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THE DISTRIBUTION, STATUS AND HABITAT ASSOCIATIONS OF MOOSE IN MAINLAND NOVA SCOTIA

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Throughout the Nova Scotia mainland, small and fragmented moose populations remain at varying densities and may be limited or regulated by a number of factors including interspecific competition, disease, habitat alteration/loss, mineral toxicity/deficiency, predation, poaching, and resource availability. Ranging behaviour and habitat requirements vary according to environmental factors; however, moose require food and cover in sufficient quantity and of appropriate interspersion to meet their daily and seasonal needs. Mature forest with a well developed understory, and open areas with early successional vegetation provide forage, while dense forest provides cover from thermal stress and deep snow. Strategies for moose conservation, such as through forest management, should concentrate on the preservation and enhancement of habitat to meet the critical requirements of viable moose populations and the re-establishment of connections among discrete populations.

Sur la terre ferme en Nouvelle-Écosse, il reste de petites populations fragmentées d'orignaux de densités variables qui sont peut-être limitées ou régulées par plusieurs facteurs dont la compétition interspécifique, les maladies, l'altération ou la destruction des habitats, la toxicité des minéraux ou le manque de minéraux, la prédation, le braconnage et la disponibilité des ressources. Les déplacements et les besoins en matière d'habitat des orignaux varient en fonction des facteurs environnementaux; cependant, les orignaux ont besoin de nourriture et d'un couvert adéquatement répartis pour satisfaire leurs besoins quotidiens et saisonniers. Les forêts matures à sous-étage bien développé et les zones ouvertes caractérisées par des espèces végétales pionnières fournissent la nourriture, tandis que les forêts denses offrent un couvert contre le stress thermique et la neige épaisse. Les stratégies de conservation des orignaux, par exemple associées à l'aménagement des forêts, devraient viser principalement la conservation et l'amélioration de l'habitat de manière à combler les besoins essentiels des populations viables d'orignaux, ainsi que le rétablissement de la connectivité entre les populations disjointes.

Introduction

Over the past few centuries, Nova Scotia has undergone extensive habitat conversion, degradation, and fragmentation as a result of increasing urbanization, agricultural development, and resource extraction. As a consequence of human exploitation and habitat loss, many elements of Nova Scotia's biodiversity are at risk and a number of local species have become endangered or extirpated (COSEWIC 2000). Mainland moose (*Alces alces americana*) are among the species at risk in Nova Scotia (CESCC 2001). To understand current threats to moose, and to plan for their conservation, it is necessary to determine the status and distribution of populations throughout the province, to understand the habitat relationships of the species, and to examine the range of factors which may be threatening or regulating the population. Little is published describing the population dynamics and habitat associations of moose in Nova Scotia, and to date there has been no attempt to synthesize what is known in Nova Scotia with information gathered from moose populations elsewhere. Thus, the purpose of this paper is to synthesize the available information describing the distribution and status of moose in mainland Nova Scotia, their critical habitat requirements, and factors contributing to their decline.

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Moose Distribution in Nova Scotia

Historically, moose were abundant throughout Nova Scotia; however, there have been fluctuations and general declines in moose numbers since the early seventeenth century (Dodds 1963, Pulsifer & Nette 1995). By the early twentieth century, moose were completely extirpated from Cape Breton, and reduced to a few localized populations on the mainland (Pulsifer & Nette 1995). When indigenous moose failed to recover in Cape Breton, 18 individuals (*A.a. andersoni*) were introduced from Alberta in 1948/49 and the population increased steadily to about 4000 individuals by the late 1980s (Dodds 1963, Kelsall 1987, Pulsifer 1995, Pulsifer & Nette 1995, Timmermann & Buss 1997). Currently, there may be more than 5000 moose in Cape Breton (Nette 2000). During the same period, remnants of the indigenous moose herd on the mainland continued to decline, and now moose remain in significant numbers in only two areas (Figure I) (Pulsifer & Nette 1995, Nette 2000, Pulsifer 2000, Hall 2000). The northeastern mainland population, concentrated mainly in the Cobequid Highlands, consists of around 500 individuals (possibly as many as 800) but is thought to be declining, while the southwest population is thought to be stable at around 300 individuals, with its core occupying the Tobeatic region. In addition, there are scattered pockets of moose throughout much of the mainland, including no more than 100 individuals in the Pictou/Antigonish Highlands. Currently, the total population on the mainland is about 1000 individuals (Kelsall 1987, Pulsifer & Nette 1995, Nette 2000, Pulsifer 2000, Hall 2000). Due to the small and fragmented nature of the population, mainland Nova Scotia moose are at risk of extirpation, and have been red-listed in the province (CESCC 2001). In light of this present threat, the focus of this paper is on mainland moose populations.

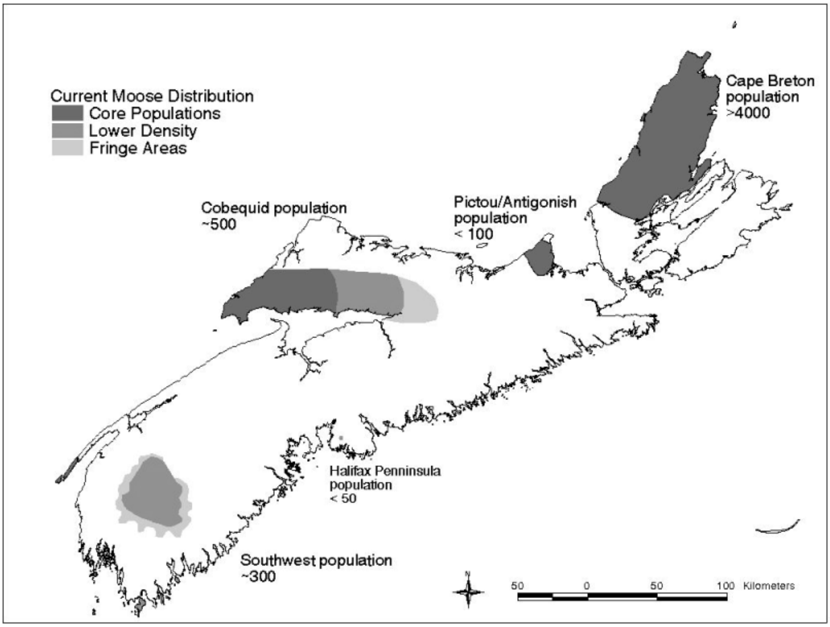

Fig 1 Current Moose Distribution in Nova Scotia

Moose Habitat Requirements

Moose require large areas and a diverse landscape to provide the resources essential for their survival (Appendix 1). The specific habitat requirements of moose in Nova Scotia have not been documented in detail. A synthesis of available information, in addition to data from populations elsewhere, will provide useful information about habitat use, ranging behaviour, and area requirements. The following sections summarize what is known about the nutritional, cover and habitat area requirements of moose, and the data is applied to the bioclimatic conditions of Nova Scotia.

Nutritional Requirements

Early successional deciduous vegetation is the primary source of moose forage, particularly during the spring and summer (see Appendices 1, 2 and 3 for references). The understory of mature forest and open areas following disturbance such as windthrow, insect damage, wildfire or forest harvesting often contain good moose forage. During the summer, moose consume a variety of terrestrial and aquatic foods including deciduous leaves, shrubs, grasses, forbs, aquatic vegetation, and young plant growth high in digestible energy and protein (Regelin et al. 1987, Timmermann & McNicol 1988). During this time, energy is required for lactation, growth, antler production, and fat storage to ensure winter survival (Timmermann & McNicol 1988).

During the winter, food intake generally decreases because food resources are limited to poorly digestible woody browse of low nutritional quality, and may be difficult to access due to snow cover and thermal stress (Coady 1974, Belovsky 1981, Schwab 1985, Schwartz et al. 1987, DelGiudice et al. 1997). Conifer consumption is likely dependent on the amount of deciduous browse available, becoming increasingly important as winter progresses or in areas where preferred species are less prevalent (NSDLF undated, Benson 1957, Knowlton 1960, Des Meules 1964, Prescott 1968, Telfer 1984, Cederlund & Markgren 1987, Timmermann & McNicol 1988, Histol & Hjeljord 1993).

Important food species in Nova Scotia include red, sugar, and mountain maple, white and yellow birch, hazelnut, and balsam fir (Appendix 2) (Benson 1957, Telfer 1967a, b, Prescott 1968, Basquille & Thompson 1997). In Nova Scotia, quantitative field studies have demonstrated that moose rely on maples for up to 50% of their winter diets, and birch for approximately 20% (Telfer 1967b, Prescott 1968). Mountain maple is the most important food species and is browsed heavily whenever available (Prescott 1968). The amount of balsam fir consumed varies from very little to 50% of the diet or more (Benson 1957, Telfer 1967a, b, Prescott 1968, Basquille & Thompson 1997).

Aquatic vegetation is an important component of moose summer diets in many areas (see Appendix 1 for references). However, wetlands are infrequent in the Cobequid area, and aquatic systems in the southwestern region are generally too acidic to support much vegetation (Morash 2000, Nette 2000). Moose have nevertheless historically persisted in these areas, suggesting that aquatic vegetation is not a critical dietary requirement in Nova Scotia (Telfer 1984).

Based on food species preferences and the vegetative characteristics of Nova Scotia (Loucks 1962, Rowe 1972, Ecological Stratification Working Group 1995, NSDOE 2000, Nette 2000), the Cobequid moose population occupies highly suitable habitat containing a wide variety of preferred hardwood species and occasional wetlands containing aquatic forage. The southwestern population inhabits a less-than-ideal area where the rocky barrens contain fewer hardwood species and are less productive due to poor soils. Although lakes and wetlands are more frequent than in the Cobequid region, aquatic vegetation is limited due to high levels of wetland acidity.

Cover Requirements

Vegetative cover is a critical element of moose habitat during all seasons and is necessary for thermoregulation and protection from sun, snow, wind, extreme cold, and predators. Thermal cover (closed-canopy, dense, mature forest at least 30 years old) is necessary to protect moose from heat stress because although moose are well-adapted to cold weather, they are sensitive to hot temperatures (Peterson 1955, Coady 1974, Renecker & Hudson 1986, Schwab & Pitt 1991).

Due to thermal radiation, moose cannot comfortably withstand temperatures above approximately 14 to 20°C in the summer and -5 to 0°C in the winter (Renecker & Hudson 1986). When temperatures reach these levels, moose restrict their activity and seek cooler micro-environments under dense forest cover or in water bodies (see Appendix 1 for references). Average summer temperatures in Nova Scotia reach about 15°C (Ecological Stratification Working Group 1995), which is within the critical range and is probably enough to necessitate the presence of forest cover throughout the summer months. An on-going study of moose in the Tobeatic indicates that moose preferentially select dense, mature deciduous forest habitat during the summer months (Nette 2000). The average winter temperatures of -1.5°C in the southwestern region and -2.5 to -5.5°C in the Cobequids (Ecological Stratification Working Group 1995) are well within the critical range and will create heat stress during the winter, forcing moose to seek shelter from thermal radiation.

In addition to thermal/heat stress, moose require cover to avoid extreme cold and deep snow conditions. As winter progresses moose move into mature conifer-dominated stands which provide the greatest protection from snow, cold, and heat. In Nova Scotia, moose move to sheltered areas during late winter regardless of snow conditions (which rarely reach critical conditions), presumably to alleviate thermal stress (Nette 2000). Moose winter concentration areas, or yards, in the Cobequid Hills of Nova Scotia were described by Prescott (1968) and Telfer (1967a, b) as the most intensively used portions of moose winter range. They are located on the upper third (at 120 m to 180 m elevation above sea level) of south-facing slopes where temperatures are mild, and are selected for forage availability as well as dense forest cover for snow, wind, and sun protection. The yards are located where the softwood slopes meet the hardwood hilltops which provides a high diversity of vegetation types and the necessary combination of food and shelter.

Security cover (dense vegetation at least 2 m high) is essential year-round to escape predators and for successful reproduction and calf-rearing (Knowlton 1960, Thompson & Euler 1987, Miquelle et al. 1992, Nette 2000). Cows seek secluded areas for calving, such as isolated patches of dense vegetation and islands or peninsulas which offer security from predators (Peterson 1955, LeResche et al. 1974, Taylor & Ballard 1979, Towry 1984, Leptich & Gilbert 1986, Allen et al. 1987, Cederlund et al. 1987, Timmermann & McNicol 1988, Miquelle et al. 1992, Puttock et al. 1996, Bowyer et al. 1999). Calving sites are typically close to open areas with high forage availability, are well sheltered from predator attack, and are near a source of water (Bowyer et al. 1999, Leptich & Gilbert 1986, Allen et al. 1987). Lowland bogs, islands, or peninsulas with thick cover are ideal and will provide protection for vulnerable calves. Water bodies provide drinking water, refuge from flies and predators, and a cooling mechanism during the hot summer months (van Ballenberghe & Peek 1971, Peek et al. 1976, 1987, Dunn 1976, Kearney & Gilbert 1976, Telfer 1984, Ackerman 1987, Joyal 1987, Timmermann & McNicol 1988, Bontaites & Gustafson 1993).

The Cobequid region, with frequent densely forested areas, and varied topography where mild microhabitat conditions can usually be found, likely provides habitat with adequate cover for moose. In the more barren southwestern region, moose must rely on less frequent and less dense forest stands for cover, but have greater access to water bodies.

Seasonal Habitat Selection

Based on the literature, the habitat requirements of moose in Nova Scotia can be summarized as follows:

Spring and early summer (April to early June): Moose require open or disturbed areas with lots of good quality forage, calving areas, and forest cover for thermal and predator protection. If available, aquatic vegetation may provide essential nutrients. Mixed habitat providing a combination of food, cover, and water bodies will provide good moose range during the spring and early summer.

Summer (mid-June to early September): During the hottest months of summer, moose require dense forest cover for protection from heat stress, and forage-rich areas which will provide enough food for growth, lactation, and fat storage requirements. Forest edges and open areas in close proximity to dense cover will provide good forage and easily accessible protection from solar radiation. Aquatic sites (for food, escape, and cooling) may be important habitat components during the summer. However, the availability of good aquatic resources is limited in Nova Scotia. Good summer habitat contains an interspersion of densely forested stands and forage producing areas such as mixed or disturbed forests with relatively open canopies or mature forests with understory for forage production.

Fall and early winter (mid-September to early January): Moose will continue making use of forage-rich areas as long as weather and snow conditions allow. Cover is less important during this time because solar radiation decreases and snow does not reach critical levels. Open and disturbed habitat with early successional vegetation is preferred during the fall and early winter.

Late winter (mid-January to late March): Dense cover again becomes critical during the late winter as snow accumulates and temperatures become extreme. Heat stress due to solar radiation, along with wind chill and deep snow, can restrict moose to densely forested areas during the late winter season. The best winter habitat will also include an interspersion of forage-rich areas such as small disturbances and forest edges.

Effects of Forest Disturbance and Management on Moose Habitat

Forest disturbances result in canopy openings which allow light penetration and natural regeneration (McNicol 1990). Early successional vegetation resulting from disturbances provides good moose forage and moose are often found at their greatest densities in areas where disturbance has occurred (Peterson 1955, Peek 1974a, Peek et al. 1976, Oldemeyer & Regelin 1987, McNicol 1990). Favourable browsing conditions exist in regenerating stands of about 5 to 40 years old, with a peak around 7 to 15 years post-disturbance (see Appendix 3 for references). Suitable cover, however, will not return for at least 30 years post-disturbance (Telfer 1970b). It is therefore essential to maintain residual stands of cover adequately dispersed throughout disturbed areas.

Natural Disturbance Regimes

Natural disturbance regimes can provide sufficient moose forage effectively interspersed with dense forest cover. Small-scale natural disturbances in mature forest continually open up the canopy and produce good understory vegetation which provides excellent forage (Houston 1968, McNicol & Gilbert 1987, Oldemeyer & Regelin 1987, Heikkila et al. 1996). Riparian habitat and floodplains undergo constant disturbance and succession, providing forage on a permanent basis (Houston 1968, Peek 1974a, Sumanik & Demarchi 1977, Doerr 1983, Oldemeyer & Regelin 1987, MacCracken et al. 1997).

Wildfire may kill or force some animals out of their range, but normally leads to browse improvement and better interspersion and heterogeneity of resources (Dodds 1974, Crawford 1993). Small burns are generally beneficial; however, severe and repeated burning can be detrimental to moose range and has produced areas of ericaceous vegetation in western Nova Scotia which are poor quality moose habitat (Dodds 1974, Muise 2000).

Forest diseases and insect damage, such as birch die-back and spruce budworm (*Choristoneura fumiferana*) infestations, can lead to habitat degradation through partial or complete defoliation (Prescott 1968, Dodds 1974). Such disturbance leads to regeneration, however, and is often beneficial to moose range by producing early successional vegetation interspersed with sufficient cover (Prescott 1968, Dodds 1974, Crawford 1993). A spruce budworm infestation in the Cape Breton Highlands led to regeneration of preferred forage species, while sufficient thermal cover was maintained, and is associated with a large increase in moose densities in the area (Basquille & Thompson 1997).

Forest Management

Forest management can enhance or degrade habitat for moose. For example, regenerating clearcuts provide good moose browse after 10 to 40 years; however, large cuts do not provide optimal moose habitat due to increased homogeneity and the reduction of critical thermal and escape cover (see Appendix 3 for references). Moose will not make use of available forage in large open areas which do not contain residual stands of mature forest cover, and generally will not move more than about 80 to 200 m from cover, particularly during periods of deep snow (Eastman 1974, Hamilton et al. 1980, Tomm & Beck 1981, Allen et al. 1987, Peek et al. 1987, Jackson et al. 1991, Thompson et al. 1995). Studies have demonstrated that moose will not begin to preferentially use cutovers until 10 to 15 years post-cut, when some degree of forest cover has returned, even if forage is available in the cuts prior to this period (Monthey 1984, Potvin et al. 1999).

Silvicultural practices which favour establishment of single-species coniferous stands do not produce desirable food species for moose, and often include the use of herbicides (Prescott 1968, Peek et al. 1976, Joyal 1987). Glyphosate is commonly used on clearcuts in Nova Scotia to discourage deciduous growth in favour of merchantable conifer species which do not provide high quality moose forage (Escholz et al. 1996, Raymond et al. 1996). Studies have produced conflicting results regarding the effects of glyphosate on moose habitat (Connor & McMillan 1990, Escholz et al. 1996, Raymond et al. 1996, Hjeljord 1994, Santillo 1994), and the effects of glyphosate ingestion on the health of wildlife are unclear, although Raymond et al. (1996) suggested that toxic effects are minimal.

Large-scale harvesting that leaves few stands of mature forest and cultivation of even-aged, single-species stands reduce and fragment moose habitat and result in forest homogeneity. Timber harvest by selective or partial cutting can enhance moose habitat by producing an interspersion of food producing areas within an adequate supply of shelter (Prescott 1968, Telfer 1984, Cederlund & Sand 1992, Pulsifer 1995). In general, forest management for moose habitat should maintain at least 55 to 70% mature cover-providing forest distributed in patches no smaller than about 8 ha, and should retain some large patches of residual cover (up to 100 ha) with disturbances designed so there is never more than 200 m to cover from any point (see Appendix 3 for references).

Land Development

Human settlement and development, land clearing, cultivation, urbanization, and recreational development restrict and eliminate moose habitat (Houston 1968, Dodds 1974). Roads, trails, and other utility corridors provide access for competitors and predators, increase hunting pressure, fragment and convert habitat, disturb wildlife during construction and use, and increase mortality by vehicle collision (Houston 1968, Prescott 1968, Peek et al. 1987, Hogg 1990, Forman et al. 1997, Jalkotzy et al. 1997, Rempel et al. 1997). Although roads may provide open forage-producing areas, moose frequently do not take advantage of the increased forage availability, and any benefits are offset by associated disturbances and increasing mortality rates (Timmermann & Gollath 1982, Forman et al. 1997, Jalkotzy et al. 1997). Analysis of pellet group data indicated that moose in mainland Nova Scotia preferentially select areas with few or no roads, and less frequently occupy areas of high road density (Snaith 2001, Beazley et al. 2004). Thus, the retention of areas of low road density, such as in the Tobeatic area, and the decommissioning of forestry harvesting roads after use may be critical to the maintenance of moose populations in Nova Scotia.

Moose Ranging Behaviour and Area Requirements

Globally, moose show considerable variation in their ranging patterns and home range size (Appendix 4). This variation is likely due to the variability among sites in climate, range quality, and the degree of interspersion of essential habitat components. Annual home range sizes reportedly vary from 12.6 km^2 in Sweden where the habitat is of excellent quality with small-scale disturbances, a mixture of successional stages, and high resource availability (Cederlund & Okarma 1988), to 200-500 km^2 in Alaska and the Northwest Territories where moose are forced to travel much further to meet their daily and seasonal requirements (Taylor & Ballard 1979, Ballard et al. 1991, Stenhouse 1995). Population density tends to be greater in areas with good habitat quality where individuals occupy smaller home ranges (Sweanor & Sandegren 1989).

There are few estimates of home range size and range use patterns for moose in Nova Scotia. Preliminary results of an ongoing study indicate that moose in the southwestern population occupy a mean annual home range of 55.2 km^2 with overlapping seasonal ranges (n = 8; r = 13.29-129.84 km^2; based on two years of observation and 51 to 63 relocations/individual) (calculation based on figures from Brannen (2000)). There are no estimates for home range size of individuals in the more mountainous habitat of the Cobequids. However, data from similar habitat areas in Maine and the Gaspé Peninsula suggest that widely separated seasonal ranges are not necessary, and that home ranges vary from 20 km^2 to 50 km^2 (Dunn 1976, Crossley & Gilbert 1983, Crete 1989, Leptich & Gilbert 1989, Thompson et al. 1995) (Appendix 4). Because moose are known to adapt to widely distributed resources by ranging over large areas (Lynch & Morgantini 1984), it is possible that the reported area requirements in the southwest region of Nova Scotia are slightly larger than estimates from Maine and the Gaspé Peninsula because resources are more sparse in the rocky barrens characteristic of southwest Nova Scotia.

Nova Scotia moose do not exhibit long-distance seasonal migrations; however, local seasonal movements do occur in response to food availability and snow conditions, especially in the mountainous Cobequid region (NSDLF undated, Benson 1957). Winter home ranges are much smaller than summer ranges because movement is restricted due to lower food availability and the constraints of travel associated with snow accumulation (Telfer 1967a, b). Moose winter ranging behaviour in the Cobequids is characterized by localized concentrations of moose in yards which are small, intensively used areas within a restricted winter range of 2.6 km^2 (Telfer 1967a, b). Summer range requirements are much larger due to increased travel associated with feeding activities. Based on the literature cited above, and the ongoing study in the Tobeatic, 20 to 50 km^2 of good habitat is likely a conservative estimate of the area required by an individual moose.

Population Density

Worldwide, there is generally a great range of variation in moose population density (Appendix 4), and it is difficult to determine the ideal density and structure of a healthy population. Although current average densities are not known, mainland moose populations are at much lower densities than they have been in the past (NSDLF undated, Benson 1957, Dodds 1963, 1974, Telfer 1968b, Prescott 1968, Pulsifer 1995, Pulsifer & Nette 1995, Timmermann & Buss 1997). Traditionally, the highlands of the northeastern mainland have maintained the greatest moose densities, and likely still do, although some evidence indicates that there are a few local concentration areas with relatively high densities in the Tobeatic (Benson 1958, Dodds 1963, Prescott 1968, Nette 2000). Currently, population density in the Cobequid Highlands is estimated to be 0.01 to 0.09 moose/km^2, while in the southwest, population density is approximately 0.05 moose/km^2 or less, with local concentrations of up to 0.35 moose/km^2 (Pulsifer & Nette 1995, Nette 2000).

Moose populations elsewhere exist at similarly low densities, and are likely maintained at low levels due to poor range conditions, restricted sodium availability, reduction of winter habitat due to forest management, hunting mortality, and predation pressure (for example, *Former Soviet Union*: Filonov & Zykov 1974, Kistchinski 1974, Syroechkovskiy & Rogacheva 1974**;** *Newfoundland*: Albright & Keith 1987; *Labrador*: Chubbs & Schaefer 1997; *Northwest Territories*: Stenhouse 1995; *Quebec*: Brassard et al. 1974, Joyal & Sherrer 1978, Crete & Courtois 1997; *Ontario*: Thompson & Euler 1987, Duinker et al. 1996; *Alberta*: Hauge & Keith 1981; *Alaska*: MacCracken et al. 1997). These factors, among others as described below, may be acting to limit or regulate Nova Scotia moose populations, and must be carefully considered when assessing population viability or designing conservation and management plans for moose habitat.

Regulating Factors

Habitat Suitability and Degradation

In some areas, moose show density-dependent population regulation based on resource availability. Reproductive rates and survival are linked to nutritional status, and poor range conditions lead to lower body weight, slower development, delayed sexual maturity, lower calf production, and increased mortality (NSDLF undated, Messier & Crete 1984, Franzman & Schwartz 1986, Fowler 1987, Karns 1987, Page

1987, Andersen 1991, Wallin et al. 1995, Sand et al. 1996, Crete & Courtois 1997, Saether 1997, Hjeljord & Histol 1999). Some studies suggest that winter food availability is an important limiting factor affecting mortality rates, population density, and carrying capacity (Stevens 1970, Peek 1974b, Crete & Jordan 1982, Albright & Keith 1987, Cederlund & Markgren 1987, Crete 1989, Andersen 1991, Ballard et al. 1991). However, a number of reports suggest that food availability is not likely a limiting factor for moose, even during winter (Crete & Jordan 1982, Messier & Crete 1984, Miquelle et al. 1992, Joyal 1987, Bontaites & Gustafson 1993, Saether et al. 1996). Hjeljord & Histol (1999) suggest that density-dependent resource limitation is unlikely to occur until moose reach very high densities. The *quality* of food resources or the presence of other critical habitat components, such as adequate cover, may be more important factors affecting moose population densities and distribution (Oldemeyer 1974, Peek 1974b, Regelin et al. 1987, Miquelle et al. 1992, Puttock et al. 1996).

Population stability is also affected by fluctuations in habitat characteristics due to disturbances such as blow-downs, fires, forest management and insect infestations, which influence forage production (Telfer 1984, Bobek & Morow 1987, Cederlund & Sand 1991, Bontaites & Gustafson 1993). Habitat disturbance at a large scale may restrict or significantly fragment moose habitat, particularly thermal cover, which may lead to decreasing moose populations while at the same time favouring the expansion of deer, a possible competitor (Telfer 1970b, Dodds 1974, Bontaites & Gustafson 1993, Pulsifer 1995). Forest conversion for agriculture, industry, and urbanization have led to the reduction and extirpation of moose in portions of Europe, the United States, Nova Scotia, Ontario, and Quebec (Dodds 1974, Telfer 1984). Continuing forest conversion, degradation and fragmentation in Nova Scotia, including through forest harvesting, may decrease habitat suitability and availability, and further increase pressure on moose populations.

Climate

Seasonal climatic fluctuations affect moose health, and in extreme cases may limit populations directly by increasing mortality, or indirectly by affecting food availability. Severe winter weather, and heat stress during hot summers, may cause decreased forage intake and increased energy expenditures for thermoregulation which in turn might decrease fat storage and ultimately increase winter mortality (Renecker & Hudson 1986, Ackerman 1987). Because Nova Scotia is near the southern limit of moose range, heat stress likely occurs during both late winter and hot summer months. Summer and winter thermal stress, if combined with a lack of adequate mature forest for thermal protection and few aquatic resources, may be an important factor affecting moose populations in the province.

The current global warming trend has the potential to greatly affect moose populations in Nova Scotia, which are already close to the limit of heat tolerance. A period of rapid human-induced atmospheric and climate change will lead to changes in range conditions and may decrease habitat quality (Peters & Darling 1985, Graham 1988, Hunter et al. 1988, Davis & Zabinski 1992, Dawson 1992, Lovejoy 1992, Murphy & Weiss 1992, Peters 1992, Shugart & Smith 1992). The effects of these changes will be compounded by an increasingly developed landscape where there are physical barriers to animal movement and few remaining connected natural areas for dispersal.

Moose Interactions with White-Tailed Deer

Northward expansion of white-tailed deer (*Odocoileus virgianus*) populations into areas traditionally occupied by moose has been associated with increasing human-induced environmental change. White-tailed deer are highly adaptable and prefer deciduous forest habitat and forest edges associated with open areas (Anderson 1972). Over the past 150 to 200 years, agricultural and linear corridor development and forest management practices throughout Nova Scotia have opened up the forests, creating browse and cover conditions suitable for deer (Anderson 1965, 1972, Karns 1967, Prescott 1974, Lankester 1987). White-tailed deer appeared in Nova Scotia in the late nineteenth century and became the dominant cervid by the mid-twentieth century, while moose numbers dwindled (Benson 1958, Telfer 1967b, Anderson 1972, Pulsifer 1995). Similar trends have been reported for New Brunswick (Telfer 1968a), Maine (Gilbert 1973, 1974), Ontario (Anderson 1965, Saunders 1973) and Minnesota (Karns 1967). These declines in moose numbers have often been attributed to a sickness caused by the parasitic nematode, *Paralephostrongylus tenuis*, normally associated with white-tailed deer. However, the initial habitat alterations themselves, or the increased interspecific food competition subsequent to the increase in deer density may also have been significant factors in the reduction of moose numbers (Wright 1956, Benson 1957, Telfer 1970b, 1984, Banfield 1974, Prescott 1974, Strandgaard 1982, Telfer & Cairns 1986, Karns 1987, Pulsifer 1995).

Direct food competition may be unlikely because moose and white-tailed deer are frequently separated by differential habitat selection (Telfer 1967b, 1968a, 1970a, Gilbert 1974, Telfer & Cairns 1986, Kearney & Gilbert 1976). In many cases, spatial separation occurs during the winter months. Because deer are less tolerant of snow, they are forced to move to lower altitudes or into more dense conifer cover than is required by moose (Telfer 1968a, Tierson et al. 1985). However, forest conversion associated with the creation of roads and open areas, as well as climate warming trends, may continue to favour deer populations over moose.

Disease

Moose populations in Nova Scotia may be significantly affected by a number of diseases including brainworm (*P.tenuis*), winter ticks (*Dermacentor albipictus*), and nutritional deficiencies or toxicity due to environmental contamination. *P. tenuis* is a common parasite of white-tailed deer in eastern North America, and can be transmitted to moose via terrestrial gastropods (snails), the intermediate host (Anderson 1963, 1972). White-tailed deer can tolerate the parasite without any pathogenic symptoms. However, *P. tenuis* is highly pathogenic and often fatal to moose (Telfer 1970a, Anderson 1972, Gilbert 1973, 1974). In moose, the worms may cause severe trauma to the central nervous system, neurological disease, paralysis, and death, and may predispose moose to mortality by other causes such as hunting and accidental death due to abnormal behaviour (Benson 1958, Anderson 1964, Gilbert 1974, Thomas & Dodds 1988).

For many years, *P. tenuis* was commonly accepted as a major factor in moose population declines that seemed to be associated with increasing deer densities (Anderson 1964, 1965, 1972, Karns 1967, Telfer 1967b, 1970a, 1984, Gilbert 1973, 1974, Saunders 1973, Dodds 1974, Prescott 1974, Peek et al. 1976, Clarke & Bowyer 1986, Geist 1987, Lankester 1987, Thomas & Dodds 1988, Pulsifer 1995). More recent evidence suggests, however, that it may only be a marginal limiting factor (Telfer 1967b, 1968a, 1970a, Gilbert 1973, 1974, Kearney & Gilbert 1976, Saunders 1973, Anderson 1972, Nudds 1990, Whitlaw & Lankester 1994, Dumont & Crete 1996, Lankester & Peterson 1996). While *P. tenuis* may not be the principal cause of mortality and declining moose populations in Nova Scotia, it is likely a contributing factor that should be assessed along with food competition, habitat alteration, and other causes of mortality.

The winter tick is a common parasite in Nova Scotia and, due to very large tick loads observed on moose in the province, may also be a significant mortality factor for moose (NSDLF undated, Nette 2000). Ticks remove nutrients and blood and introduce pharmacological agents to the bloodstream which trigger increased grooming and thus premature shedding of the winter coat (Hodgdon 1961, Samuel et al. 1986, Samuel 1991). Loss of hair during the winter months can lead to thermal stress, increased metabolic demands, and hypothermia (Samuel 1991). These effects have been linked to winter nutritional stress, increased mortality, and declining moose populations in Michigan and Alberta (DelGiudice et al. 1997). Increased tick infestations seem to be associated with relatively short and mild winters; mild autumn weather allows a longer infestation period, and early spring melt produces favourable conditions for the reproduction and survival of ticks (Telfer 1984). Telfer (1984) observed these conditions in southern Alberta where a heavy tick load has been associated with increased mortality and may be limiting moose populations and distribution. Similar conditions may exist in other areas at the southern limit of moose range such as Nova Scotia.

Environmental contaminants and nutritional deficiencies have also been linked to moose disease/mortality and population declines. Elevated levels of heavy metals and trace metal imbalances due to environmental contamination may be contributing to moose mortalities in Nova Scotia (Nette 2000). Industrial pollution causes soil acidification and increased cadmium availability (Scanlon et al. 1986, Outridge et al. 1994, Selenius et al. 1996, Frank & Galgan 1997, Selenius & Frank 2000, Freedman 2001). At high levels, cadmium may have toxic effects on the central nervous and reproductive systems of moose (Scanlon et al. 1986). Outridge et al. (1994) determined that mammals are at risk when kidney cadmium concentrations exceed 30 mg/kg. Moose kidneys collected in Nova Scotia between 1998 and 2000 have shown cadmium concentrations as high as 148 mg/kg (wet weight, 7 year old animal), well beyond the level considered to be safe, and much higher than levels recorded in neighbouring jurisdictions (Nette 2000). Elevated cadmium levels may be a factor contributing to high rates of moose calf mortality in the southwestern region of the province (Nette 2000).

In areas with little buffering capability, soil acidification is associated with decreasing copper availability due to leaching (Frank et al. 1994, Frank & Galgan 1997). This may result in copper deficiency among moose, causing symptoms similar to those of *P. tenuis* including atrophy, neurological disease, impaired vision, emaciation, motor disturbances, circling, convulsions, and death (Frank et al. 1994, Selenius et al. 1996, Frank 1998). Interestingly, an increase in pH, as occurs with liming treatment to counter the effects of acidification, may also decrease the availability of copper in soil and cause copper deficiency, the effects of which are compounded by an increase in environmental molybdenum, which also results from liming (Frank et al. 1994, Frank & Galgan 1997, Frank 1998). Further investigation is required to provide conclusive evidence regarding moose mortality due to cadmium toxicity or copper deficiency in Nova Scotia (Nette 2000).

Hunting and Predation

Hunting pressure has been the cause of major moose declines in Nova Scotia and elsewhere (Dodds 1974, Bontaites & Gustafson 1993), and has been responsible for maintaining low population densities or for extirpation in some portions of traditional moose range (Telfer 1984, Wolfe 1987, Duinker et al. 1996). Due to declining populations, the hunting season was closed in 1937 in the western and central portions of mainland Nova Scotia, while some eastern counties periodically opened the hunt until 1981 (Dodds 1963, Nette 2000). Although there is currently no legal harvest of moose on the mainland, with the exception of that by First Nations, there is evidence to suggest that a few animals are illegally taken on a yearly basis, especially in the Cobequid Hills where more roads provide easier access (Nette 2000). Thus, it remains possible that poaching is among the factors affecting moose populations (Dodds 1963, Wolfe 1987, Pulsifer 1995, Chubbs & Schaeffer 1997, Nette 2000).

Although wild predators are rarely responsible for local extirpation of prey species (because to do so would be maladaptive), heavy predation in combination with other factors such as disease, severe winters, and marginal range may limit populations and perhaps cause declines and extirpation (Telfer 1984). It has often been assumed that due to the absence of wolves, predation has had little effect on moose populations in Nova Scotia (NSDLF undated, Benson 1957, Dodds 1974). However, it has been recently recognized that black bear predation can be a significant calf mortality factor, and can potentially restrict populations in areas of low population density (Wright 1956, Messier & Crete 1984, Franzmann & Schwartz 1986, Fowler 1987, Karns 1987, Larsen et al. 1989, McNicol 1990, van Ballenberghe & Ballard 1994, Bontaites & Gustafson 1993, Pulsifer 1995, Stenhouse 1995, Chubbs & Schaeffer 1997). Low-density moose populations are sympatric with stable black bear populations throughout their range in Nova Scotia (Nette 2000); thus, black bear predation of calves may be a potentially significant limiting factor.

Population Viability

Natural populations are subject to stochastic and deterministic factors which influence birth and death rates and lead to fluctuations in population size. Small, isolated populations are especially vulnerable to extinction in the face of demographic, genetic and environmental changes (Diamond 1976, Terborgh & Winter 1980, Shaffer 1981, Newmark 1985, Samson et al. 1985, Gilpin & Soulé 1986, Gilpin 1991, Henriksen 1997). Population viability assessment (PVA) has become a popular tool in wildlife conservation, and is used to determine the minimum viable population size (MVP) (Shaffer 1990, Boyce 1992, Theberge 1993, Lacy 1993/94, Reed et al. 1986, 1998). MVP represents the population size below which the probability of extinction is unacceptably high, but at or above which the probability of extinction is reduced to an acceptable level over a given time period (Samson 1983, Gilpin & Soulé 1986, Lacy 1993/94, Henriksen 1997). To obtain a useful and reliable prediction of MVP through PVA, detailed information is required on species demography, ecology, genetics, and habitat relationships, as well as local environmental conditions and variability. In many cases, these data are not available; however, some general rules have been developed based primarily on genetic considerations and are supported by empirical and experimental evidence (Franklin 1980, Soulé 1980, Shaffer 1981, 1983, Brussard 1985, Samson et al. 1985, Lande 1987, Berger 1990, Thomas 1990, Henricksen 1997). For short-term viability (a few decades), a minimum effective population of 50 individuals is required to avoid inbreeding depression; however, to avoid the long-term (centuries) loss of genetic variability through drift, a population should include at least 500, or even 5000, individuals. Furthermore, these estimates only refer to the genetically effective population (N_e) which represents the number of randomly breeding individuals, and is often much lower than the actual census population (N) (Franklin 1980, Brussard 1985, Newmark 1985, Samson et al. 1985, Henriksen 1997).

Preliminary MVP figures have been calculated for moose in mainland Nova Scotia (Beazley 1998, Snaith 2001). Because the information required for a reliable PVA is unavailable, these figures are estimates based on the general assumption that 500 breeding individuals are enough to ensure long-term viability (Franklin 1980). A ten-to-one relationship between N and N_e was applied based on calculations made for moose elsewhere (Ryman et al. 1981, Arsenault 2000). Using this 10% relationship, it follows that for an effective population size of 500 moose, an actual minimum viable census population of 5000 individuals is required to ensure long-term persistence. The current population of 1000 moose, fragmented among a number of smaller and isolated populations, is not enough to ensure the persistence of moose over the long term (Snaith 2001, Snaith & Beazley 2003).

In order to address conservation problems, MVP requires spatial application; in other words, the amount of habitat required to support the MVP must be calculated. The minimum critical area (MCA) represents the minimum amount of suitable habitat required to support the population, and is calculated based on the number of individuals and their area requirements or population density (Soulé 1980, Shaffer 1981, Lehmkhul 1984, Newmark 1985, Metzgar & Bader 1992, Theberge 1993, Doncaster et al. 1996, Arsenault 2000).

For moose in Nova Scotia, MCA can be calculated using the MVP size, multiplied by the area requirements (home range size) of each individual or by dividing MVP by the average regional population density (Shaffer 1981, Newmark 1985, Theberge 1993, Doncaster et al. 1996, Beazley 1997, 1998, Snaith 2001). Based on local average home range sizes (30-55 km^2) and density (0.05/km^2), MCA for long term viability was calculated as 100 000 to 200 000 km^2 (Snaith 2001, Snaith and Beazley 2003). The total area of mainland Nova Scotia is about 45 000 km^2. Clearly, if these calculations are correct, Nova Scotia is not large enough on its own to maintain a viable moose population over the long term. Connectivity among local moose populations and to those in New Brunswick is essential for the maintenance of moose in Nova Scotia.

Conclusion

Mainland Nova Scotia moose populations have been considerably reduced from pre-Euro-American contact levels and may currently be declining due to a number of factors including habitat conversion, degradation, and fragmentation, interspecific competition, disease, environmental contamination, predation, and poaching. Although the causes of the decline of moose in Nova Scotia remain ambiguous, it is clear that the population has dropped to levels low enough to place them at risk. Because Nova Scotia moose populations are small and isolated, they are particularly susceptible to further reductions through genetic, demographic, or environmental fluctuations.

Currently, the Nova Scotia mainland does not support a moose population large enough to persist for the long term, nor does it contain enough area to support such a population in isolation. In order to ensure the persistence of moose in Nova Scotia, conservation efforts should concentrate on the following:

i. maintaining and enhancing all seasonally critical habitat elements (including forage, thermal and escape cover, calving areas, winter yards, and water bodies) in and around areas where moose currently exist;

ii. designing forestry management strategies to maintain and enhance sufficient thermal cover and interspersion of habitat elements;

iii. increasing understanding, through empirical research, of potential population limiting/regulating factors;

iv. reestablishing habitat connectivity for dispersal/migration between the two mainland populations to allow genetic exchange which will increase the effective population size;

v. restoring the critical habitat area and components required to support an increase in the population to long-term MVP level: habitat restoration should aim to improve the quantity of habitat (to support more individuals on a larger area) and the quality of habitat (to support a larger population on the same area at higher densities); and,

vi. reestablishing habitat connectivity with New Brunswick to allow dispersal and migration to increase gene flow and to further increase effective population size over the long term; this will also allow opportunities for responses to climate change.

In light of the information presented in the literature, as well as what is known about moose in mainland Nova Scotia, further attention to their distibution, status and habitat associations is warranted.

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Appendix 1 **Critical Habitat Components**

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
NSDLF undated	Nova Scotia		Aquatics		Salt licks spring
Telfer 1967a	Nova Scotia - Cobequids			Winter yards on upper SW facing slopes. Have patches of dense mature forest critical for shelter and open areas (20 years old cut) with good forage	
Telfer 1967b	Nova Scotia - Cobequids			Winter yards with dense softwood for cover and open areas with diverse species for food	
Prescott 1968	Nova Scotia - N. mainland			Concentrate in areas with diverse vegetation types for combination of food and shelter. Like high elevation, usually boundary of softwood and hardwood forests	
Wright 1956	New Brunswick	Secondary vegetation from disturbances such as fire, insect outbreaks, blowdowns - good after a few years, peak after 40y. Aquatics	Aquatics	Diverse tree species	Mineral licks

Appendix 1 cont'd

Source	**Site**	**General**	**Summer (Spring/Fall)**	**Winter**	**Special Components**
Telfer 1968a	New Brunswick	Cover adjacent to food areas	Forage rich areas and shelter providing dense forest	Early winter -dense hardwoods and open softwood food producing areas. Late winter shelter is critical - use dense softwood or dense cover mixedwood stands with little browse availability so edges of adjacent food areas also used	
Telfer 1970a	New Brunswick			Early winter deciduous cover and open areas for food Late winter dense conifer for cover related to snow depth	
Leptich & Gilbert 1989	Maine		Aquatic vegetation and cutover areas		
Crossley & Gilbert 1983	Maine		Lowland areas, aquatic areas, Cedar stands for cover	Upland areas	
Leptich & Gilbert	Maine				Calving sites - 1986 secluded, undisturbed, forested, near water, browse availability
Dunn 1976	Maine		Aquatic feeding and ponds for heat stress Softwood cover and mixed orest		

Thompson et al. 1995	Maine		Aquatics and mature hardwood and mixedwood stands	Mature conifer stands for cover. 10 - 30 year old cutovers for forage (with residual cover)	
Bontaites & Gustafson 1993	New Hampshire		Males - mature hardwood in summer, clearcuts in fall Females - clearcuts and wetlands in summer mature hardwoods in fall	Mixed wood stands	Salt licks - most animals will elongate HR to include
Banfield 1974	Canada		Higher altitudes Aquatic vegetation	River edges Valleys Shrubby open woodland	
Kelsall 1987	North America review article				
Jordan 1987	Review article		Aquatic food is an important source of sodium		
Albright & Keith 1987	Newfound-land		Open barrens	Wooded sites with mature conifers but little food. Cover is critical in severe winters.	
Crete & Jordan 1982	Quebec			Late winter closed canopy	
Joyal & Scherrer 1978	Quebec		Aquatic vegetation		
Joyal 1987	Quebec	Disturbances increase browse production	Ponds and bogs with aquatic food	Mixed forests with conifer cover	
Brassard et al. 1974	Quebec	Diversity, interspersion, early succession			

Appendix 1 cont'd

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
Kearney & Gilbert 1976	Ontario		Waterways and beaver ponds Open areas with forage Late summer taller forest for thermal cover	Forage is important	
Forbes & Theberge 1993	Ontario			Local scale: critical winter cover closed canopy conifer forest Regional scale: disturbance 33% of area for browse availability	
deVos 1958	Ontario		Aquatic veg important all summer June to October		
Puttock et al. 1996	Ontario		Aquatics. Early succ. tree species for high quality forage Disturbed open areas Mature mixed forests	Mature stands Cover near forage Conifer-dominated stands with dense canopies 1-20 years old stands with <30% stocking Conifer stands >20yo with <50% canopy closure Avoid open areas	Calving sites: islands, peninsulas, elevated locations
Thompson & Vukelich 1981	Ontario			Cover is critical, stay within 12m of cover	
Thompson & Euler 1987	Ontario	Coniferous cover for thermal stress and escape	Early successional habitat for food Aquatic feeding sites for sodium	Mature stands of coniferous cover Yarding areas	Calving sites Mineral licks

McNicol & Gilbert 1987	Ontario	Mature forests continually produce moose habitat through natural disturbances such as fire, disease, and blowdowns.			
Allen et al. 1987	Lake Superior region (HSI modeling)	Habitat interspersion and species diversity	Wetlands with aquatic forage rich in sodium Mature dense conifer cover for heat stress Early succ. veg for forage	Cover is critical - dense conifer or mixed stands Early succ. veg for forage Mosaic of shelter and food. In very deep snow will select for cover even if no food	Mineral licks Calving sites - isolated, near water, dense vegetation
Peek 1974b	W. North America			Riparian areas and willows	
Hauge & Keith 1981	Alberta		Spring - open lowlands are critical Summer - open uplands	Early winter- lowlands Late winter - forested uplands	
Mytton & Keith 1981	Alberta	Avoid human disturbance	Open areas, aspen islands, muskegs	Tall, dense forest	
Quinlan et al. 1990	Alberta	Scattered coniferous shelter interspersed with browse-producing areas			
Eastman 1974	British Columbia	Forests and small scale disturbances	Selectively logged areas for forage	Burns and partial cutovers for forage in early winter. Forests for shelter in late winter	
Eastman & Ritcey 1987	British Columbia	Early serial stages Riparian habitat	Cover from heat stress Forage in open areas at higher elevations Aquatic vegetation	Cover, especially in areas with deep snow	Calving sites

Appendix 1 cont'd

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
Demarchi & Bunnell 1995	British Columbia		Summer thermal cover very important for weight gain and winter survival		
Schwab 1985	British Columbia		Spring - open for forage Summer - closed forest for heat stress	Early winter - open for forage Mid/Late winter - heavy forest cover	
Sumanik & Demarchi 1977	British Columbia			Riparian habitat have food, cover and less snow for easy travel	
Bowyer et al. 1999	Alaska				Calving sites with high quality forage and good cover for predator protection
Collins & Helm 1997	Alaska		Early succ. habitat	Early shrub for forage Old poplar for browse and cover	
Doerr 1983	Alaska	Clearcut forests and riparian habitat		High volume old growth conifer forest Riparian shrub	
Miquelle et al. 1992	Alaska	Willows heavily used for forage	Females select cover for predator protection Males select open areas for browse	Forest thermal cover critical especially for females	Forested calving sites

MacCracken et al. 1997	Alaska	Landscape scale select for forage availability cover HR scale select for cover and forage or primarily	Aquatic plants		
Taylor & Ballard 1979	Alaska	Spruce dominated forest interspersed with willows or scrub birch		Valley bottoms are winter concentration areas	Forested spruce dominated calving sites
Oldemeyer & Regelin 1987	Alaska	Prefer early succ. stages. Mature forest and river valleys can support small pops.			
Krefting 1974	NC North America		Disturbed areas with early seral vegetation	Conifer cover	
Ackerman 1987	Michigan		Mature forest cover from heat stress Water bodies		
Peek et al. 1987	Idaho		Variability in cover types Occasional use of lakes and ponds	Old growth, double canopy conifer stands with understory shrubs Riparian zones	
Pierce & Peek 1984	Idaho	Select habitat for abundant forage Old growth important	Even aged pole timber stands and open areas including clearcuts	Dense old growth stands are critical for cover and forage	
Peek et al. 1976	Minnesota		Aquatics Sparsely stocked forest stands	Dense conifer cover from deep snow	
van Ballenberghe & Peek 1971	Minnesota		Swampy and upland forest Aquatic feeding sites	Dense habitat during rapid snow accumulation	

Appendix 1 cont'd

Source	**Site**	**General**	**Summer (Spring/Fall)**	**Winter**	**Special Components**
Phillips et al. 1973	Minnesota		Low open habitat provides first green vegetation. Not much use of aquatics	Dense aspen cover from snow depth	
Berg & Phillips 1974	Minnesota	Willows are an important food species	Low willow habitat	Tall willows and deciduous and coniferous forests. Need for cover correlated with snow depth	
Knowlton 1960	Montana	Prefer uplands >7500 ft.	Higher elevations with green up Subalpine meadows and willow bottoms Coniferous forest for rest and escape cover	Forced to lowlands due to snow depth Winter concentrations in willow bottoms along waterways Coniferous forest for snow cover	
Houston 1968	Wyoming	Dense willow important year round Climax conifer forest has cover and food Floodplain forest veg	Grasslands with forbes and grasses important spring and early winter	Spruce/fir and floodplain forest	
Towry 1984	Colorado	Willows Aquatic plants, upland shrubs, forbes and grasses			Calving sites - thickets, dense vegetation near openings and water

Bobek & Morow 1987	Poland	Forest cutting creates browse production		
Cederlund & Markgren 1987	Sweden	Young deciduous vegetation and Scots Pine are most important moose foods in Europe		Young pine forests have good quality winter browse
Cederlund & Okarma 1988	Sweden	Clearcuts, young and medium aged forests preferred Avoid mature stands and bogs		
Strandgaard 1982	Sweden			Dense forest edges for cover Open areas 0-40 years old for forage Old forest 40-60 years old for cover and forage
Hjeljord et al. 1990	Norway	Diversity of habitat and food types		
Heikkila et al. 1996	Finland	Forested peatlands	Old and middle aged forests with lots of undergrowth and edge	Closed forest

Appendix 2 Moose Food Preferences by Species

Source	Site	Food Species
Benson 1957	Nova Scotia	**Winter:** Fir (Abies spp.) White birch (Betula papyrifera) Yellow birch (Betula alleghaniensis) Beaked hazelnut (Corylus cornuta) Maples (Acer sp.) **Available but not eaten:** Spruce (Picea sp.) Wire birch (Betula sp.) Beech (Fagus grandifolia)
Prescott 1968	Nova Scotia N. mainland	Mountain maple (Acer spicatum) (25.5% of diet; 15.9% of available food) Yellow birch (Betula lutea) (19.9%; 9.5%) Sugar maple (Acer saccharum) (16.5%; 15%) Balsam fir (Abies balsamea) (13.6%; 16.2%) Red maple (Acer rubrum) (8.5%; 6.4%) Hazel (Corylus cornuta) (6.1%; 2.5%) Elderberry (Sambucus pubens) (1.4%; 2.2%) Striped maple (Acer pensylvanicum) (1.4%; 0.9%) White birch (Betula papyrifera) (1.2%, 2.1%) Honeysuckle (Lonicera canadensis) (1.1%; 6.8%) Beech (Fagus grandifolia) (0.9%; 1.6%) Blackberry (Rubus allegheniensis) (0.7%; 0.6%) Hobblebush (Viburnum alnifolium) (0.6%; 0.2%) Cornus spp. (Cornum spp.) (0.6%; 0.8%) Raspberry (Rubus stringosus) (0.6%; 12.2%) Cherry (Prunus pensylvanica) (0.5%; 1.8%) Willow (Salix spp.) (0.5; 0.1) imp. at low elev. Ribes spp. (Ribes spp.) (0.1%; 2.3%) **Available but not eaten:** Red spruce (Picea rubens) White ash (Fraxinus americana) Yew (Taxus canadensis) Mountain Ash (Sorbus americana) Speckled Alder (Alnus rugosa) Blueberry (Vaccinium myrtilloides) White spruce (Picea glauca) Rose sp. (Rosa sp.)
Telfer 1967a	Nova Scotia Cobequids	**Winter concentration areas:** Balsam fir (Abies balsamea) White birch (Betula papyrifera) Yellow birch (Betula alleghaniensis) Sugar maple (Acer saccharum)
Telfer 1967b	Nova Scotia Cobequids	**Winter** Maples (Acer rubrum, A. saccharum, A. spicatum) (50% of diet) Yellow birch (Betula alleghaniensis) (18%) Balsam fir (Abies balsamea) (small amount)

Appendix 2 cont'd

Source	Site	Food Species
		Abundant but not eaten Raspberry (Rubus strigosus)
Basquille & Thompson 1997	Nova Scotia Cape Breton Highlands	**Ordered by preference index** White birch (Betula papyrifera) Balsam fir (Abies balsamea) Mountain ash (Sorbus americana) Shadbush (Amelanchier sp.) Sugar maple (Acer saccharum) Striped maple (Acer pensylvanicum) Red maple (Acer rubrum) Speckled alder (Alnus rugosa) Mountain maple (Acer spicatum) Elderberry (Sambucus pubens) White ash (Fraxinus americana) Beech (Fagus grandifolia) Pin cherry (Prunus pensylvanica) Balsam poplar (Populus balsamifera) White pine (Pinus monticola) Wild raisin (Viburnum cassinoides) Ironwood (Ostrya virginiana) White spruce (Picea glauca) Black spruce (Picea mariana) Currant (Ribes sp.) Hemlock (Tsuga sp.) Larch (Larix sp.) Yellow birch (Betula alleghaniensis) White elm (Ulmus americana) Red Oak (Quercus rubra) Jack pine (Pinus banksiana) Trembling aspen (Populus tremuloides)
Telfer 1968a	New Brunswick	**Early winter:** Red maple (Acer rubrum) Wild raisin (Viburnum cassinoides) Striped maple (Acer pensylvanicum) Beaked hazel (Corylus cornuta) Mountain maple (Acer spicatum) Sugar maple (Acer saccharum)
Wright 1956	New Brunswick	**Winter: Heavy use:** Gray birch (Betula populifolia) Yellow birch (Betula alleghaniensis) White birch (Betula papyrifera) Red maple (Acer rubrum) Striped maple (Acer pensylvanicum) Willow (Salix sp.) Aspen (Populus sp.) White cedar (Thuja sp.) Viburnum (Viburnum sp.) Cherry (Prunus sp.) Hard maple (Acer sp.)

Appendix 2 cont'd

Source	Site	Food Species
		Leatherleaf (Chamaedaphne calyculata) **Slight/moderate use:** Balsam fir (Abies balsamea) Alder (Alnus sp.) White pine (Pinus monticola) Raspberry (Rubus sp.) Silver maple (Acer saccharinum) Hazel (Corylus cornuta) Oak (Quercus sp.) **Present but NOT eaten:** White spruce (Picea glauca) Black spruce (Picea mariana) Tamarack (Larix laricina) Hemlock (Tsuga sp.) Beech (Fagus grandifolia) Shadbush (Amelanchier sp.)
Crete 1987	Quebec Gaspe Peninsula	**Winter:** White birch (Betula papyrifera) (49% of diet; 7% of available biomass) Balsam fir (Abies balsamea) (19%; 88%) Mountain maple (Acer spicatum) (10%; 1%) Amelanchier (Amelanchier sp.) (9%; 2%) Red-osier dogwood (Cornus stolonifera) (6%; 1%) Cranberrybush (Viburnum edule) (3%; 1%) Willow (Salix sp.) (2%; <1%) Mountain ash (Sorbus americana) (1%; <1%) Alder (Alnus crispa) (1%; <1%) Quaking aspen (Populus tremuloides) (<1%; <1%) Pin cherry (Prunus pensylvanica) (<1%; <1%)
Raymond et al. 1996	Maine	Paper birch (Betula papyrifera) Pin cherry (Prunus pensylvanica) Aspen (Populus tremuloides and P. grandidentata) Red maple (Acer rubrum) Yellow birch (Betula alleghaniensis) Striped maple (Acer pensylvanicum) Sugar maple (Acer saccharum) Mountain maple (Acer spicatum) Willow (Salix sp.) Mountain ash (Sorbus americana) Balsam fir (Abies balsamea)
Crossley & Gilbert 1983	Maine	**Winter:** Balsam fir (Abies balsamea) Quaking aspen (Populus tremuloides) Paper birch (Betula papyrifera)
Telfer 1984	Atlantic Canada and New England	Mountain maple (Acer spicatum) Striped maple (A. pensylvanicum) Wild raisin (Viburnum cassinoides) Witch Hazel (Hammalis virginiana)

Appendix 2 cont'd

Source	Site	Food Species
		Blueberry (Vaccinium sp.) Fir (Abies sp.) Birch (Betula sp.) Aspen (Populus sp.)
Banfield 1974	Canada	**Winter:** Willows (Salix spp.) Balsam fir (Abies balsamea) Red-osier dogwood (Cornus stolonifera) Mountain ash (Sorbus americana) Aspen (Populus grandidentata) Birch (Betula spp.) Beaked Hazel (Corylus cornuta) Balsam (Abies balsamea) Poplar (Populus balsamifera) Pin Cherry (Prunus pensylvanica) Maple (Acer spp.) Viburnum (Viburnum spp.)

Some species/common names from Rowe (1972)

Appendix 3 Forestry and Management Recommendations

Source	Site	Forestry and Management
Prescott 1968	Nova Scotia - N. mainland	Small scale disturbances like selective cutting are beneficial to moose because openings produce browse while maintaining enough cover. Bigger clearcuts not good because regeneration is poor, edges of remaining cover sustain wind damage, monoculture regeneration is no good.
Telfer 1968a	New Brunswick	Cuttings adjacent to winter shelter will provide winter food. Moose will not make use of forage in large open areas. Need detailed local information on moose habitat selection and ranging patterns.
Telfer 1970b	New Brunswick	60-80% of an area should be >35 years old at all times. Need information on moose distribution and key habitat areas for consideration in forest management operations. Clearcut patches or strips <100 feet wide and arranged to ensure adequate cover remains near forage production areas.
Kelsall 1987	North America	review article Some management can improve habitat and allow expansion of moose range.
Joyal 1987	Quebec	Logging provides short term benefit of increased browse production, peaks 5-15 y after cut. Leave ten 2-3 ha stands per 10 km^2 . Consider suitability of planted species. Large clearcutting reduces habitat, and if few small clumps of cover left behind, moose are trapped and vulnerable and must compete for small remaining areas.
Brassard et al. 1974	Quebec	Logging provides only short term benefits of early successional forage. Production of monocultures is poor moose habitat.
Thompson et al. 1995	Maine	Moose will use cuts 10 to 30 years old for forage only if residual softwood stands remain for cover
Hogg 1990	Ontario	Large cuts >100ha must include shelter patches of 3-8ha or be shaped so never more than 200m to cover. Harvesting and access roads located with care to avoid critical habitat components such as calving areas and aquatic feeding sites.
Thompson & Vukelich 1981	Ontario	Moose use cuts after 18y post cut Cows with calves rarely more than 60m from cover

Appendix 3 cont'd

Source	Site	Food Species
Thompson & Euler 1987	Ontario	Large clearcuts with successional vegetation not as useful as small ones Must leave some uncut areas
McNicol & Gilbert 1987	Ontario	Irregular shaped cuts Scattered shelter patches Stands with diverse age/ species composition
Hamilton et al. 1980	N. Ontario	Use of clearcuts restricted to areas within 80m of cover
Allen et al. 1987	Lake Superior region	(HSI modeling) Ideal year round habitat: 40-50% of area is sites with (50% shrub or young forest <20yo 5-15% conifer >20yo 35-55% deciduous or mixed forest >20yo 5-10% wetlands with aquatic foods Food within 100m of cover
Tomm & Beck 1981	Alberta	Moose use of cutblocks depends on the size of the cut, the interspersion of mature stands within the cut and levels of harassment. Prefer cuts 0.17 to 0.32 km^2 which are buffered from other openings by 200 to 400m of forest
Eastman 1974	British Columbia	Recent clearcuts least used. Partially logged stands or burns 11-20 years old are important.
Telfer 1995	Western Canada	Stand conversion to conifers with control of deciduous vegetation may limit moose numbers Uncontrolled human access may also limit numbers
Doerr 1983	Alaska	Moose use cuts <30 years post cut
Oldemeyer & Regelin 1987	Alaska	Manage large areas (2000ha management units). Intersperse undisturbed areas (40%) with disturbances.
Peek et al. 1987	Idaho	Moose did not use logged/open areas much even when available so management for early successional browse will not be effective for creating habitat. Must retain at least 55% of area in mature forest. Road closure following completion of operations.
Pierce & Peek 1984	Idaho	Avoid timber harvest in old-growth forest.
Peek et al. 1976	Minnesota	Manage township sized areas with 40-50% cutover with <20yo regeneration; 5-15% spruce/fir cover; 35-55% aspen-white birch >20y and water Cuts create browse but if plant with dense stocking or use herbicides or unfavoured species then habitat and browse decrease

Appendix 3 cont'd

Source	**Site**	**Food Species**	
Houston 1968	Wyoming		Human development will cause decreasing forage availability ie. through road construction and campsite development
Cederlund & Markgren 1987	Sweden		Clearcuts can provide high quality forage.
Strandgaard 1982	Sweden		Clearcuts produce forage but pesticides decrease food availability. Older forest and dense edges also important.
Hjeljord et al. 1990	Norway older forests.		Benefit of a heterogeneous mixture of plantations and
Heikkila et al. 1996	Finland		(Managed forest) Logging areas produce patchy habitat with lots of food over a long period
Kusnetsov 1987	USSR		Cutting creates more habitat /forage and can increase population density beyond CC which becomes detrimental to habitat / forage /forest regeneration

Appendix 4 Moose Population Densities, Area Requirements, and Ranging Behaviour

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
NSDLF undated*	Nova Scotia			5.18 to 25.9 km^2 and much larger if resources are scarce		
Telfer 1968b*	Nova Scotia	High density areas: 0.46 / km^2 (Cobequids and Pictou-Antigonish highlands) Medium density: 0.05/km^2 (Tobeatic and adjacent to high density areas) Low density: 0.02				
Prescott 1968*	Nova Scotia N mainland	Ave: 0.22 / km^2 High density areas: 0.48 / km^2 >80% of population is in upland areas	Hunting - but maintaining high density population levels			
Pulsifer & Nette 1995	Nova Scotia	Cobequids: 0.01 - 0.12/ km^2 Tobeactic: 0.35 / km^2 in some areas but likely much lower in most areas				

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Pulsifer 1995	Nova Scotia	Mainland 1995: 0.08 / km^2 1969s: 0.46 / km^2 Cape Breton 1995: 1 to 2.8 / km^2	*P. tenuis* Deer competition Poaching Habitat fragmentation by forest management Black bear predation			
Wright 1956	New Brunswick		Deer competition may limit food availability (some overbrowsing seen in shared range)			
Crete 1987	Eastern Quebec Gaspe Peninsula	1.8 - 2.0 / km^2	No hunting Bear / wolf predation Not food limited because below calculated K. Regulated by predation	(M) 31.2 km^2 (F) 26.1 km^2		Sed
Crete 1989	Eastern Quebec Gaspe Peninsula	1.8 - 2.0 / km^2 Record high for Quebec vs. Just to north and south of study area 0.1 / km^2	No hunting Limited predation High food availability vs Hunting pressure			

Crossley & Gilbert 1983	Maine Rolling mountains with lowlands and bogs. Mosaic of vegetation			Su: 25.79 km² Wi: 3.37 km²	Range fidelity Some individuals have separate seasonal ranges, others summer range is extension of winter core
Leptich & Gilbert 1989	Maine			Su: 25.2 km² (varies from 2 - 60 km²)	Home range fidelity
Thompson et al. 1995	Maine			Su: 15-30 km² (varies from 5-126 km²) Au: 3 km² Wi: 7.1 km² (non snow restricted year) 1.5 km² (snow restricted)	Seasonal ranges overlap or are within 7 km
Raymond et al. 1996	Maine Timber management area with mixture of clearcuts, partial harvests, regeneration, older second growth	1.2-1.8 / km²			
Dunn 1976*	Northcentral Maine Mountainous with lakes, ponds and watercourses		51 km²	Su: 18 km² Wi: 4.7 km² Au: 39 km²	

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Bontaites & Gustafson 1993	New Hampshire		Black bear predation Other calf mortality	M 93 km^2 F 153 km^2		
Banfield 1974*	Canada	0.77 / km^2 Winter concentrations up to 3.9 / km^2	Winter range restriction and severe food competition with deer			
Post & Stenseth 1998	North America		Direct/indirect/ cumulative effects of climate and snow depth effects predation and winter food availability			
Albright & Keith 1987	Newfoundland Barrens Poor winter range	960-1973 decline from >1.9 / km^2 to 0.8 / km^2 11973-1983 maintained at low density of 0.8 / km^2	Annual harvest Low productivity due to poor winter range/ nutrition and severe winter weather Pop maintained due to high calf survival because no predators			Distinct seasonal ranges up to 10 km apart
Chubbs & Schaefer 1997	Labrador	0.013 to 0.168 / km^2	Hunting Predation by wolves, black bears and possibly lynx.			
Brassard et al. 1974	Quebec	Large parts of Quebec <0.04 but up to >0.3/ km^2 in small areas				

Crete & Courtois 1997 (data from previous work)	Quebec-Labrador Peninsula	0.4/ km²	Predation by wolves and bears. Low habitat productivity.			
Crete & Courtois 1997	Northern Quebec	<0.1 / km² study area 0.033 / km²	Low habitat productivity limited forage availability. Also climate changes and drowning affect this low density pop without predators.	(M) 112 km² (F) 171 km²	Su: (M) 67.1 km² Su: (F) 90.1 km² Wi: (M) 39.0 km² Wi: (F) 60.2 km² (M-F sig.)	7 moose: distinct seasonal ranges 8 moose: overlapping seasonal ranges
Messier & Crete 1984	Southwest Quebec	Stable at 0.37 / km² (equilibrium density) Lower density harvested populations 0.17-0.22/km²	Not harvested Not food limited Wolf and bear predation - likely regulated by predation			
Joyal & Scherrer 1978	Western Quebec	0.04 / km²				Distinct seasonal ranges
McNicol 1990	Ontario		Habitat quality affects HR size	20 to 40 km²		
Puttock et al. 1996	Ontario -Algonquin Irregular topography, mixed forests, lakes, logging activity	1975: 0.2 to 0.3 / km² 1983: 0.4 - 0.7 / km² 1996: 0.8 / km²	Increase associated with decline in deer.			
Thompson & Vukelich 1981	Ontario				Wi: (FC) 0.2-2.5 km²	
Thompson & Euler 1987	Ontario	0.30 - 0.35 / km²	Predation by wolves. Forestry may limit late winter habitat. Sodium availability.			

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Arsenault 2000	Saskatchewan	0.29 / km^2 in good habitat 0.05 / km^2 in poorer habitat 0.07 / km^2 in poor habitat with agricultural areas				
Mytton & Keith 1981	Alberta	0.64 / km^2 in winter	No large predators No legal hunting		Su and Wi: approx 15 km^2	Mig and Sed Mig: seasonal ranges separated by (M) 13km (F) 7km
Hauge & Keith 1981	Northeast Alberta Boreal forest. Forested uplands, more open lowlands.	0.18 / km^2	Hunting. Predation by wolves.	Sed 97 km^2	Mig Su and Wi: each >20 km^2	24% Sed with overlapping seasonal ranges 76 % Mig, of these 38% distinct ranges sep. by 6km, and 62% Mig >20 km
Lynch & Morgantini 1984	Northcentral Alberta Undulating topography varied elevation and habitat in boreal environment. High degree of habitat interspersion.	0.7 to 1.6 /km^2	Food limited because widely dispersed patches. Winter browse is limited. Predation by wolf grizzly bear and black bear. Hunting		Su: (M) 22.1 km^2 Su: (F) 22.7 km^2 Su: (JM) 25.9 km^2 Su: (JF) 7.5 km^2 Su: (YM) 29.7 km^2 Su: (YF) 4.9 km^2 Au: (M) 26.1 km^2 Au: (F) 15.4 km^2 Au: (JM) 47.9 km^2	

					Au: (JF) 10.9 km^2 Wi: (M) 51.6 km^2 Wi: (F) 46.8 km^2 Sp: (M) 33.2 km^2 Sp: (F) 25.6 km^2	
Eastman & Ritcey 1987	British Columbia	0.3 / km^2 of moose range provincially. Varies from coast <0.07 / km^2 to boreal upland 0.7 / km^2				
Larsen et al. 1989	Yukon	0.19-0.25 / km^2	Some hunting Predation by grizzlies and wolves is major limiting factor preventing population increase			
Stenhouse 1995	NWT Mackenzie Valley. Low relief, northern boreal orest, a lot of early successional stage forest, also open and closed bog forest, lakes, streams and bogs	0.14 to 0.16 /km^2	Predation by wolf and grizzly bear. infer possibly limited by forage because of low pop density and large HR.	(F) 203 km^2 (40 to 942 km^2)	Au (F) 132.2 km^2 Wi (F) 57.58 km^2 Su (F) 68.35 km^2	Sed Overlap of seasonal HR.
Doerr 1983*	Southeast Alaska Varied terrain, lots of coniferous forests with productive understory	2.3 / km^2		40.3 km^2	Su: 2.1 km^2 Wi: 9.3 km^2	Mig. and Sed Sed individuals have overlapping seasonal ranges

Appendix 4 cont'd

Source	**Site and Physical Characteristics**	**Population Density and Local/Seasonal Variations**	**Limiting/ Regulating Factors**	**Annual Home Range**[1]	**Seasonal Home Range**[1]	**Seasonal Range Overlap**[2] **and Migrations and Range Fidelity**
Taylor & Ballard 1979	Alaska Susitna River Basin Forested mountainous terrain and tundra above timberline.			295.7 km^2 (43 to 1104 km^2)	Su: 55.7 km^2 (10 to 319 km^2)	Mig or Sed (in different areas) Mig.>150 km fidelity to migratory routes
Ballard et al. 1991	Alaska, Susitna River Basin	0.71 - 0.844 / km^2	Predation, especially brown bear but also wolf Severe winters	Mig: 505 km^2 Sed: 290 km^2	Mig Su: 263 km^2 Mig Wi: 151 km^2 Mig Au: 322 km^2 Sed Su: 103 km^2 Sed Wi: 113 km^2 Sed Au: 157 km^2	Mig and Sed. Seasonal range fidelity F philopatry M dispersal
Miquelle et al. 1992	Southcentral Alaska Denali National Park and Preserve Variable habitat, rivers and varied elevation	0.9 / km^2	Predators No hunting			
MacCracken et al. 1997	Coastal southcentral Alaska Copper River delta Delta wetlands and glacial outwash,	0.4 / km^2 (but thought to be below carrying capacity which is estimated at 0.5 - 2 / km^2) With local winter concentrations in two areas	Hunting Predation of calves by brown bears	59 ± 5 km^2	Su: 55 ± 5 km^2 Wi: 60 (7 km^2	Sed and Mig Sed: Seasonal range fidelity with >50% overlap of seasonal ranges

	highly varied habitat and shifting mosaic ie. due to river disturbance	where 90% of the population aggregates in groups of 20 -30 animals at 2.4 to 7.4 / km^2		Mig: seasonal range fidelity with <50% overlap where overlap area is used during migration (transitional zone) maximum migratory distance 25 km. Migrations related to snow
conditions.				
Allen et al. 1987*	Lake Superior Region (estimations for habitat modeling)	2/ km^2 is optimal habitat carrying capacity		
Ackerman 1987	Isle Royale, Michigan Island with diverse vegetation, ridges, valleys, lakes and streams	1 - 3/ km^2	No hunting	
DelGiudice et al. 1997	Isle Royal, Michigan	2.2 -3.5 / km^2	Winter ticks causing nutritional stress and hair loss causing winter mortality	

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
van Ballenberghe & Peek 1971*	Northeast Minnesota Low-relief Boreal conifer forest, lakes, mosaic of species and ages due to forestry				Su: < 2.6 km^2 core but up to 38.9 km^2 Wi: a number of cores connected by wanderings of 0.65 km to 7.8 km	In some cases, seasonal ranges are adjacent, in other cases separated by several miles.
Peek et al. 1976	Northeast Minnesota Low relief	0.43 - 1.96 / km^2				
Phillips et al. 1973*	Northwest Minnesota Varied habitat. Marsh and open water, forests, open fields, various stages of succession.	0.77 to 1.2 / km^2			Su: (AF) 17.9 km^2 Su: (AM) 14.5 km^2 Wi: (AF) 3.6 km^2 Wi: (AM) 3.1 km^2	25% Sed with overlapping seasonal HRs 15% Sed with adjacent seasonal HRs 20% Mig. 14.6 to 34 km Fidelity to migratory routes
Knowlton 1960*	Montana Gravelly Mountains Mountainous terrain. Variable habitat with forests, meadows, moist stream edges.		Hunting		Su: (AM) 2.6 km radius Su: (FC) 1.3 km radius	

Stevens 1970	Montana Gravelly Mountains	Lower than other nearby populations	Poor range conditions Low reproductive rate and low twinning rate (density dependent response to poor range)			
Peek et al. 1987	Northcentral Idaho Steep terrain. Dense Forests.	0.9 / km^2 abundant and productive	Some hunting. .			
Houston 1968*	Wyoming 1296 km^2 site Varied vegetation and topography with mountains, valleys, wetlands, rivers, floodplains, glacial outwash.	Wi: 0.54 / km^2 up to 30.9 / km^2 in localized winter habitat areas ie. flood plains. (0.6 / km^2 in conifer forest Su: 0.15 / km^2 Winter has higher population density because of presence of migratory animals in study area.	Food availability (willow) as related to snow depth Competition for forage with cattle and elk. Human activities have decreased /altered habitat and reduced forage availability. Calf mortality Hunting Little effect of parasites, disease, predators.		Wi and Su (A) : 1.6 to 2.4 km^2 Su (Y): >4.0 km^2 and up to 38.9 km^2	Sed and Mig Sed: present year round in study area. 8-16 km between summer and winter ranges (some animals have completely overlapping seasonal ranges) Mig: present winter and spring. Up to 32 km between summer and winter range. Most moose have distinct seasonal ranges. Seasonal range idelity in most cases sed and mig.

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Bobek & Morow 1987	Poland		Hunting and Predation.			
Lehtonen 1998	Finland	1970s: 0.7 / km^2 but did damage, now managed at 0.4 / km^2	Hunting (managed population - kept under ecological K)			
Nygren 1987*	Finland	0.4 / km^2 coast 0.3 / km^2 inland 0.2 / km^2 north				
Heikkila et al. 1996*	Southern Finland Managed forest, small scale patchy mosaic.			41.54 km^2 with a 40.8 km^2 core used in all seasons	Wi: 18.88 km^2 Su: 26.57 km^2 Au: 10.17 km^2	Sed with overlapping seasonal ranges.
Cederlund & Sand 1992	Southcentral Sweden Grimso Rugged plateau, Mainly forests fragmented by logging into various successional stages, also bogs, swamps and uplands.	1.2 / km^2	Hunting removes 50% of pop annually.			Sed. Philopatric to natal HR

Cederlund & Okarma 1988	Sweden Grimso			AF 12.6 km² containing at least 2 core areas	AF Su 9.1 km² Wi 4.9 km²	Sed with at least 10% overlap between all seasons
Cederlund & Sand 1994	Sweden Grimso			M 25.9 km² F 13.7 km² Young M/F 10 to 20 km²	Seasonal 3 to 20 km²	
Cederlund & Sand 1991	Sweden Grimso	1.3 / km²	Regulated by hunting Highly productive with potential to increase numbers (lots of food, no predators, mild winters, little dispersal)			
Cederlund et al. 1987	Central Sweden	1.0 / km² Wi: concentr. lowlands 9 / km² ; uplands 0.2 / km² Su: uplands 1.3 / km² with local concentr. Of 2 to 3 / km²	Hunting removes large numbers annually	(AF) 27.3 km² (0.9 to 30.3 km²)		Primarily migratory with seasonal range fidelity
Sweanor & Sandegren 1989	Sweden	0.2 to 11.7 / km² Greater in winters with less snow	Hunting 30% of pop. harvested annually	HR tended to be larger at lower density	Wi: 11.5 km²	Migratory. Spatial fidelity to Wi HR
Cederlund & Markgren 1987	Sweden		Hunting			

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Solberg & Saether 1999	Northern Norway - Vefsn Boreal environment, lowland forests, upland pastures.	<0.08 / km^2	Hunting. Food resources.			
Solberg et al. 1999	Northern Norway - Vefsn	0.07 to 0.79 / km^2 (pre-harvest)	Managed density dependent hunt. Climatic variation. Intrinsic variation in age structure of females in pop.			
Histol & Hjeljord 1993	Norway				Su: 9 km^2 Wi: 2.5 km^2	Mig. and Sed. All share common summer range, then some migrate up to 11 km to winter range
Syroechkovskiy & Rogacheva 1974	USSR (Asia)	0.01 to 1 / km^2 varies depending on habitat, highest in more southerly vegetated regions S. Mongolia 1 / km^2 Taiga 0.1 to 0.4 / km^2	Hunting/poaching pressure Disease			

		N. Taiga 0.02 to 0.1 / km^2 Tundra 0.01 to 0.05 / km^2	
Filonov & Zykov 1974	USSR (Europe and Urals)	0.05 to 0.67 / km^2 varies depending on habitat S. forest steppe 0.01 to 0.63 / km^2 Urals 0.05 to 0.18 / km^2 C. forest 0.13 to 0.49/ km^2 N. forest 0.18 to 0.67/ km^2 N. Taiga 0.06 to 0.18/ km^2	Hunting pressure
Kistchinski 1974	USSR (Siberia)	0.023 to 0.13 / km^2 concentrate in best habitat areas i.e. riparian brush up to 0.62 / km^2	

* Values have been converted to km^2

Abbreviations:

F	Female	Wi	Winter
M	Male	Su	Summer
A	Adult	Au	Autumn
J	Juvenile / 2 year old	Sp	Spring
Y	Yearling	Mig	Migratory
FC	Adult Female with Calf	Sed	Non-Migratory
K	Carrying capacity		

[1] Annual and seasonal home range sizes given per individual

Note: HR size per animal cannot be directly used to calculate area requirements of a population because some authors indicate that there is overlap of HR among individuals (but don't indicate degree of overlap) (Phillips et al. 1973, Doerr 1983, Cederlund & Okarma 1988, Leptich & Gilbert 1989, Cederlund & Sand 1992, Stenhouse 1995)

Note: In many cases males extended their normal range in the fall due to rutting behaviour i.e. searching for females (Knowlton 1960, Houston 1968, van Ballenberghe & Peek 1971, Phillips et al. 1973, Ballard et al. 1991).
In one case, 2 year old males displayed this pattern, presumably due to earlier maturation (Lynch & Morgantini 1984).

[2] Seasonal range overlap indicates that the winter and summer ranges of one individual overlap (this column does not indicate overlap among individuals).