principal components as the independent variables. Only the first principal component was significantly related to harvest ($P<0.05$, model $r^2=0.046$).

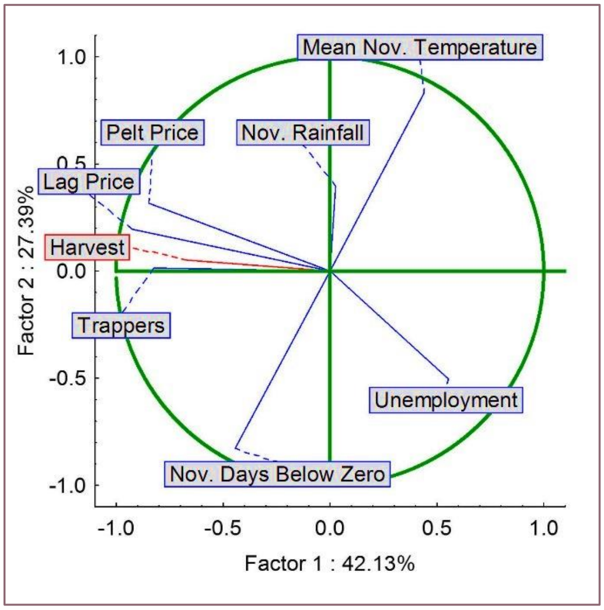

Figure. 3. Principal Components Analysis (PCA) of number of trappers, price, unemployment and weather variables (all blue). Annual harvest is overlaid as a supplemental variable (red). The length of the vector is proportional to its loading and the green circle represents a value of 1.

Growth and survival of muskrats

A total of 324 trap nights were employed between 29 June and 20 August, 2009. Trapping success was 19.1%, with a total of 62 captures (Table 1). 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. Fifty-one of the captured muskrats were tagged with PIT tags, and an additional 10 muskrats were captured and tagged while carrying out house searches. These additional tagged individuals included a single litter of 9 very young muskrats (each weighing <50 g) in Larkin's Pond and a single juvenile muskrat in Doc's Marsh. The total number of tagged muskrats available to trappers for harvest in the fall of 2009 was 61. Thirty-nine (63.9%) of these tagged muskrats were juveniles while the remaining 22 (36.1%) were adults.

A total of 20 tagged muskrats (32.8%) were recovered in the 2009 fall harvest of which 14 were juveniles and 6 were adults. Two additional tagged muskrats were recovered after the fall harvest of 2009. Juvenile survival from summer to trapping season was thus estimated to be at least 35.9%, while adult survival was estimated to be at least 36.4%. The minimum number of days elapsed between the original date

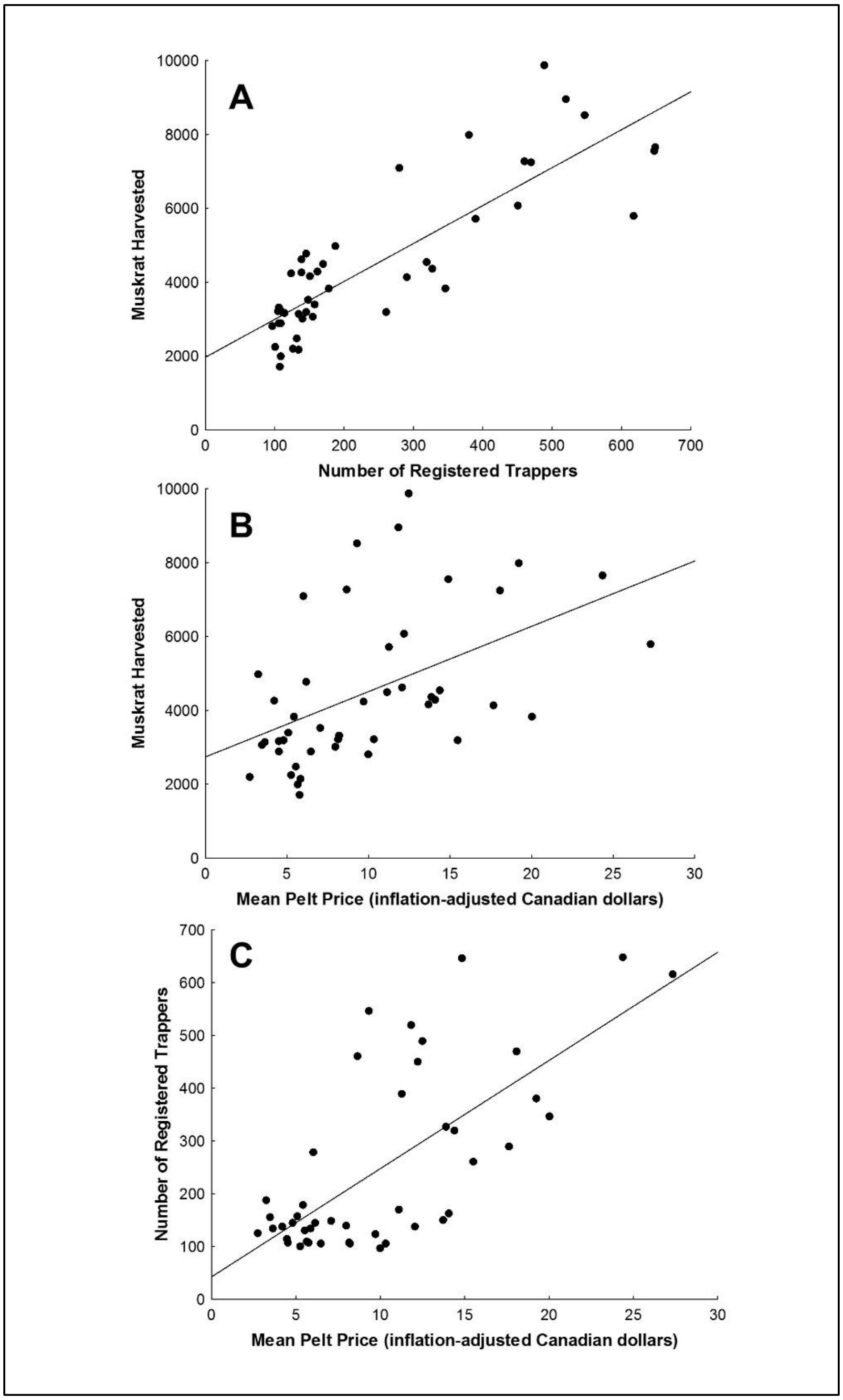

Figure. 4. Regression of A) muskrats harvested and number of trappers; B) muskrat harvested and mean inflation-adjusted pelt price; and C) number of trappers and mean inflation-adjusted pelt price.

of capture and tagging and the recapture date in the fall harvest was 81. Mean growth rate (rate of weight gain) was 7.38 ± 1.02 (mean ± 95% confidence interval) g/day for juveniles and 2.43 ± 0.63 g/day for adults.

Table 1. Estimated muskrat population sizes and densities in the 3 study areas.

Area	Number of PIT Tagged Muskrats	Total Captures in the Fall Harvest	Number of PIT Tagged Muskrats Captured in the Fall Harvest	Estimated Population Size	Estimated Density (muskrats/ha)
Indian River Impoundment	14	17	7	34	1.36
Doc's Marsh	20	27	4	135	1.23
Larkin's Pond	27	105	9	315	5.00

Table 2. Counts and proportions (in parentheses) of muskrat age/sex classes in 1968/69.

	Count of Each Age/Sex Class (Proportion of Total Sample)			
Year	Juvenile Males	Juvenile Females	Adult Males	Adult Females
1968/1969	1292 (45.0)	998 (34.7)	289 (10.1)	294 (10.2)
2008/2009	434 (45.4)	302 (31.6)	113 (11.8)	108 (11.3)

Table 3. Summary of house count data for the present study, and for the study conducted in 1968-1969 (Dibblee 1971).

Marsh	Active Houses (number/ha)	Active Houses in 1968-69 (number/ha)
Larkin's Pond	7 (0.11)	-
Doc’s Marsh	3 (0.03)	-
Indian River Impoundment	2 (0.08)	-
Whitlock's Pond	5 (0.07)	29 (0.41)

Muskrat population structure

Population structure data collected as part of this study was compared to the only other existing dataset for PEI that was collected in 1968-1969 to examine for long-term changes (Table 2). The overall proportion of juveniles among all muskrats from known capture locations was 0.769, compared to 0.797 in the 1968-69 study. This difference was not significant (χ^2= 3.395, *P*= 0.065). Juvenile female ratios were also not significantly different between the study periods (Figure 4B; χ^2= 3.238, *P*= 0.072) nor were the male juvenile ratios (χ^2= 0.042, *P*= 0.838). In the 2008/09 sample, the proportion of adult females and adult males accounted was 0.113 and 0.118, respectively, compared to 0.102 and 0.101 in the 1968/69 sample. The differences in the proportions of these age/sex classes in the samples were not statistically significant (χ^2= 0.846, *P*= 0.358 and χ^2= 2.336, *P*=0.126). The overall proportion of males among all muskrats from known capture locations was 0.572, compared to 0.550 in the 1968-69 study, and there was no significant difference in the overall sex ratio between the 2 studies (χ^2= 1.317, *P*= 0.251). In both the 2008/09 and 1968-69 samples, the adult sex ratios were not significantly different from 1:1 (χ^2= 0.113, *P*=0.737 and χ^2= 0.043, *P*= 0.836, respectively).

Muskrat house counts

The mean house density of the 4 marshes intensively searched was 0.07/ha (Table 3; 95% C.I. 0.02-0.13). At Whitlock's Pond, only 5 active houses were located during the course of field investigations, compared to 29 found by Dibblee (1971) in the late 1960s. The density of houses from the Dibblee's (1971) study was 0.41 house/ha, well outside of the 95% C.I. for the 2009 data. Houses were counted at 4 additional marshes of similar size Deroche Pond, Pisquid Pond, MacEwen's Pond, and MacDonald's Pond and 4, 0, 1, and 0 verified active houses were counted, respectively. However, these evaluations were not considered exhaustive enough to calculate house densities with confidence. Nevertheless, these counts were indicative of similarly low number of houses to the other marshes examined.

DISCUSSION

This study demonstrated that that majority of muskrat trappers on PEI, many of which have been trapping for a large number of years, perceive that there have been declines in the muskrat population. The most cited cause for this decline was increases in predators. Harvest of muskrat declined sharply in the mid-1980s, but has remained relatively stable, not changing by more than 2-fold for almost 3 decades. As expected, there were strong relationships between muskrat harvest, the number of trappers and the pelt price. Muskrat population age and sex structure was not different than historical data from the late 1960s, however, a change in the number of active houses observed in some locations is suggestive of a decrease in population size.

Opinions from more experienced trappers on PEI support the suggestion of a decline in muskrat abundance. All trappers who reported a decline in their harvest, with the exception of 1 individual, had at least 20 yrs of experience trapping on PEI, and many would have been trapping during the sharp declines in harvest during the 1980s as the survey was conducted in 2008. It must also be considered that the year the survey was conducted was the lowest muskrat harvest in the 46 yrs examined. While those who are relatively inexperienced would not necessarily be as aware of historical muskrat population sizes, they may have been influenced by more recent changes in harvest. Most of the trappers who reported a decline in their harvest indicated that they first noticed the decrease more than 10 yrs 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.

The majority of muskrat trappers on PEI felt that increased predation pressure is responsible for current low population levels. Significant emphasis was placed on bald eagle predation. 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 2 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 1 known nest in the early 1980s (MacDougall 1999) to the current estimate of more than 30 active nests (MacDougall, 2019, retired, Department of Communities, Land, and Environment, 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 and populations increased rapidly (Prince Edward Island Environmental Advisory Council 2001). This arrival added to the suite 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).

The magnitude and pattern of decline in muskrat harvest examined 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 with the sharp decreases in the PEI muskrat harvest. Roberts and Crimmins (2010) used values from 1948-1968 as a historical data set and values from 1986-2006 as a contemporary data set. The results of the current study suggest that the number of trappers was the strongest determinant of muskrat harvest, and that the number of trappers was also related to pelt price. Similar results were found by Ahlers *et al.* (2016) using a 36-

yr dataset from Illinois. That study also showed the pelt price was the strongest determinant of the number of harvesters, and number of trappers was also negatively associated with unemployment. The weaker correlation between price and harvest as compared to number of trappers and harvest is expected for 2 reasons: 1) price indirectly influences harvest through its influence on the number of trappers, and 2) there will be a threshold price where trappers no longer deem it worthwhile to trap as opposed to a strictly linear relationship. This threshold was illustrated in these data as the first pelt price drop between 1980 and 1982 did not result in a precipitous decline in trappers such as occurred with subsequent drops in the late 1980s. 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, inactive, or part-time trappers. It is likely that the harvest accounted for by the group of full-time trappers remains relatively consistent from year to year and high pelt prices experienced in the 1980s was considerable incentive to recruit more part-time trappers while prices were high. 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). 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.

Due to the fact that such a high proportion of the variation in muskrat harvest is explained by number of trappers and pelt price, harvest data must be examined with the context of those covariates driving the number and type of trapper. 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). In their review, Poole and Mowat (2001) acknowledged that 1 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. It has been pointed out that furbearer harvest data does not provide any reflection of trapping effort (DeVink *et al.* 2011). This is also the case for muskrat harvest on PEI and anecdotally, experienced trappers report increased trapping effort required to maintain their harvest. For these reasons, the use of harvest data as a population monitoring technique has been criticized (Winterhalder 1980) based on the hypothesis that ‘differential foraging’ is not accounted for. Thus, harvest data should be supplemented either with measures of trapper effort, pelt prices (Ahlers *et al.* 2016) or with actual abundance estimates for management purposes. Regardless of those caveats, harvest data on PEI indicates some cyclical fluctuations with a sharp drop in the 1980s, but also long-term relative stability in harvest over 3 decades given a very consistent number of trappers.

Trapper perceptions of excessive mortality between summer and fall trapping seasons were not supported in the 3 studied areas. 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 (36%) were lower than those previously reported from PEI, they nonetheless fall within a reasonably expected range as seen in other populations. Calculated survival rates from summer to trapping season are conservative because they do not account for muskrats which may have lost their tags or eluded capture in the fall harvest (Simpson and Boutin 1993). 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%.

The muskrat densities estimated in this study provide evidence for relatively low muskrat abundances at some marshes on PEI. Proulx and Gilbert (1983) estimated between 19 and 46 muskrats/ha in Luther Marsh, Ontario, Canada. Muskrat densities in habitat with open water in the upper Mississippi, Iowa range from 1 to 9 muskrats/ha (Clay and Clark 1985). Westworth (1974) reported densities of 2.8 and 4.8 muskrats/ha over 2 years in the Peace-Athabasca Delta. Densities in experimental wetlands at Delta Marsh, Manitoba reached varied from 0.4 to 21 muskrats/ha (Clark and Kroeker 1993), and older estimates from that Marsh have shown fall densities of 8.4 muskrats/ha (Errington 1963). The highest muskrat density found was 86 muskrats/ha (Errington 1963). As the literature demonstrates, muskrat populations are known to fluctuate dramatically over more than two orders of magnitude with a range from just under 1 to almost 100 muskrats/ha. Thus, Doc’s Marsh and Indian River Impoundment would appear to be on the low end of muskrat density range at around 1 muskrat/ha, whereas Larkin’s Pond appears to have relatively good population density with about 5 muskrats/ha.

Muskrat house counts provide further support for relatively low muskrat population levels in PEI. Examination of active houses at Luther Marsh, Ontario, Canada over 2 yrs revealed a house densities ranging from 1.2-3.5 houses/ha (Proulx and Gilbert 1984). Average densities of muskrat houses ranged from 0.6 to 7/ha 2 years after a management drawdown in Lake Erie wetlands (Kroll and Meeks 1985). Ervin (2011) found an average of 0.23 active house/ha between 2008 and 2010 in marshes in Le Pas Manitoba that had not experienced recent water level drawdown. In that study, water drawdown reduced house density to 0.09 house/ha, similar to, but still higher than in most locations in the present study. Water level changes at Indi Lake, Saskatchewan also saw lodge densities drop from a maximum of 3.6/ha to virtually none (Messier and Virgl 1992). As the PEI marshes studied are formed from impoundments and thus have relatively stable water levels, this is unlikely to have influenced house counts in the present study. Larkin's Pond had the highest house count, consistent with the highest population density at this marsh. The only location from which historic house count data was available was Whitlock's Pond and suggested an almost 6-fold lower house count than was found in the late 1960s. As these surveys were conducted on the same system, with the assistance of the author of the original study, they present the most compelling evidence of a decline in the number of muskrat houses in this particular marsh. However, house density may not always relate to population size as muskrats can also create dens in banks, and they often do on PEI. It has been suggested that preferential use of bank dens may occur at low population size, possibly due to higher maintenance requirements and susceptibility to predators that occur with houses, as the ratio of lodges to burrows increases with as total number of dwellings increases (Messier and Virgl 1992). Thus, low house counts may be a response to low population size, rather than a direct indicator of it.

The results indicate that in both the Dibblee's (1971) study and the current study, there was no bias in age or sex structure that could account for an apparent decline in overall abundance. The ratio of juveniles to adults fell within the range reported for muskrat populations in other jurisdictions (Gashwiler 1950; Sather 1958; Errington 1963). In addition, Sather (1958) noted that the proportion of juveniles in the fall harvest varied by up to 12% in successive years. A very high proportion (38.5%) of adults in the fall population was linked to reduced productivity and population decline by Errington (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.

MANAGEMENT IMPLICATIONS

This study illustrated the challenges of conducting wildlife population surveys in the absence of a strong baseline dataset. This study was initiated on the basis that there was a strong belief among trappers that muskrat populations on PEI had declined and have been in decline for at least a decade, so that overall perception in experienced trappers was not unexpected. The perceptions of no decline and sustained harvest of less experienced trappers suggest that populations are relatively stable in more recent years. As it is currently collected, muskrat harvest data alone were clearly limited in their usefulness for examining population trends. Harvest varies very strongly with trapper numbers, which are in turn influenced by price, and contains no measure of trapper effort in terms of trap nights for muskrats. While aspects of the population structure such as sex ratio of the muskrat population have been stable since the late 1960s, there is evidence based on muskrat density that populations in some, but not all marshes, are low. For management purposes, direct population monitoring would be warranted, but is often not practical. In the absence of direct monitoring, harvest data would be best supplemented with some measure of individual trapper effort. Further study will examine potential factors related to muskrat decline on PEI, which may include predation, disease, habitat contamination, and/or harvest.

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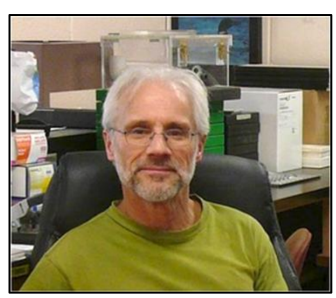

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