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Assessing the potential for impacts by feral mink on wild mink in Canada

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ABSTRACT

Invasive feral American mink (*Neovison vison*) have had well-documented impacts in Europe and South America. We tested the hypotheses that escape of ranch-raised mink is also common in Canada where the species is endemic, and that declines of Canadian wild mink apparent from harvest data are related to mink ranching. Consistent with these hypotheses, we found positive relationships among Canadian provinces: between mink ranch density and mink harvest density; between ranch density and the density of ranch mink caught by trappers; and between mink harvest density and the density of trapped ranch mink. A multiple regression and variance partitioning demonstrated that the density of trapped ranch mink explained the largest component of unique variation in annual mink harvest by trappers per province. Moreover, the change in mink harvest by trappers per province estimated over a 30-year interval ($\lambda_{harvest}$) had a close, positive relationship ($R^2 = 0.92$) to the change in ranch density estimated over the same interval (λ_{ranch}). Our analysis suggests that the conditions exist for feral mink to contribute to wild mink declines through outbreeding depression or the introduction of disease.

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1. Introduction

The feralization of domesticated species can have negative effects on native biodiversity, especially on the fitness of closely-related wild species. Negative effects on fitness can occur through a number of mechanisms, including the spread of disease, competition, and hybridization, with or without introgression. For example, farm-raised elk (*Cervus elaphus*) have likely spread chronic wasting disease to wild cervids (Williams et al., 2002). Farmed Atlantic salmon (*Salmo salar*) are more aggressive than wild salmon, and thus may be more successful than wild salmon in competitive encounters (Fleming et al., 2002). Leary et al. (1993) reported that wild bull trout (*Salvelinus confluentus*) hybridize with stocked brook trout (*Salvelinus fontinalis*), but that F1 individuals appear to have very low reproductive output. Introgression of stocked trout alleles is low and so a major effect of the introduced species in this case is reducing fitness of the native species by wasting reproductive effort (Rhymer and Simberloff, 1996). Finally, McGinnity et al. (2003) demonstrated that back-crosses between wild and farmed Atlantic salmon have lower fitness than wild salmon. This reduced fitness is due to outbreeding depression, which itself is thought to result from a reduction in local adaptation or a breakdown of co-adapted gene complexes (Allendorf et al., 2001; McGinnity et al., 2003).

American mink (*Neovison vison* Schreber, 1777), have been widely domesticated for the fur industry. Mink are endemic to North America, and the first mink farms started in Canada

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in the 1800s. Since then, "mink ranching" has spread around the globe: in 1982, there were nearly 26 million mink pelts produced in more than 20 different countries (Joergensen, 1985). As the ranching industry spread across Europe and South America, so did escape and feralization of farmed mink (e.g., Wildhagen, 1956; Gerell, 1967; Kauhala, 1996; Medina, 1997). Feral mink have had dramatic effects on native biodiversity (Bonesi and Palazon, 2007). For example, mink are reducing the size of water vole (*Arvicola terrestris*) populations in the United Kingdom (Woodroffe et al., 1990). Mink predation reduces coot (*Fulica atra*) fitness (Ferreras and Macdonald, 1999). Maran et al. (1998) suggested that feral mink may be limiting endangered European mink populations (*Mustela lutreola*) through competition.

Despite the history of effects in Europe, South America, and elsewhere, and despite mink ranching being widespread in continental North America, there has been no attention paid there to the potential effects of the feralization of ranched mink. It has been documented that mink escaped from ranches and colonized the island of Newfoundland where they are not endemic (Northcott et al., 1974). Jurisdictions with endemic wild mink however, appear content to accept the hypothesis that mink escaping from ranches have little ecological impact.

Many furbearers are difficult to census, and for this reason, natural resource managers often use harvest trends as an index of population status (Raphael, 1994). By this measure, wild mink in Canada appear to be declining (Fig. 1). Declines in mink harvest have been noted by others, and often attributed to contamination by organochlorine chemicals or mercury (Wren, 1991; Osowski et al., 1995), because they affect mink reproduction (Aulerich et al., 1971). It has been suggested also that declines in mink harvest merely reflect declines in the market value of mink pelts (and therefore trapper effort) (Wren, 1991).

An alternative hypothesis is that wild mink populations in Canada have declined in part due to the effects of feral mink. In particular, hybridization with introgression between ranch and wild mink is a likely scenario. Ranch mink have undergone many generations of artificial selection (Joergensen, 1985) and exhibit many characteristics of domesticated animals. For example, they have reduced brain size (Kruska,

1996), are inbred (Belliveau et al., 1999), and exhibit behavioural syndromes such as aggression that are pleiotropically linked to selected pelt colours (Trapezov, 2000; Sih et al., 2004). Many of these traits are likely maladaptive in a natural North American context, where wild mink evolved. Thus, interbreeding between ranch and wild mink could lead to outbreeding depression due to the introduction of maladaptive genes and traits into the wild mink population.

For hybridization with ranch mink to be an important cause of declines of wild mink populations, the necessary conditions would include common and widespread escape of ranch mink. We assumed that some proportion of the mink escaping from ranches would be caught by fur trappers. Therefore, we tested the hypothesis of common and widespread escape of ranch mink in Canada by comparing spatial patterns of mink harvest by trappers to spatial patterns of mink ranch density, expecting a positive relationship. We also reasoned that if ranch mink are an important cause of wild mink declines, there should be a correlation among different areas between the temporal change in ranch density and mink harvest. In other words, where there are temporal declines in the density of mink ranches (and therefore reduced supplementation of the wild population) there should be similar declines in wild mink harvest. We tested this hypothesis using spatial and temporal patterns of both mink harvest density and mink ranch density.

2. Methods

Our approach was to use available data both on mink harvest by Canadian fur trappers and on mink ranches in Canada to test for spatial and temporal relationships that would be predicted if escapes of mink from ranches are common and widespread.

First, we tested for a spatial relationship across Canadian provinces between mink ranch density and mink harvest density. Making the assumption that trappers catch some proportion of the mink that escape from ranches, we predicted that if escapes from mink ranches are common, then there should be a positive relationship between ranch density and the density of mink harvest by trappers. We estimated the average, current mink harvest density for each Canadian province during the most recent 10 years (1994–2003), using data obtained from Statistics Canada (catalogue 23-013-XIE) and compared that to the most recent (2001) Census of Agriculture (Statistics Canada, 2001) estimate of mink ranch density for each province. The relationship between mink harvest and ranch densities was linear without transformation, but skewed, so the variables were log_{10}-transformed to improve symmetry and then compared using a linear regression. The average [SD] size of Canadian provinces was 550×10^3 km^2 [441×10^3]; the average [SD] annual mink harvest per province was 3450 [3224]; and the average [SD] number of mink ranches per province in 2001 was 22 [23].

Our analyses were unbiased with respect to Canada since these data represented a census of all 10 Canadian provinces. Indeed, we used national census data to obtain harvest and ranch densities. We use parametric regressions to demonstrate effect sizes, and to partition variation in some analyses.
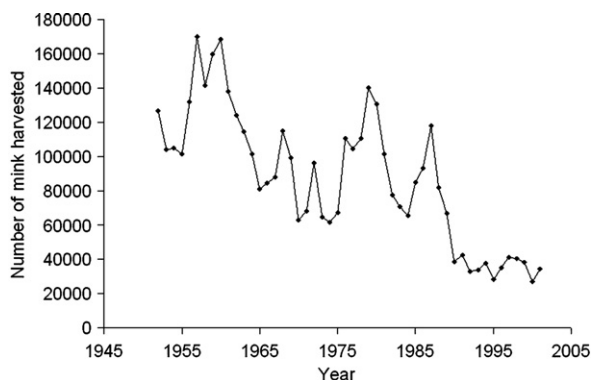

Fig. 1 – Total harvest of mink (*Neovison vison*) by trappers in Canadian provinces during 1952–2001 (Statistics Canada catalogue 23-013-XIE).

However, to guard against the undue influence of single data points (a risk given the small sample size) we paired each regression with a Spearman rank correlation.

We tested the relationship between harvest and ranch density at a different spatial scale by looking at patterns within a province (Nova Scotia) where mink harvest and ranch densities could be determined easily over the same spatial units (census counties). Here again, mink ranch density per county in Nova Scotia was estimated from the 2001 Census of Agriculture (Statistics Canada, 2001), and average mink harvest density per county was estimated for recent data obtained from the Nova Scotia government (unpubl. data, 1996–7 to 2004–5). Data were again $\log_{10}$-transformed to improve symmetry and compared using a linear regression. The average [SD] size of Nova Scotia counties was 3070 km^2 [1072]; the average [SD] annual mink harvest per county was 98 [91]; and the average [SD] number of mink ranches per county in 2001 was 4 [12]. Some counties in Nova Scotia had 0 mink ranches, so a constant of 1 was added to this value for all counties prior to transformation.

Our assessment of the relationship between mink harvest density and mink ranch density would be confounded if mink ranchers tend to prefer habitats that are good for wild mink (i.e., such a mechanism could mean that a higher ranch density is correlated to, but not causing, a higher harvest). This is not an unlikely scenario (Joergensen, 1985). We sought to clarify the relationship using data on the density of escaped ranch mink harvested by fur trappers (hereafter, trapped ranch mink), which would demonstrate the relative importance of escapes vs. ranches to the mink harvest. Auction houses that receive annual shipments of fur from trappers sort the pelts based on pelage quality and colour and classify mink as ranch-origin or wild. We obtained data on the proportion of ranch-origin and wild mink in the harvest from the largest of the 2 auction houses in Canada for the years 2002, 2003, and 2004. We compared the density of trapped ranch mink per province (total for the 3-year period) to mink ranch density per province estimated from the 2001 census, predicting a positive relationship if ranch mink are commonly escaping across the country and being caught by trappers. We then tested whether mink harvest density per province (using the 1994–2003 average) was related to the density of trapped ranch mink per province. We predicted a positive relationship if escapes are making a measurable contribution to the mink harvest. It should be noted that there was a strong correlation between the total mink harvest density (wild + trapped ranch animals) per province estimated from the auction house data and the average mink harvest per province estimated during 1994–2003 from Statistics Canada data ($r = 0.966$, d.f. = 8, $P < 0.0001$) (i.e., the auction house was a representative sample of the country). We used a multiple linear regression to partition the variation in mink harvest density per province due to 2 covariates: the density of trapped ranch mink per province, and mink ranch density, in order to determine the relative importance of escapes and ranches to the mink harvest. This would clarify the potential confound previously described between ranch and harvest density. All comparisons were regressions using $\log_{10}$-transformed data.

Inflation-adjusted mink prices have declined since the 1950s (e.g., Eagle and Whitman, 1987), and the decline in price often is noted as the cause of the apparent declines in mink harvest (Wren, 1991). According to this idea, trapper effort is reduced due to low prices for fur, and so harvest levels are also reduced. The potential for a price effect makes harvest an unreliable estimate of population trend. Mink ranch density also has declined and in the case of ranches, the decline is certainly due, at least in part, to prices. We reasoned that we could remove the effect of declining fur prices by testing whether declines in mink harvest and ranch density were correlated among provinces, since prices were the same for each province. In other words, there is no reason to suspect that declines would be greater in one province than another simply due to price, which operates at a global level. Mink ranch density in each province is determined by both the price of fur and the provinces' geography and agricultural history (Joergensen, 1985). These latter characteristics should cause declines in the number of mink ranches to vary by province, despite prices declining equally among provinces. Therefore, we reasoned that if mink harvest declines in each province were related to ranch density rather than just fur price, the declines in ranch density and harvest density should be correlated (independently of price, which does not vary among provinces). This test required some variation by province in the trend of mink ranch density. Reporting on the abundance of mink ranches per province began in 1968 (Statistics Canada catalogue 21-003); we estimated mink ranch density per province at that time using an average of 5 years (1968–1972, median year 1970). We then estimated ranch density per province 30 years later during 1998–2002 (median year 2000). Mink harvest density in each province was estimated for the same 2 periods. For both ranches and harvest, we estimated the 30-year $\lambda (N_t/N_{t-1})$ and regressed $\lambda_{harvest}$ against λ_{ranch}, predicting a positive relationship if a change in ranch density caused a change in mink harvest density. Newfoundland was omitted from this analysis because the island has no endemic mink.

3. Results

We found a positive linear relationship between the current mink harvest density in Canadian provinces and the current mink ranch density in those provinces ($F = 11.75$, d.f. = 1, 8, $p = 0.009$, $R^2 = 0.59$; $r_s = 0.75$, $p = 0.026$) (Fig. 2). There was a
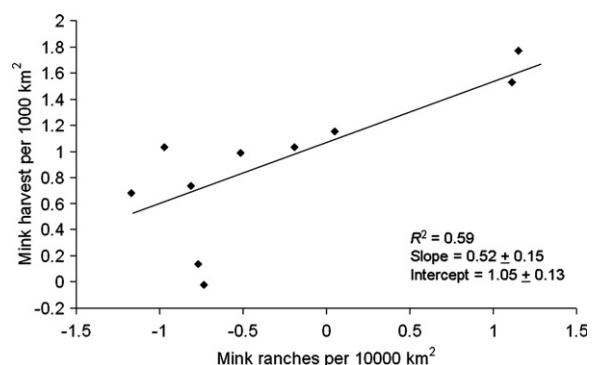

Fig. 2 – Mink (*Neovison vison*) harvest density in Canadian provinces (average during 1994–2003) compared to mink ranch density (2001). Data were obtained from Statistics Canada (catalogue 23-013-XIE for harvest data; Census of Agriculture for ranch data) and were $\log_{10}$-transformed.

similar, positive linear relationship between these measures in the different counties of Nova Scotia ($F = 8.72$, d.f. = 1, 16, $p = 0.009$, $R^2 = 0.35$; $r_s = 0.48$, $p = 0.047$) (Fig. 3).

The proportion of mink harvested during 2002–2004 that was classified at the auction house as being of ranch origin varied between 0.1% (Saskatchewan) and 38% (Nova Scotia). There was a positive linear relationship between the density of trapped ranch mink in different provinces and mink ranch density ($F = 16.40$, d.f. = 1, 8, $p = 0.0037$, $R^2 = 0.67$; $r_s = 0.66$, $p = 0.048$) (Fig. 4). There also was a positive linear relationship between mink harvest density in Canadian provinces and the density of trapped ranch mink ($F = 14.13$, d.f. = 1, 8, $p = 0.005$, $R^2 = 0.64$; $r_s = 0.92$, $p = 0.006$) (Fig. 5).

We used a multiple regression in combination with bivariate regressions reported in the previous paragraphs to partition the variation in mink harvest per province that was due to the density of trapped ranch mink and mink ranch density. We found that 68% of the variation in mink harvest density during 1994–2003 could be explained by a linear combination of the 2 covariates ($F = 7.42$, d.f. = 2, 7, $p = 0.019$); of this, 9% could be uniquely attributed to the density of trapped ranch mink, 4% could be attributed to mink ranch density, and 55% was shared between the 2. If we instead used the density of the total mink harvest at the auction house during 2002–2004 as a response variable, 79% of the variation in this variable could be explained by the covariates ($F = 13.49$, d.f. = 2, 7, $p = 0.004$), 18% by the density of trapped ranch mink ($F = 29.26$, d.f. = 1,8, $p < 0.0001$), 1% by the mink ranch density ($F = 12.42$, d.f. = 1,8, $p = 0.008$), and 60% shared.

There was a positive linear relationship between $\lambda_{harvest}$ and λ_{ranch} ($F = 83.5$, d.f. = 1, 7, $p = 3.8 \times 10^{-5}$, $R^2 = 0.92$; $r_s = 0.98$, $p = 0.006$) (Fig. 6). The intercept of the least-squares best-fit line was not significantly different than 0, and the slope was 2.4. We could use this equation to estimate the change in ranch density associated with declines in mink harvest density over the 30-year interval. For example, declines in mink harvest ($\lambda_{harvest} < 1$) were observed wherever $\lambda_{ranch} < 0.42$. Extrapolating to a hypothetical province where

Fig. 4 – Relative density of trapped ranch mink (*Neovison vison*) in Canadian provinces (total during 2002–2004) compared to mink ranch density (2001). Trapped ranch mink were mink of ranch origin caught by trappers. Data were obtained from a national fur auction house (trapped ranch mink data) or the Statistics Canada Census of Agriculture (ranch data) and were log$_{10}$-transformed.

Fig. 5 – Average mink (*Neovison vison*) harvest density in Canadian provinces (1994–2003) compared to relative density of trapped ranch mink (2002–2004). Trapped ranch mink were mink of ranch origin caught by trappers. Data were obtained from a national fur auction house (trapped ranch mink data) or from Statistics Canada catalogue 23-013-XIE (harvest data) and were log$_{10}$-transformed.

$\lambda_{ranch} = 1$ results in $\lambda_{harvest} = 2.4$: a 140% increase in harvest over the interval, or 4.7% of the starting population per year.

4. Discussion

Our results were consistent with the hypothesis that domesticated mink commonly escape from ranches in Canada. It was apparent that wild mink were not as abundant as harvest data suggested because the harvest was supplemented by escaped ranch animals. Further, our estimates of the frequency of ranch mink in the fur harvest were conservative estimates of the impact of ranch mink on wild mink populations because many ranch pelt colours are heterozygous or homozygous recessive and would return to a wild phenotype within a single generation following interbreeding (Joergensen, 1985). If there is hybridization, the prevalence of ranch mink
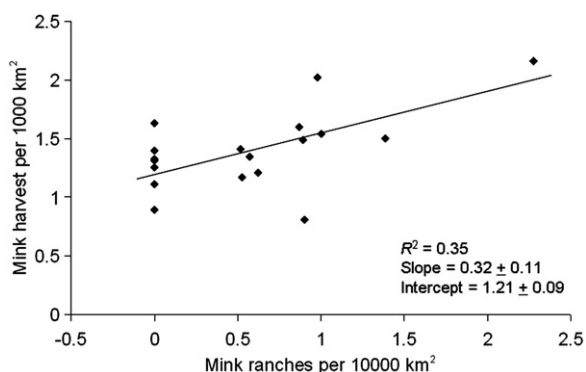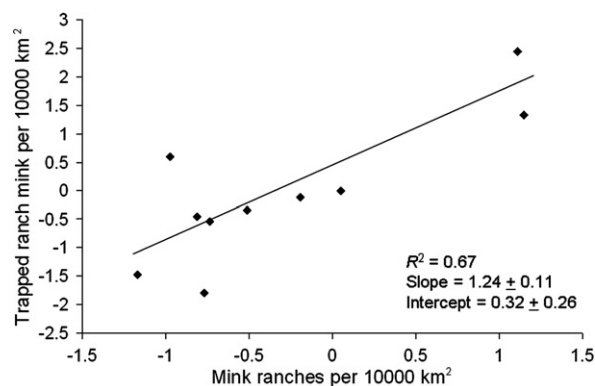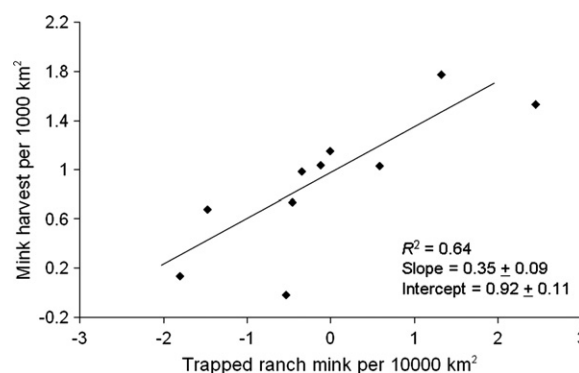
Fig. 3 – Mink (*Neovison vison*) harvest density in counties of Nova Scotia (average during 1996–2004) compared to mink ranch density (2001). Data were obtained from the Nova Scotia government (harvest data) or the Statistics Canada Census of Agriculture (ranch data). A constant of 1 mink ranch was added to all counties and the data were log$_{10}$-transformed.
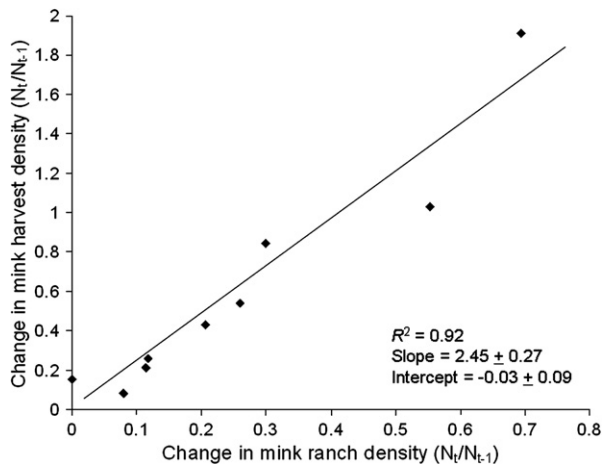
Fig. 6 – Change (λ) in mink (*Neovison vison*) harvest in Canadian provinces (1970–2000) compared to change (λ) in mink ranches during the same interval. Data were obtained from Statistics Canada (catalogue 21-003). Estimates at the start and end of the 30-year interval were 5 year averages (1968–1972; 1998–2002).

genes in the harvested population could be much larger than our estimated proportions based on pelt colours.

Even with the supplementation of the free-ranging mink population by ranch escapes, the population appears to be declining in Canada. We have shown that declines in mink harvest since the late 1960s were coincident with declines in the density of mink ranches. It does not appear that mink harvest declines were solely due to declining fur prices (and therefore trapper effort) because the declines were variable among provinces and fur prices have declined across the country. Rather, there appears to be a relationship between the magnitudes of the declines in both mink harvest and ranch density. The provinces with the smallest declines in mink ranch density have also had the smallest declines in mink harvest.

It is not clear whether the abundant historic mink harvests were ever a result of abundant wild mink; it is likely that some proportion of the annual Canadian mink harvest has consisted of ranch escapes since the first mink ranches appeared in the country more than 100 years ago. In fact, Obbard et al. (1987) showed that pre-20th century harvests of mink in Canada tended to be relatively small. We see three possible scenarios. It could be that wild mink have not declined, and have just never been abundant. This scenario implies that high mink harvests during the last 100 years always consisted of abundant feral animals. Alternatively, mink populations may have declined due to some effect unrelated to ranches, such as aquatic contamination. Finally, mink populations may have declined due to the effects of ranch escapes. These last two alternatives are not mutually exclusive. We discuss each below.

The most commonly suggested cause of widespread declines in mink populations, which has been much studied, is the effect of aquatic contaminants such as organochlorine chemicals and mercury (Wren, 1991). Our analysis suggests that declines since the 1968–1973 period were related to declines in mink ranches. For contaminants to be an important

cause of mink declines, time-order relationships suggest that there were declines prior to 1968 caused by contaminants (and hence that the mink population during 1968–1973 was dominated by ranch animals due to the previous decline of wild ones). Declines due to contaminants prior to 1968 are a possibility. Wren (1991) noted that contamination of the Great Lakes basin began in earnest during the 1940s. It could be difficult to test this effect however, given that any analysis of mink harvest data will have to control for the effect of mink ranches, and historic data on mink ranches may not be available. We also note here that numerous studies have used harvest data or carcasses collected from trappers to assess the effects of contaminants on mink populations in North America. The confounding effect of mink ranches has not been controlled in any of these studies (e.g., Proulx et al., 1987; Yates et al., 2005). Certainly, the presence of mink in highly contaminated areas could be misleading if the population is being supplemented by ranches. Moreover, studies that have sampled contaminant burdens in putatively wild mink that are actually ranch-raised would be confounded.

Our analysis demonstrated that the necessary conditions exist for hybridization with introgression to be a cause of declines of wild mink populations. That is, there appeared to be common and widespread escape of mink from ranches. Mink ranches occur across North America, usually in good mink habitat (Joergensen, 1985), which likely has resulted in many perforations of the wild mink distribution with escaping ranch animals. Ranch mink have the characteristics of domesticated species, including reduced brain size (Kruska, 1996), altered behaviour (Trapezov, 2000; Malmkvist and Hansen, 2002), reduced sexual dimorphism (Kruska and Sidorovich, 2003), and increased inbreeding (Price, 1984; Belliveau et al., 1999). Furthermore, Kruska and Sidorovich (2003) demonstrated that the brain-case volume of feral mink in Europe remained smaller than mink of wild origin, even after 50 years.

Feral mink appear to have high fitness in Europe and South America where they are "out of context" (Macdonald and Harrington, 2003), but they need not be as successful in North America, where mink are endemic. For example, in contrast to our Canadian findings, feral mink occurrence in England does not appear related to supplementation by mink ranches (Bonesi et al., 2006). The European and North American situations differ in that there is greater potential in North America for escaped ranch mink to reduce fitness of free-ranging mink through outbreeding depression. We believe it is plausible that mink populations in Canada have declined due to outbreeding depression following hybridization between ranched and wild mink and introgression of ranch alleles into wild mink populations. Outbreeding depression may have resulted from a loss of local adaptation, the occurrence of maladaptive domestic traits, the breakdown of co-adapted gene complexes, epistasis, or any combination of these (McGinnity et al., 2003; Rhode and Cruzan, 2005).

An alternative, potentially important mechanism for escaped ranch mink to affect wild mink populations is by introducing disease into the wild mink population. There are a number of diseases that can infect mink in ranches, including Aleutian disease (Bloom et al., 1980; Yamaguchi and Macdonald, 2001), an often fatal parvovirus first characterized in

Aleutian-coloured ranch mink. A disease effect would not be mutually exclusive of outbreeding depression.

There is a clear need for a study of wild mink genetics in North America to ascertain the size and extent of wild mink populations relative to feral and hybrid ones. We know of no such study (but see Belliveau et al., 1999; Hammershøj et al., 2005). Once wild mink populations have been identified, field studies should be undertaken to test the hypothesis of reduced fitness of hybrid and feral mink. Finally, there are currently inadequate regulations in many jurisdictions of North America concerning prevention of escape of mink from ranches. This issue needs to be addressed to protect our native biodiversity.

Acknowledgements

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