COMPLEXITY AND INFORMATION GAPS IN RECOVERY PLANNING FOR MOOSE (*ALCES ALCES AMERICANA*) IN NOVA SCOTIA, CANADA

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ABSTRACT: In 2003, the Eastern moose (*Alces alces americana*) on mainland Nova Scotia was declared an endangered species under the Nova Scotia Endangered Species Act. Subsequently, as required by the Act, a recovery team was established and the recovery planning process was initiated. Very early in this process, it was recognized that developing a recovery strategy for this moose population was going to be difficult due to the complexity of issues involved. The basic demographic data on population size, structure, reproduction, and mortality are not current for the population, and the assessment methodologies are inconsistent. The ability to evaluate potential factors limiting the population is hindered by a lack of information, primarily in the subject areas of genetic structure, health, illegal harvest, and habitat suitability and fragmentation. There are great difficulties in establishing cause-effect relationships, as well as verifying the potential cumulative and synergistic effects of the factors impacting the moose population. Answering these questions is challenging and will require substantial social, political, and financial support as well as a properly designed research program to acquire the requisite data. Until the information gaps can be addressed, it is prudent to adopt a precautionary and adaptive approach to the recovery of this species.

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Beginning in the late 1700s, and accelerating through the 1800s, the southern range limits of eastern moose (*Alces alces americana*) retreated north from most New England states due to loss of habitat and excessive hunting pressure (Peterson 1955, Alexander 1993, Bontaites and Gustafson 1993, Morris and Elowe 1993, Vecellio et al. 1993). In New Brunswick and Nova Scotia, moose met a similar, although delayed, fate (Nova Scotia Department of Natural Resources, unpublished data). Moose numbers in pre-European mainland Nova Scotia may have been in the range of 0.38 moose/km^2 or approximately 15,000 animals, but declined to a low of several thousand by 1825 (Peterson 1955). A 3-year closed hunting season enacted in 1874 was followed shortly by a prohibition on snaring and hunting with dogs; restrictions that may have saved the moose from extirpation (Province of Nova Scotia 1934). Greater legislative protection and increased enforcement allowed moose to slowly increase throughout the mainland; by 1908, their numbers may have rivaled those of the pre-European era. Moose in Nova Scotia declined through the 1920s and 1930s and the hunting season was closed in 1938 (Benson and Dodds 1977). In eastern and northeastern mainland Nova Scotia, where densities remained moderate, an experimental hunting season was opened from 1964 to 1974, closed in 1975 and 1976, and re-opened from 1977 to 1981 (Nova Scotia Department of Natural Resources, unpublished data). The season has been closed since 1981 due to concerns about declining moose numbers. Recent surveys confirm that the decline in moose abundance on mainland Nova Scotia, although somewhat abated, has continued in spite of the hunting season closure and moose probably now only number between 1,000 and 1,200 animals (Parker 2003; Nova Scotia Department of Natural Resources, unpublished data). Moose were extirpated on Cape Breton Island in the 1800s, reintroduced in the late 1940s (from moose transplanted from Elk Island National Park in Alberta), and are common throughout the northern two-thirds of the Island, where hunting is currently permitted (Nova Scotia Department of Natural Resources, unpublished data).

In 2003, following the preparation of a status report (Parker 2003), mainland Nova Scotia moose were declared 'endangered' under the Nova Scotia Endangered Species Act. In accordance with an endangered status under the Act, the moose receives full protection, which includes a prohibition on all hunting, a recovery team has been established, and a recovery plan is currently in preparation.

This paper describes some of the challenges facing the recovery planning process for the endangered mainland Nova Scotia moose population due to complexities in, and gaps in knowledge about, population dynamics and cause-effect relationships with potential threats and limiting factors related to habitat, viability, genetics, health, and climate change.

DEMOGRAPHICS AND VIABILITY

Demographics

For over 200 years, the highly fragmented and discontinuous moose habitat remaining in the area of the Chignecto Isthmus, at the border between Nova Scotia and New Brunswick, is believed to have minimized movement of moose between the two provinces. This near absence of connectivity has resulted in these two populations having developed identifiably different genetic characteristics (see Genetics section). Similarly, there does not appear to be any significant genetic flow among the 3 remaining localized groups[1] of moose on mainland Nova Scotia and the reintroduced Cape Breton Island population, which currently numbers about 8,000 animals (Nova Scotia Department of Natural Resources, unpublished data) (Fig. 1). Efforts by Nova Scotia Department of Natural Resources biologists have been less than successful in achieving an overall population estimate with an acceptable level of confidence for moose on mainland Nova Scotia. However, based on trend information and familiarity with specific areas where moose have existed in the past and where they exist presently, the total number of moose remaining on the mainland has been estimated at between 1,000 and 1,200 (Parker 2003; Nova Scotia Department of Natural Resources, unpublished data). Existing data suggest that cow:bull ratios of moose on mainland Nova Scotia are within normal values (Dodds 1963, Benson and Dodds 1977, Brannen 2004; Nova Scotia Department of Natural Resources, unpublished data). However, far less data exists relative to calf representation as moose management efforts in the province have focussed on determining abundance and distribution, hunter success rates, kill per area,

[1]We use the term localized groups rather than subpopulations because there are currently insufficient data to determine whether they qualify as distinct populations or subpopulations; from a genetic perspective, a subpopulation is defined as individuals within a given larger population that are further defined by some recognizable level of relatedness; since this is not clearly defined throughout Nova Scotia, we use the more general term, localized groups.

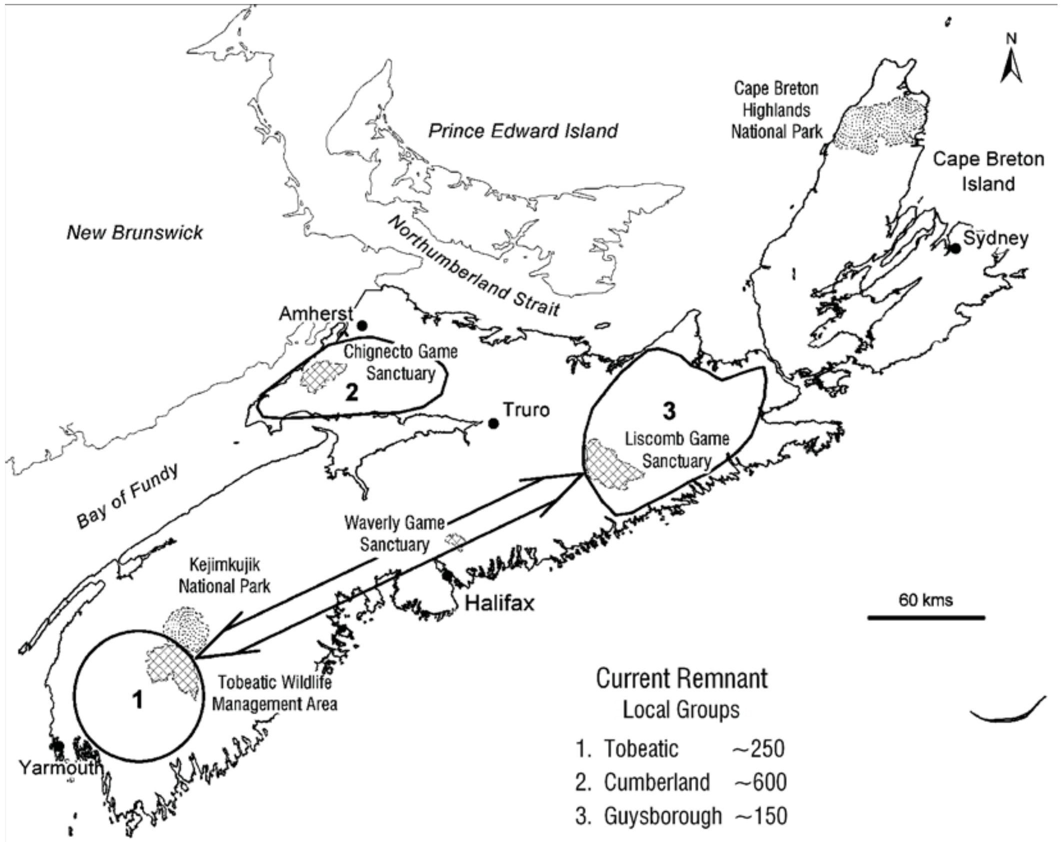

Fig. 1. General location and size of largest remaining localized groups of moose on mainland Nova Scotia. Note: Arrows indicate the only confirmed genetic interchange between mainland localized groups. Evidence of genetic flow in recent generations among the New Brunswick and Cape Breton Island populations, and mainland Nova Scotia localized groups has not been found.

age, sex, carcass weights, and antler measurements of hunter-harvested animals (Nova Scotia Department of Natural Resources, unpublished data). According to the limited and varied sources available, there appear to be widely differing values on calf numbers reported both spatially and temporally.

Prior to 1956, abundance of moose in Nova Scotia was determined through hunter success rates and observation reports, wildlife and forest ranger reports, and casual observation (Peterson 1955, Dodds 1963, Benson and Dodds 1977). Big game hunter moose observation reports for eastern mainland Nova Scotia between 1950 – 1952 indicated that the number of calves to 100 cows was 14 in 1950, 47 in 1951, and 32 in 1952 (Dodds 1963). Observational data submitted by "unsuccessful" eastern mainland moose hunters in 1964, 1977, and 1978 indicated that the number of calves to 100 cows in those years were 14.5, 38, and 50, respectively, in that region (Nova Scotia Department of Natural Resources, unpublished data). According to wildlife sanctuary warden moose observation reports for the period 1934-1953, the number of calves to 100 cows for the 4 largest wildlife sanctuaries on mainland Nova Scotia (Fig. 1) ranged from a low of 15 in the Waverley Sanctuary during the period 1949-1953, to a high of 62 in the Tobeatic Wildlife Management area during the period 1934-1938 (Dodds 1963). Vukelich (1977) analysed the reproductive tracts of moose of known age, which were killed by hunters in the eastern mainland in 1973 and 1974. Fifty percent of yearling cows were found to be pregnant (all carrying single fetuses), while 85.3% of adult cows were pregnant (25% with single fetuses and 75% carrying 2 fetuses). According to this study, "comparison of the Nova Scotia data with that from other regions indicate that the moose in Nova Scotia are as productive as any other North American moose herd studied" (Vukelich 1977:54). The first official aerial survey of moose in Nova Scotia was conducted by D. W. Benson in the late winter of 1956 (Nova Scotia Department of Natural Resources, unpublished data). However, little data were gathered on calf:cow ratios in early surveys since they focused on density and distribution. Recent moose surveys on mainland Nova Scotia have observed so few animals that little insight could be gained on productivity and calf survival, with the exception of: (1) a January 1993 aerial survey of the Tobeatic area, which documented 50 calves per 100 cows (Nova Scotia Department of Natural Resources, unpublished data); and (2) a 1999-2001 study conducted in the same area, which documented 22 calves per 100 cows (Brannen 2004).

The limited and infrequent data available are insufficient to draw conclusions relative to long-term rates of reproduction, calf survival, recruitment, or overall population structure of moose on mainland Nova Scotia. There is no apparent consistent pattern and, with insufficient data, the reasons for widely ranging calf representation between years within the same localized group of moose and between different localized groups remain unclear. Acquiring adequate data on this subject will be challenging and costly. Conducting moose surveys in Nova Scotia is arduous, not only because of low moose densities on the mainland, but also due to unpredictable weather conditions (including frequent winter rain storms), poor snow conditions near coastal areas, and sporadic availability of government-owned helicopters (Pulsifer and Nette 1995).

Population Viability

A viable population is one that will continue to exist and function naturally so that reproductive rates are higher than or equal to mortality rates (Salwasser et al. 1984, Newmark 1985). A minimum viable population (MVP) is the population size below which the probability of extinction is unacceptably high, but above which the probability of extinction is reduced to an acceptable level, over a given period of time (Shaffer 1981, Samson 1983, Lehmkhul 1984, Gilpin and Soulé 1986). Population viability analysis is a method used to determine MVP, which can be used to identify threatened populations and quantitative targets of population size for recovery efforts (Salwasser et al. 1984, Shaffer 1990, Boyce 1992). Population viability analyses are data intensive since viability is a function of genetic (i.e., to prevent inbreeding depression), demographic (i.e., birthrate, mortality, reproductive age, and fecundity), environmental (i.e., stochasticity), and spatial (i.e., distribution) factors (for an overview see Snaith and Beazley 2002).

There are insufficient demographic and other specific data on moose in mainland Nova Scotia to conduct viability analyses even using simple computer-based models such as VORTEX (for an assessment of such models see Lindenmayer et al. 1995). Nonetheless, it is important to understand viability issues since the remnant localized groups of moose in mainland Nova Scotia are small (< 500 individuals per group) and thus may not be viable. Although small founder groups are able to expand when good habitat becomes available (Timmermann and McNicol 1988) and some have grown to widely distributed populations (Pulsifer 1995, Basquille and Thompson 1997, Wangersky 2000), since heterozygosity is likely reduced (as is the case in Newfoundland and Cape Breton, Nova Scotia), long-term viability may be compromised due to reduced genetic variability (Broders at al. 1999). While moose in mainland Nova Scotia formerly constituted a continuous population, remnant localized groups are currently isolated from each other by distances of 200-300 km, highways, and areas of low habitat suitability (Snaith and Beazley 2002). Thus, it is unlikely that there is sufficient exchange of individuals (at least one reproductively successful migrant per generation [Soulé 1980, Brussard 1985, Reed et al. 1986, Beier 1993]) for these groups to function and persist as a metapopulation (i.e., localized groups loosely associated by periodic exchange of individuals [Levins 1970, Fahrig and Merriam 1994, Beissinger and Westphal 1998]).

In the absence of sufficient population-specific data, Snaith and Beazley (2002) conducted a rough estimate of moose MVP using a 50/500 rule-of-thumb proposed by Franklin (1980) and Soulé (1980) as an alternative to data-intensive analysis. The 50/500 rule suggests that *effective* or ideal breeding populations (N_e) of 50 and 500 individuals are required to maintain short-term (decades) and long-term (centuries) viability, respectively, based on inbreeding considerations alone. To estimate the size of *census* populations (N) required to support N_e for moose, an average 10:1 ratio of N:N_e was assumed from ratios reported by Ryman et al. (1981) and Arsenault (2000). Accordingly, census populations for short- and long-term viability were calculated as 500 and 5,000 individuals, respectively. Although such coarse estimates are subject to criticism, several empirical, modeling, and genetic studies have found consistent results, and thus they may serve as a general guideline in the absence of more precise data (Brussard 1985, Samson et al. 1985, Lande 1987, Thomas 1990, Henriksen 1997, Belovsky et al. 1999). These estimates indicate that current isolated, localized groups of less than 500 individuals each are unlikely to persist over the short-term. If connectivity among localized groups is such that they do collectively function as a metapopulation, at less than a total of 5,000 individuals, they are unlikely to persist over the long-term. Nonetheless, considerable uncertainty and complexity exists in assessing population viability and in devising strategies to address concerns arising from potential extirpation caused by the small size and isolated locations of localized groups.

GENETICS

One of the most significant interactions between landscape features and population dynamics is the impact on the movement of individuals. Animal movement has a significant role in the persistence of a species. It facilitates gene flow among subpopulations, which is necessary for the maintenance of genetic diversity, thus enabling individuals to adapt to their environments, while rendering the species as a whole more resilient to changes such as disease and climate (Hedrick and Miller 1992, Wayne et al. 1992, O'Brien 1994, Haig 1998). The movement of individuals may also promote the persistence of populations where their net reproductive rate is less than replacement (Watkinson and Sutherland 1995, Dias 1996, Novaro et al. 2000). In such cases, population viability is dependant upon not only its own population parameters, but also the population dynamics of neighboring patches and ease of movement among these patches (Caprio 2001). Alternatively, the movement of individuals can also be a detriment to a species. For example, movement of individuals among areas can promote the spread of disease or could potentially introduce animals into environments to which they may have difficulty adapting. Either of these scenarios could have devastating consequences for population recovery. In Nova Scotia, understanding the dispersal dynamics of resident and neighboring moose populations, subpopulations, and localized groups is essential for any potential recovery efforts.

The relationship between the landscape and wildlife movement is a complex issue to address using traditional methods of population and landscape ecology. However, with the advent of molecular genetic tools, new approaches have evolved to address specific questions regarding population structure and evolutionary processes, such as genetic drift and gene flow, in the context of landscape dynamics (Manel et al. 2003). In 2002, analysis of microsatellite data derived from a limited number of moose from mainland Nova Scotia ($n = 35$) and neighboring Cape Breton Island ($n = 23$) and New Brunswick ($n = 16$) showed that moose currently experience little movement and genetic exchange between these areas. In addition, the analysis showed little genetic exchange occurring among moose from the Cumberland region with those collected from both the Guysborough and Tobeatic regions, presenting the likelihood of two genetically structured populations occurring on mainland Nova Scotia (Fig. 1). Measures of genetic variability of moose on mainland Nova Scotia showed that the levels were significantly lower than populations in Cape Breton and Northern Ontario where there are few barriers to movement. The deficiency of genetic variability in moose from mainland Nova Scotia could be a response to 2 factors: (1) non-assortive mating; and (2) pooling of samples from locally structured populations within the geographic area, otherwise known as the Wahlund effect. Discriminating among these different variables is difficult with the present data set; however, these findings do raise important concerns regarding the highly fragmented nature of localized moose groups on the mainland of Nova Scotia. Acknowledging the analytical limitations of our low sample sizes and high dispersion of sampling areas, a more comprehensive genetic analysis could be obtained with additional samples from a greater number of areas. The current low numbers of mainland moose and their endangered status could present difficulties in obtaining additional tissue and blood samples for DNA analysis. As a result, a non-invasive approach has been developed that involves the collection of moose fecal material as a source of DNA. This method, which has proven highly successful for woodland caribou (Ball et al. 2007), has the potential to significantly augment the data set and could be used for future population monitoring.

The development of conservation and recovery plans to increase moose movement and thus gene flow within mainland Nova Scotia will prove to be an arduous task in light of many of the problems confronting Nova Scotia moose. The danger of population fragmentation and isolation increases concerns about progressive genetic deterioration, which would reduce individual health and population productivity and potentially eventually lead to extirpation (Snaith 2001). However, considering limitations on the available moose habitat remaining on mainland Nova Scotia, as well as the presence of a parasite (*Parelaphostrongylus tenuis*) potentially fatal to moose throughout the province, facilitating the effective movement of migrant moose through either the creation of interconnecting habitat corridors or translocation of effective breeders from neighboring New Brunswick may prove difficult. Furthermore, since it originated from moose transplanted from Alberta, the reintroduced Cape Breton moose is a distinct subspecies from those inhabiting the mainland (Pimlott and Carberry 1958, Dodds 1975). Therefore, the effectiveness of Cape Breton moose as breeders with the mainland population may be limited, and even if successful, would change the genetic identity of the mainland moose. With this said, a clear assessment of moose population structure, dispersal, and gene flow, in association with habitat and disease data, will prepare managers to identify threats to moose population dynamics and implement appropriate solutions.

HEALTH

The study of mortality factors, including those that are directly related to disease and those that are not (e.g., predation, trauma, and environmental conditions), provides essential information that can lead to a greater understanding of processes contributing to the decline of any wildlife population. Therefore, since 1998, opportunistic moose mortalities and euthanized sick or injured moose have been utilized to assess the health of the mainland Nova Scotia moose population. Whenever possible, entire carcasses were necropsied at the post mortem facilities of the Atlantic Veterinary College, University of Prince Edward Island or the Veterinary Diagnostic Laboratory, Nova Scotia Department of Agriculture and Fisheries. When this could not occur, necropsies were performed in the field by Nova Scotia Department of Natural Resources staff, and the entire head, spinal column, heart, lungs, liver, and kidneys, together with a section of quadriceps muscle and an intact femur from one of the hind legs were collected and frozen for later pathological examination. In addition, 2 animals exhibiting neurological clinical signs were live captured and transported to Nova Scotia Department of Natural Resources' wildlife park in Shubenacadie, Nova Scotia. These individuals were held in quarantine for a 1 – 2 month period of clinical assessment, and subsequently, due to the progression of their clinical disease and a continued deterioration of their body condition, both animals were euthanized and necropsied. The gross examination of the carcasses and tissues submitted for necropsy was combined with ancillary diagnostic testing, including histology and, when required, parasitology, bacteriology, and virology, to obtain a definitive final diagnosis. Also, the incisor bar was collected for aging, and the liver and kidneys were sampled for inclusion in a cervid trace element study initiated by Nova Scotia Department of Natural Resources, Canadian Wildlife Service, and Environment Canada.

Sixteen female moose, 3 of which were pregnant, and 6 male moose were necropsied. Six females were in the 0 – 2-year-old age class, 8 were in the 2 – 8-year-old age class, and 2 were in the > 8-year-old age class. Two males were in the 0 – 2-year-old age class and 4 were in the 2 – 8-year-old age class.

Trauma was the most common cause of mortality. Vehicular collision was the cause of death in 6 animals, another 2 were killed by gunshot, and 1 died as the result of an accidental fall from a cliff. All of the affected animals were in very good to excellent body condition with normal skeletal muscle mass and abundant adipose tissue stores. Underlying significant disease conditions were not identified in any individual, strongly suggesting that the accident causing the trauma was the result of a simple mishap.

Parelaphostrongylosis was another significant mortality factor affecting the population. A diagnosis of parelaphostrongylosis was confirmed when *P. tenuis* adults, larvae, or eggs were identified within the inflamed central nervous system (CNS) neuropil. In cases where there were random multifocal, linear areas of necrosis, and/or degeneration of the CNS neuropil associated with nonsuppurative and eosinophilic inflammation, these findings were considered compatible with parasitic tracts and strongly suggestive of an infection with *P. tenuis* despite the absence of nematode adults, larvae, or eggs. Based on these criteria, parelaphostrongylosis was confirmed as the cause of death in 2 animals and was the most likely cause of death in an additional 5 cases. In one of the affected moose, *P. tenuis* eggs were present in the interstitium of the pulmonary alveolar septa, which is consistent with a patent infection.

In 2000, 3 moose were euthanized because they exhibited neurological clinical signs. One animal was uncoordinated and circling, and the other 2 were unable to rise due to hind limb paralysis. All affected individuals were adult females in very good body condition and had a diffuse, nonsuppurative encephalomyelitis. During that same year, 2 moose from the other Nova Scotia moose population in Cape Breton were euthanized due to similar neurological abnormalities. These moose, an adult male and a yearling female, were in very good body condition and had comparable inflammatory changes in the CNS. In all cases, the lesions were suggestive of a viral etiology, but the cause was not determined. Additional cases have not been observed in either of the Nova Scotia moose populations since that time.

One moose died from exertional myopathy and pulmonary hemorrhage post-collaring due to capture-related complications. The cause of death could not be determined in 2 mortalities.

Additional incidental findings affecting a small number of the moose necropsied included the presence of *Dictyocaulus viviparous* (lungworm), *Dermacentor albipictus* (winter tick), and antler deformities. The parasitic infections were of low intensity and only found in animals affected by neurological disease. There were 6 cases of mild dictyocaulosis and 5 cases of winter tick infestation with alopecia affecting 0 – 10% of the affected animal's body surface, primarily the head and neck regions. Antler deformities were identified in 2 of the 6 males necropsied, 1 healthy and 1 with parelaphostrongylosis. Also, similar antler deformities were observed in 3 of the 9 males necropsied from the Cape Breton moose population.

Calf survival was considered as a potential measure of population health. A concurrent study on a localized group of moose in mainland Nova Scotia's Tobeatic region indicated that calf survival for the radio-collared females was very low during the years 1998 – 2001 (Brannen 2004). The causes of calf mortality were not investigated in this study, and it remains to be determined if calf survivorship is similar in the other localized groups of mainland Nova Scotia moose.

The data from the cervid trace element study are analyzed in another report (Pollock 2005). The kidney and liver samples were analyzed for arsenic, cadmium, cobalt, copper, lead, manganese, nickel, selenium, and zinc. Kidney cadmium concentrations were high in some Nova Scotia moose and, relative to reference values for cattle, cobalt, copper, manganese, selenium, and zinc levels in some animals were deficient to marginally deficient (Pollock 2005). However, gross or microscopic lesions compatible with cadmium toxicity or cobalt, copper, manganese, selenium, and zinc deficiencies were not identified in any of the moose necropsied, suggesting clinical disease associated with these trace elements is not occurring in Nova Scotia moose.

Accidental random vehicular trauma is a frequent and often unavoidable cause of mortality in wildlife populations. However, in the case of endangered species, these losses may be considered unacceptable and may need to be mitigated, if possible. Two of the 6 traffic fatalities in this study occurred on a section of a 4-lane Nova Scotia provincial highway known as the Cobequid Pass. This piece of highway has been a common site of moose-vehicle collision since its completion in 1997, and, in addition to those identified through necropsy, there are 8 known moose mortalities from this area (T. Nette, Nova Scotia Department of Natural Resources, unpublished data). Therefore, as in other jurisdictions, investigation of management options, such as strategic fencing, implementation of signage, creation of wildlife underpasses or overpasses, and reduction of speed limits, is required to address this problem.

Parelaphostrongylosis is a significant mortality factor affecting the moose population of mainland Nova Scotia. There is ample support in the literature demonstrating the affect of this parasite on the population dynamics of moose and other cervid species in Nova Scotia and elsewhere in North America (Benson 1958a, b; Smith et al. 1964; Smith and Archibald 1967; Anderson 1971, 1972; Thomas and Dodds 1988). The refugia hypothesis (Kearney and Gilbert 1976) was used to explain sympatric habitat use by moose and white-tailed deer (*Odocoileus virginianus*) when *P. tenuis* is present in the environment. This hypothesis and the role *P. tenuis* plays in regulating cervid populations has been challenged in the literature (Nudds 1990, Whitlaw and Lankester 1994, Bender et al. 2005), but circumstantial evidence exists to suggest that parelaphostrongylosis is regulating moose on mainland Nova Scotia, and the localized groups are surviving in refugia. This evidence includes the following observations:

1. The current decline of the Nova Scotia mainland moose population began subsequent to the significant white-tailed deer population growth that occurred in the late 1920s through the early 1950s and has continued in association with a fluctuating but persistently high white-tailed deer population density (Benson and Dodds 1977; T. Nette, Nova Scotia Department of Natural Resources, unpublished data);
2. The remnant localized groups of moose appear to be geographically limited to the elevated regions of the province, in areas where white-tailed deer are absent or in low density (T. Nette, Nova Scotia Department of Natural Resources, unpublished data);
3. The remnant localized groups of moose are also geographically limited to a granitic soil type that is not compatible with the presence of the intermediate molluscan hosts of *P. tenuis* (R. Cameron, Nova Scotia Department of Natural Resources, unpublished data).

It is clear that further research is required to determine the exact role of white-tailed deer and parelaphostrongylosis in influencing mainland Nova Scotia moose population dynamics. Selectively decreasing the populations of white-tailed deer or molluscan intermediate hosts of *P. tenuis* are management tools that could be utilized to address this problem in certain areas of critical moose habitat.

Antler deformities were relatively common, affecting approximately one-third of the males examined in both the Nova Scotia mainland and Cape Breton moose populations. In cervids, antler deformities have been associated with genetic abnormalities; traumatic skeletal injuries; copper, calcium, phosphorus, and protein deficiencies; and physiological factors such as failure of the antler's testosterone receptors during growth and testosterone imbalances due to testicular atrophy (Marburger et al. 1972, Gogan et al. 1988, Carrasco et al. 1997, Tiller et al. 1997, O'Hara et al. 2001). Injuries to the antler or skeletal system were not identified in any of the cases. In a mortality study like this one, a genetic abnormality cannot be confirmed because it requires observation of an individual and/or his offspring with the same deformity over several consecutive years. The potential involvement of nutritional or physiological etiologies remains to be determined.

Based on the available data, calf mortality appears to be a problem in at least one localized group on mainland Nova Scotia. In other North American moose populations, calf mortality is most often associated with predation, and, to be a significant population regulator, it is strongly suggested to require sympatry with both wolves (*Canis lupus*) and a bear species (*Ursus americanus* or *U. arctos*) (Franzmann et al. 1980, Ballard et al. 1981, Boer 1988, Crête and Courtois 1997). A significant black bear population is present in the province (Nova Scotia Department of Natural Resources, unpublished data). Historically, the Eastern wolf (*C. l. lycaon*) was rare in Nova Scotia and was extirpated from the province in approximately 1870 (Dodds et al. 1969, Lohr and Ballard 1996). However, the Eastern coyote (*Canis latrans*) is present in the province and has greatly expanded its numbers since extending its range into mainland Nova Scotia during the mid-1970s (Moore and Parker 1992). While coyotes are reported to be a predator of large cervids in other studies

(Smith and Anderson 1996), the combined impact of bear and coyote predation on the Nova Scotia mainland moose population has yet to be assessed. As in other cervid populations, health related stressors such as infectious diseases and nutritional problems could also affect the survivability of moose calves (Smith and Anderson 1996). However, the potential involvement of disease in the death of calves can only be documented through post mortem examination of carcasses. As stated previously in this paper, from what limited data are available, reproduction and calf survival in the mainland Nova Scotia moose appear to vary temporally and spatially. However, it is difficult to compare studies due to the inconsistency in methodologies. Excessive calf mortality can be a major factor in the decline of a moose population. Therefore, a moose calf mortality study is required to address this data gap and evaluate its significance.

Despite the lack of supporting evidence of clinical disease associated with trace element toxicity or deficiency, the possibility that marginal or deficient levels of cobalt, copper, manganese, selenium, and zinc and/or high levels of cadmium may impact the health of individual animals, either directly or through interactions with other factors (e.g., infectious and noninfectious diseases, harsh environmental conditions, and habitat limitations), cannot be dismissed (Pollock 2005). Therefore, ongoing trace element monitoring, especially in cases of natural mortality, is essential to discover the potential role of these compounds in the ongoing decline of the Nova Scotia mainland moose population.

In conclusion, 22 animals represent a small sample size. However, the necropsy results have identified potential problems that may be contributing to the decline of the mainland moose population or impeding the recovery process. Continued disease surveillance, with complete necropsies when possible, integrated with additional targeted research designed to address the specific disease problems highlighted above, is essential to determine the impact of health-related issues on the recovery of the endangered mainland Nova Scotia moose population.

HABITAT SUITABILITY AND AVAILABILITY

Moose have a relatively small home range and show strong fidelity to a geographic area (Youmans 1999). Use of selected areas is learned and traditional with the home range of individual animals encompassing adequate resources to meet their basic year-round needs of water, food, cover, and security. Required habitat features for moose related to thermal relief, security, and aquatic resources, as well as their juxtaposition, have been explored to only a very limited extent in the Acadian forest setting. A review of research in Nova Scotia and Maine indicates that key habitat components vary seasonally and biogeographically and that a mix of components within ranging distances are required to meet annual and life-history needs, especially for cows (Prescott 1968, Cioffi 1981, Leptich 1986, Thompson 1987, Miller 1989, Brannen 2004). Winter moose range is reported as being unimpeded by average snow depth in mainland Nova Scotia and comprised of cover areas of mixedwood greater than 13 m in height with 40 – 50% canopy closure (of mature softwood in years and areas with deep snow), young or successional forage stands nearby (less than 30 years since disturbance), and/or partial cuts with remaining overstory and residual stands (Prescott 1968, Cioffi 1981, Thompson 1987, Miller 1989, Brannen 2004). Moose avoid poorly drained lowlands, and hardwood and hardwood-softwood stands in winter (Thompson 1987). Preferred browse is balsam fir (*Abies balsamea*), paper (*Betula papyrifera*) and yellow birch (*B. alleghaniensis*), sugar maple (*Acer saccharum*), mountain maple (*A. spicatum*), aspen (*Populus* spp.), willow (*Salix* spp.), and other shrubs (Prescott 1968, Cioffi 1981). In summer, there is greater use by cows of wet lowlands and softwoods, hardwood-dominated cut areas, and mixedwood and softwood with canopy closure ranging from 0 to 60%, aquatic areas and licks, residual stands, areas with dense to moderate overstory for hiding and cover, and an interspersion of food and cover in proximity to water (Leptich 1986, Thompson 1987, Miller 1989, Brannen 2004). For calving, cows select secluded, undisturbed, poorly-drained lowlands, which have young stands nearby for food and are less than 100 m from water (Leptich 1986, Thompson 1987, Miller 1989).

Minimum Critical Habitat Area

Uncertainty exists surrounding the area of habitat required to support a viable population or metapopulation of moose in Nova Scotia. Minimum critical area (MCA) is a rough measure of the quantity (spatial-area) of suitable habitat required to support a viable population over time, and is calculated as a function of viable population size, home range size, and moose density. It is a useful measure for setting habitat targets for species recovery and conservation. Snaith and Beazley (2002) conducted coarse MCA calculations for moose in mainland Nova Scotia using two methods: (1) multiplying short- and long-term *N* by home range size; and (2) dividing *N* by density. *N* (500/5,000) multiplied by the mean (40 km^2) annual home range size for moose in mainland Nova Scotia (~55 km^2) (D. Brannen, Nova Scotia Department of Natural Resources, personal communication) and in the Acadian forest region (~25 km^2) (Dunn 1976, Crossley and Gilbert 1983, Crête 1987, Leptich and Gilbert 1989, McNicol 1990) results in short- and long-term MCAs of 20,000 and 200,000 km^2, respectively. *N* (500/5,000) divided by mean density (0.05 / km^2) of moose in mainland Nova Scotia (0.01 – 0.09 / km^2) (Pulsifer and Nette 1995) results in short- and long-term MCAs of 10,000 and 100,000 km^2, respectively. Obviously there is considerable uncertainty in such simple and coarse estimates and the range of MCA calculations they produce. Nevertheless, they indicate that a significant area of habitat is likely required to maintain viable populations of moose in Nova Scotia over both short and long terms, and that long-term viability is likely dependent upon continued habitat connectivity to New Brunswick since the total area of mainland Nova Scotia is ~45,000 km^2, which is well below long-term MCA estimates.

Habitat Suitability Analysis

The complexity of seasonal, annual, and life-history variations in habitat requirements make it difficult to precisely model habitat suitability and availability and to manage forests for moose. However, preliminary assessments of the availability of forage, security, thermal cover, and aquatic habitat components in mainland Nova Scotia have been conducted, though they are relatively coarse, localized, and/or incomplete (Snaith 2001, Snaith et al. 2002, Brannen 2004, Kwan 2005). Snaith (2001) (also see Snaith et al. 2002) conducted a coarse-scale habitat suitability analysis to quantify the proportional availability of 4 habitat components (forage, softwood cover, mixedwood cover, and wetlands) using Allen et al.'s (1987) habitat suitability index (HSI) Model II. The results indicated little optimal habitat according to all 6 theoretical models and a total extent of 1,000 – 6,000 km^2 of very good and good habitat (Snaith et al. 2002). Logistic regression analysis indicated no statistically significant correlation between HSI values and moose pellet presence/absence on pellet group inventory (PGI) transect lines (Nova Scotia Department of Natural Resources, unpublished data); however, forage and forage-in-proximity-of-cover suitability index values alone could predict pellet presence/absence. This obviously raises questions about the validity of the model, its assumptions, and application in mainland Nova Scotia since significant differences in the relative importance of habitat components for moose may exist between boreal and Acadian forest regions. Although HSI values alone were unable to predict moose pellet presence/absence, in subsequent multivariate regression analyses, Snaith et al. (2002) found statistically significant correlations ($P < 0.05$) between moose pellet presence/absence and: (1) road density alone; (2) HSI values and road density combined; (3) road density after HSI values are accounted for; and (4) 2 of the 6 HSI equations after road density is accounted for. These results must be interpreted with caution since pellets indicate only winter habitat use, and the PGI data are incomplete and contain sampling biases. Nonetheless, it appears that higher road densities may reduce the effectiveness of otherwise suitable habitat for moose (see Beazley et al. 2004 for a review), though specific influencing factors in the relationship between roads, habitat suitability, and moose distribution in Nova Scotia are not known.

Habitat Disturbance and Human Access

There are few examples in the literature specific to describing physiological reactions in moose or demographic changes in moose populations in response to human activities (Youmans 1999). According to a review of the existing literature on this subject relative to North American ungulates provided by Youmans (1999), responses of these animals to human-induced disturbances may include considerable energy expenditure, depletion of existing energy stores, and the abandonment of areas of desirable habitat. Moose have been shown, for example, to avoid areas frequented by cross-country skiers, snowmobilers, and hunters (Forman et al. 1997, Jalkotzy et al. 1997). While moose are, to an extent, able to adapt to and tolerate disturbances caused by human activities that are predictable and non-threatening (Geist 1971, Shank 1979, Westworth et al. 1989), backcountry recreational pursuits in the form of hiking, mountain biking, angling, snowshoeing, cross-country skiing, off-highway-vehicle use, and snowmobiling are not highly predictable either spatially or temporally (Shank 1979, Ferguson and Keith 1982, Rudd and Irwin 1985). Although moose hunting is illegal on mainland Nova Scotia, poaching and hunting of other species may be major sources of human-induced disturbance. Although the extent and frequency of poaching in the province are unknown, these activities not only cause a direct loss of animals, but may, even at low frequencies, effectively elevate the level of disturbance associated with other back-country human activities. The inundation of moose winter habitat by recreational snowmobilers over the past 40 years is not unique to Nova Scotia, nor is the more recent invasion of moose spring, summer, and fall habitat (as well as winter to an extent) by the new generation of recreational off-highway wheeled vehicles. The impact of these vehicles on Nova Scotia's natural environment may be greater than that experienced in other jurisdictions because of the province's relatively small land base, high percentage of land existing as small privately owned parcels, and very large number of access roads and trails, combining to make regulation and control of this form of recreation difficult.

There is considerable debate on the direct and indirect effects of roads, trails, and other linear developments relative to direct mortality from vehicle collisions, habitat fragmentation and avoidance, displacement and disturbance, poaching, and ingress of non-indigenous flora and fauna. For example, while moose often browse on the vegetation along road verges, they also suffer direct mortality from collisions and indirect effects resulting from the access afforded to humans and other species, which may outweigh any benefits of increased forage opportunities (Timmermann and Gollat 1982, Lyon 1984, Boer 1990, Jalkotzy et al. 1997, Gucinski et al. 2001). The fact that vehicular trauma is a significant cause of mortality in the mainland Nova Scotia moose population is supported by data discussed in the Health Section of this paper. Roads and their use (compaction by snowmobilers, for example) also provide predators, such as the Eastern coyote, and other species, such as white-tailed deer, access into moose habitat. Facilitating deer movement into moose habitat refugia serves to decrease the spatial separation between moose and deer, and consequently increases the likelihood of transmission of *P. tenuis*, a significant mortality factor for moose (see Health section). While indirect, these effects may nonetheless be substantial, especially in combination; yet, a direct cause-effect relationship is difficult, if not impossible, to establish or prove. Nonetheless, it is well documented that moose and other ungulates are negatively affected by roads, trails, and other linear developments (for summaries see Beazley et al. 2004, Jalkotzy et al. 1997, and Gucinski et al. 2001).

Habitat loss, conversion, degradation, and fragmentation result from roads and related human activities and developments such as agriculture, forestry, mining, and urbanization, sometimes to the extent that areas of suitable habitat are eliminated or reduced to small, isolated patches that can no longer support viable localized groups of moose over time. For species that are sensitive to human activities, such as herbivores, road density is often the most accurate predictor of habitat effectiveness (Lyon 1983, Thiel 1985, Noss et al. 1999). Consequently, this factor has been suggested as an index for human activity and a counter-indicator for suitable habitat for large vertebrates and ecological integrity (Forman 1995, Noss 1995, Rudis 1995, Forman et al. 1997, Noss et al. 1999). Although statistical analyses have indicated a correlation between road density and moose pellet presence/absence in mainland Nova Scotia (Snaith et al. 2002, Beazley et al. 2004), it is unclear whether this is as a consequence of direct or indirect effects of the roads themselves, the access that roads provide to humans, or some other factor for which road density may serve as a surrogate, such as human settlement, population density, forest harvesting intensity, or other activities or developments. Nonetheless, Brannen (2004) also found that the length of primary and secondary roads in study areas in mainland Nova Scotia had a negative effect on moose presence.

The level and type of use of the road or trail affects the nature and magnitude of the associated impact, thus limiting our ability to come to general conclusions about cause-effect relationships and potential management options. Nonetheless, given the necessity and popularity of existing roads, trails, and other linear corridors for recreation, forestry, urban and rural developments, and many other uses, the challenges in deriving politically acceptable and defensible solutions are not insubstantial. Approaches to minimize direct and indirect human-related disturbances to moose and the conversion and fragmentation of remaining moose habitat must be explored. Public awareness and budgetary enhancements will be necessary to achieve effective implementation of existing and future regulations and to undertake habitat restoration and conservation efforts.

DISTRIBUTION AND CLIMATE CHANGE

Moose in mainland Nova Scotia exist near the southern limit of their natural distribution on the North American continent. Issues of heat stress, thermal cover, snow depth, moose/deer separation, and temperature and precipitation changes associated with climate change raise questions about the persistence of moose at this latitude. Climate change scenarios for mainland Nova Scotia project that by 2080 mean annual temperatures will rise from current rates (1961-1990) by approximately 3°C in the southwest (i.e., Tobeatic localized group) and 4°C in the northeast (i.e., Cobequid localized group) (Canadian Institute for Climate Change, Canadian Climate Impact Scenarios, http://www.cics.uvic.ca/scenarios/index.cgi?Scenarios). Temperature rises are likely to result in increased thermal stress, particularly in summer. Consequently, moose may spend more time under thermal cover during the heat of the day and travel at night to feed, thereby increasing travel time and energy expenditures and therefore potential risks to calves and calf mortality. Aquatic resources, thermal cover in proximity to forage, and habitat in coastal areas and at higher-elevations are likely to become increasingly important.

While further warming would be to the detriment of moose in terms of thermoregulation, it would be to the benefit of deer, and greater abundance and distribution of deer would mean greater exposure of moose to *P. tenuis*. Total annual days with snow are projected to be less than half of current rates in both the southwest and northeast (from 51 to 23 and 42 to 19, respectively), while days with rain are predicted to increase (Canadian Institute for Climate Change, Canadian Climate Impact Scenarios, http://www.cics.uvic.ca/scenarios/index.cgi?Scenarios). Decreases in annual days-with-snow, increases in days-with-rain, and increases in mean winter temperatures are likely to result in significantly lower snow depths. Lower snow depths may also facilitate deer movement into areas from which they may be currently excluded, reducing habitat refugia for moose from white-tailed deer, and thereby increasing moose exposure to *P. tenuis*. A direct positive relationship has been established between warmer climates, higher winter precipitation, and prevalence of a lungworm parasite similar to *P. tenuis* (Ball et al. 2001), thus suggesting a potential increase in the prevalence of *P. tenuis* as a consequence of warming.

Potential climate-change-induced increases in direct and indirect factors, such as thermal stress and *P. tenuis*-related mortality, pose significant challenges for moose recovery. While climatic changes may ultimately limit the ability for moose recovery in Nova Scotia, the predictions indicate that measures for increasing thermal cover and for addressing *P. tenuis*-related mortality will be even more critical in the future than at present. Furthermore, if genetic diversity is valued as a component of biodiversity conservation, measures to retain genetic material of localized groups of *A. a. americana* (i.e., as a species and as individuals hypothetically adapted for persistence at the southern limits of their contemporary range) may be warranted even if the material does not reside in mainland Nova Scotia. In the eventuality that climate change exceeds the ability of moose to persist in mainland Nova Scotia, portions of the genetic material could potentially be retained, for example, by translocations of individuals to more northerly regions. Regardless, the uncertainties around the projections and the consequent impacts on moose require a precautionary and adaptive approach to recovery planning.

CONCLUSION

It is apparent that the number of moose in mainland Nova Scotia is in decline and that it may be as a consequence of one or all of several direct and indirect factors related to habitat suitability and effectiveness, human access and disturbance, population demographics and viability, genetics, health, and climate change. There are considerable complexities and knowledge gaps with respect to these factors and their interrelationships that present a challenge to recovery planning.

While areas of apparently suitable habitat remain, there are questions as to their effectiveness for moose where road densities are high and white-tailed deer are present, since moose appear to be only occupying a small portion of otherwise suitable habitat (possibly in refugia), which is isolated from deer and human activities. It is difficult to restrict or limit human access and to monitor and prevent illegal activities due to the proliferation of roads, trails, and off-highway vehicles, which facilitates access into otherwise remote areas, some of which may currently be functioning as moose refugia. Existing localized groups of moose consist of small numbers of individuals that are isolated from each other and unlikely to be functioning as a metapopulation. These localized groups are at population levels that are well below estimates of minimum viable population size, especially for the long term, suggesting negative implications for genetic viability and an unacceptably high probability of extirpation. Opportunities for reconnecting isolated groups through physical habitat restoration at the landscape and regional scales or through artificial translocations of animals are limited due to physical barriers such as long distances, major highways, and the small numbers of remnant moose. Opportunities for increasing the number of individuals within localized groups are hindered by various mortality factors related to trauma from vehicular collisions and gunshots, *P. tenuis*, calf-mortality, potential nutritional and toxicity effects, and our lack of understanding of the interrelationships among these and genetic and environmental factors. Climate factors exacerbate the situation, since moose in mainland Nova Scotia exist at the current southern limit of their range and predictions of future climate change indicate increases in temperature and decreases in snow cover, both of which may increase heat stress and transmission of *P. tenuis*. Moose recovery in mainland Nova Scotia will increasingly need to address thermal cover requirements and *P. tenuis*-related mortality.

There is difficulty in establishing cause-effect relationships between these factors and moose decline, since it is likely that the decline is the result of synergistic and cumulative effects of several, if not all, of the factors. Addressing these challenges will require substantial social, political, and financial support to acquire the requisite data and to adopt a precautionary and adaptive approach to recovery planning.

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