STATUS AND MANAGEMENT OF MOOSE IN THE NORTHEASTERN UNITED STATES

David W. Wattles[1] and Stephen DeStefano[2]

[1]Massachusetts Cooperative Fish and Wildlife Research Unit, Department of Environmental Conservation, University of Massachusetts, Amherst, MA 01003 USA, [2]U. S. Geological Survey, Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts, Box 34220, Amherst, MA 01003 USA

ABSTRACT: Moose (*Alces alces*) populations have recolonized much of their historic range in the northeastern United States in the past 30 years, with their southern range edge extending to southern New England and northern New York. This southerly expansion occurred when certain other populations in the United States were in decline along the southern range edge, with climate change often cited as a probable cause. The areas that moose have recently occupied in the northeastern United States are some of the most densely human populated in moose range, which has raised concern about human safety and moose-vehicle collisions (MVC). We conducted a literature search about moose in the northeastern United States, and distributed a questionnaire and conducted phone interviews with regional biologists responsible for moose management to determine the status of moose, management activity, and research deficiencies and needs. Moose numbers appear stable throughout much of the region, with slow population growth in northern New York. Management activity ranges from regulated harvest of moose in Maine, New Hampshire, and Vermont, to no active management in southern New England and New York. The combined annual harvest in Maine, New Hampshire, and Vermont is >3,000. MVCs are a widespread regional concern with >1,000 occurring annually involving several human fatalities. Research should address impacts of parasitism by winter tick (*Dermacentor albipictus*) and brain-worm (*Parelaphostrongylus tenuis*) on productivity and mortality of moose, influence of climate change on population dynamics and range, and conflicts in areas with high human population density.

ALCES VOL. 47: 53-68 (2011)

Key words: *Alces alces*, management, moose, New England, New York, status.

Although exact records of historic moose (*Alces alces*) distribution and numbers are difficult to document, Goodwin (1936) claimed through anecdotal evidence that moose once ranged as far south as the Alleghany Mountains of Pennsylvania in eastern North America. By 1870 moose had likely been eliminated throughout the southern portion of their range by unregulated and commercial hunting, and forest clearing for agriculture. Allen (1870) claimed that moose were extinct in Massachusetts, southern Vermont, southern New Hampshire, and southern Maine, but inhabited northern portions of Maine and were probably still in northern New Hampshire, Vermont, and the Adirondack Mountains of New York.

The eventual recovery and expansion of moose populations in the northeastern United States (Northeast) likely resulted from a number of factors, the 2 most important being regulation of moose hunting and reforestation of abandoned farmland. The 1936 closure of moose hunting in Maine provided protection of a core population of moose in the Northeast, and as farms were abandoned across the region, reforestation and subsequent logging that created patchy younger forest amid even-aged stands increased and improved habitat for moose (Alexander 1993, Bontaites and Guftason 1993). Other contributing factors to the population increase were the reintroduction and spread of beaver (*Castor canadensis*) and corresponding increase in wetland habitat, and the decline of white-tailed deer (*Odocoileus virginianus*) populations and their associated parasite *Parelaphostrongylus tenuis* (Alexander 1993, Bontaites and Guftason 1993).

By the 1970s moose had increased in sufficient number in Maine to disperse to and augment the small population in adjacent New Hampshire in which there were ~500 moose by 1977. Exploiting unoccupied habitat, moose in New Hampshire quickly increased to ~1,600 in 1982 and 5,000 by 1993 (Bontaites and Guftason 1993); the same pattern followed in Vermont, with the population increasing from 200 in 1980 to 1,500 in 1993 when a hunting season was reinstated (Alexander 1993).

Despite the historical presence of moose in southern portions of the Northeast, many biologists considered the region to have marginal habitat and thought it unlikely that moose would establish viable populations (Karns 1997; W. Woytek, Massachusetts Division of Fisheries and Wildlife [MDFW], pers. comm.), particularly given the human-dominated landscape and high potential for human conflict (Vecellio et al. 1993, Peek and Morris 1998). Other factors that could impede their reestablishment were the highly fragmented mid-late stage mixed deciduous forest, relatively limited early successional habitat, and lack of key browse species found in the boreal forest such as balsam fir (*Abies balsamea*), willow (*Salix* spp.), mountain ash (*Sorbus aucuparia*), and trembling aspen (*Populus tremuloides*). The regional northern forest type where moose are common is dominated by spruce (*Picea* spp.), balsam fir, beech (*Fagus grandifolia*), birch (*Betula* spp.), hemlock (*Tsuga canadensis*), and maple (*Acer* spp.); transitional hardwood forests occur more southerly and are increasingly dominated by oak (*Quercus* spp.) and white pine (*Pinus strobus*) where little is known about moose habitat use and requirements. Exceptions are in northern New York and the Berkshire Mountains in western Massachusetts with forests similar to that in northern New England. Presumably, higher temperatures in southern portions would increase the likelihood of negative impacts due to thermal stress (Renecker and Hudson 1986, Murray et al. 2006, Lenarz et al. 2009). Moose must also cohabit with higher deer densities from north to south; however, the effects of *P. tenuis* on moose populations may be less severe than previously believed (Whitlaw and Lankester 1994).

Despite these presumed barriers to regional expansion, moose were sighted occasionally in the 1960s (presumably from Vermont and New Hampshire) in Massachusetts where few public reports occurred prior to 1966 (Vecellio et al. 1993). Regular occupation in New York began in 1980, initially in the border regions near Quebec, Ontario, and Vermont, and spread quickly into the Adirondack Mountains (Hicks 1986). By the late 1980s-early 1990s moose appeared in Connecticut, and by 1998 there was evidence of a breeding population (Kilpatrick et al. 2003). Moose are now considered established in New York, Massachusetts, and Connecticut.

To best describe moose status and management in the Northeast, we defined 2 regions relative to the time of establishment and size of population. Southern New England and New York included Massachusetts, Connecticut, and upstate New York where moose are more recently established and management policies are forming. Northern New England included Maine, New Hampshire, and Vermont where moose populations are well established and been actively managed for several decades. Our objectives were to report on the current status of moose populations and management policies, identify differences and similarities between the 2 regions, and identify research and management strategies to aid management of the regional population.

STUDY AREA

The states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and

New York currently have resident moose populations, and Rhode Island, New Jersey, and Pennsylvania are states where moose occurred historically (Goodwin 1936; L. Gibson, Rhode Island Division of Fish & Wildlife [RIDFW], pers. comm.; C. Condolf, New Jersey Division of Fish and Wildlife [NJDFW], pers. comm.). New York, Connecticut, and Massachusetts represent the southern edge of current moose range in eastern North America. The population is between 66° 57' W longitude in eastern Maine and 76° 10' W longitude on the western side of the Adirondack Mountains in New York, and between 47° 28' N latitude in northern Maine and 41° 38' N in central Connecticut (Ed Reed, New York Department of Environmental Conservation, Bureau of Wildlife [NYDEC], pers. comm.; H. Kilpatrick, Connecticut Department of Environmental Protection [CDEP], pers. comm.; L. Kantar, Maine Department of Inland Fisheries and Wildlife [MDIFW], pers. comm.) (Fig. 1). New Jersey, Rhode Island, Massachusetts, and Connecticut are the most densely populated states in the United States (U.S. Census Bureau n.d.) where human development and road networks make forest habitat patchy and highly fragmented; southeastern New Hampshire and coastal southeastern Maine also have high levels of human development. In general, human density decreases to the north and west as forested area and available moose habitat increases.

The region is heavily forested with extensive streams, rivers, lakes, ponds, and wetlands; elevation ranges from sea-level to 1,916 m in the White Mountains of New Hampshire. DeGraaf and Yamasaki (2001) identified 5 forest regions, each with characteristic tree species and specific physiographic and climatic conditions. The spruce-balsam fir forest occurs in the coldest areas of the northeast, >150 m in Maine and at higher elevations in New Hampshire, Vermont, and New York. The northern hardwoods-spruce forest is at lower elevations in Maine and at <850 m in

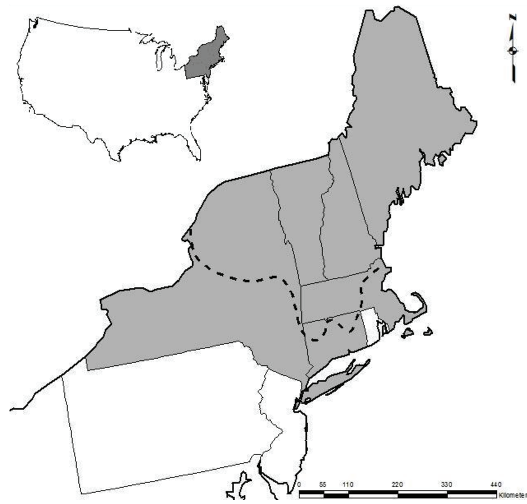

Fig. 1. Range of moose in the northeastern United States (dashed line represents southern edge of moose range).

mountains of New Hampshire, Vermont, and northern New York; small pockets are found in the mountains of western Massachusetts. The northern hardwood forest is at 150-790 m in Maine, New Hampshire, Vermont, New York, and western Massachusetts. The transitional hardwoods-white pine forest is at lower elevations in the uplands of northern New England, and is the dominant forest in Massachusetts and northeast Connecticut. The central hardwoods-eastern hemlock-white pine forest is found throughout Connecticut, southern and eastern Massachusetts, and extreme southeastern New Hampshire and Maine (DeGraaf and Yamasaki 2001).

METHODS

We conducted an electronic mail (e-mail) survey of state agency deer and moose biologists managing established moose populations in Maine, New Hampshire, Vermont, Massachusetts, New York, and Connecticut. We asked about the abundance, distribution, status, population goals, management practices including hunting and habitat management, issues and concerns, and experience with public perception of moose. We asked follow-up questions via telephone and e-mail when additional information or clarification was needed. We also conducted telephone interviews with the deer biologists of Rhode Island, New Jersey, and Pennsylvania (adjacent to states with moose populations and where moose were believed to be historically) and asked about sightings and anecdotal information about moose in their state. We also gathered, reviewed, and summarized literature on the status and management of moose populations in the region.

RESULTS

Southern New England and New York

Massachusetts - Moose numbers increased rapidly in Massachusetts in the 1990s after re-colonizing the state in the 1960s. The MDFW estimated a population of 850-950 in 2010 (S. Christensen, MDFW, pers. comm.) based on a regression model developed in New Hampshire that uses moose sighting surveys by deer hunters and available suitable habitat to estimate moose abundance (Bontaites et al. 2000). The population has stabilized since 2001 with the possible exception of slight increase in the Berkshires Hills in the western part of the state. The MDFW prefers to maintain the population at the current level, with the overall goal "to maintain and sustain a resident breeding moose population in the state in areas of suitable habitat throughout its historic range at levels which support ecological and cultural values while minimizing human-moose conflicts" (S. Christensen, pers. comm.).

Moose habitat in Massachusetts is found primarily in the central and western portions of the state, west of the city of Worcester. However, moose are frequently reported farther east in an area that constitutes the greater Boston metropolitan region where patches of suitable habitat are smaller and more fragmented; high human population density makes it likely that moose are considered problem animals in this area. In western Massachusetts the 2 main forest regions are separated by the Connecticut River Valley and the Interstate 91 highway corridor, both of which run N-S. These regions are fragmented by state highways and towns, but enough forest habitat remains to support a stable moose population.

As the number of moose increased in the late 1980s and early 1990s, Vecellio et al. (1993) and McDonald (2003) questioned whether a state as densely populated as Massachusetts could support a larger moose population; Massachusetts has the third highest density of people in the United States, averaging about 313 people/km^2 (U.S. Census Bureau n. d.). They speculated that the cultural carrying capacity would be exceeded and the issue would become untenable and conflict would be inevitable without proactive management. As predicted, the moose population increased rapidly after 1993, as did the number of moose-vehicle collisions (MVC) that peaked at 52 in 2004 (Fig. 2; Vecellio et al. 1993; MDFW, unpublished data); 2 human fatalities occurred in 2003 and 2007 (Table 1). Despite the increase in costly and dangerous MVCs, moose have apparently not exceeded cultural carrying capacity as public perception is almost universally positive, based on MDFW's and our interactions with the public. Moose density is relatively low and a moose sighting is still somewhat of a novelty as most residents have never seen a moose in Massachusetts.

The MDFW regards the return of moose as a conservation success; however, as of 2010 it does not have authority to initiate a regulated hunt because moose hunting is specifically prohibited by state statute. Legislation was first introduced in 2002 to give management authority to the MDFW, but the bill has not progressed beyond the legislative committee stage which is influenced by both those desiring a moose hunt and a large animal rights and anti-hunting population in Massachusetts. Management activities include monitoring MVCs, continued analysis of deer hunter surveys, and response to problem animals.

Table 1. Human fatalities resulting from moose-vehicle collisions in the northeastern United States, 1998-2007.

	State						
Year	Maine	New Hampshire	Vermont	Massachusetts	Connecticutt	New York	Total
1998	5	0	2	0	0	0	7
1999	1	1	1	0	0	0	3
2000	3	2	0	0	0	0	5
2001	1	1	0	0	0	0	2
2002	2	1	1	0	0	0	4
2003	3	1	1	1	0	0	6
2004	4	2	0	0	0	0	6
2005	1	0	1	0	0	0	2
2006	2	0	2	0	0	0	4
2007	5	0	1	1	1	0	8
Totals	27	8	9	2	1	0	47

Massachusetts has developed a Large Animal Response Team (LART) composed of MDFW and Environmental Police personnel who respond to problem moose and other large mammals. Such situations occur when a moose is a threat to their own or public safety by wandering into towns or onto busy roadways. The current policy has 3 stages: 1) the animal is hazed or herded back to suitable habitat, 2) if hazing fails and immediate public safety is not an issue, the animal is immobilized and relocated to a wildlife management area, state forest, or other suitable area away from development, or 3) the animal is euthanized if an immediate threat and hazing and immobilization are unfeasible. The LART has performed 1-9 relocations and 0-5 euthanasias annually in the past 10 years; the number of problem animal responses of all types has declined in the last 5 years.

In southern New England, as elsewhere, regenerating forests are an important source of browse. In any given season, moose preferentially use (50-65%) early successional habitat created by logging (USGS Massachusetts Cooperative Fish and Wildlife Research Unit [MCRU], unpublished data). Large tracts of managed state land tend to support higher moose density and appear to have greater browsing impacts. Commercial foresters and large logging companies are increasingly concerned with the long-term impacts of browsing on the species composition and structure of Massachusetts forests.

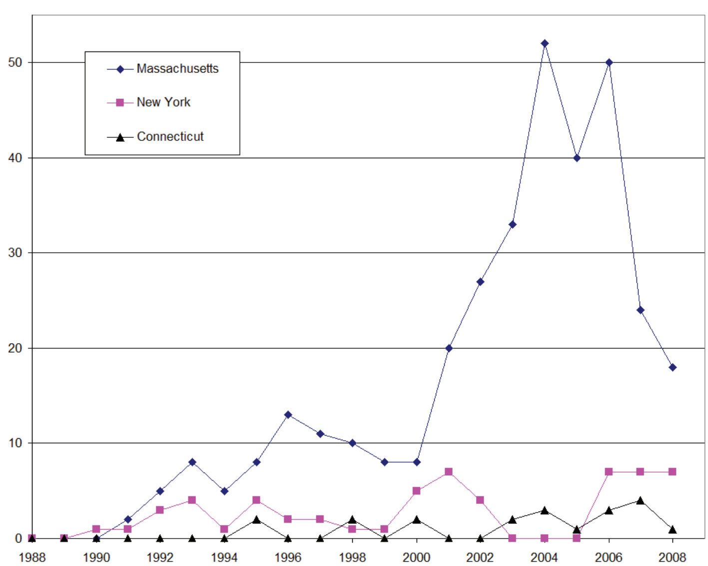

Fig. 2. Reported moose vehicle collisions in southern New England, 1989-2007.

Research includes studying how moose use the landscape, respond to dense human populations, cope with high temperature, and interact and influence the deciduous forest. The MCRU and MDFW began studying movements and habitat use of moose equipped with global positioning system (GPS) collars (n = 35) in 2006. Faison et al. (2010) studied moose browsing in the deciduous forest of Massachusetts; additional studies will integrate vegetation and GPS data to further evaluate moose browsing. Also, several sets of 20 x 20 m fenced exclosures have been built with paired control plots to estimate the effect of moose browsing on species composition and rate of forest regeneration (Compton and DeStefano 2009, Faison et al. 2010).

New York - Re-colonization began around 1980 from moose dispersing from Vermont and Canada. By 1990 the population was estimated as ~20 animals, with a bull to cow ratio of 3:1 typical of a colonizing population (Garner and Porter 1990). The NYDEC considered augmenting the population with relocations in the early 1990s, but did not due to lack of public support, concern of increased moose-human conflict, and a desire for moose to repopulate naturally (Hicks and McGowan 1992, Lauber and Knuth 1997).

The population has grown steadily as moose exploit unoccupied habitat; NYDEC estimated the population at 300-500 animals in 2008 with most in and around the 25,000 km^2 Adirondack Park and Reserve in the northern third of the state. Public sightings indicate that moose are also present and increasing in the Taconic highlands on the Vermont and Massachusetts borders. Moose density was highest on private land along the northern edge of the Adirondack Park where forest management is more active. Conversely, the Adirondack Park represents the majority of moose habitat in the state, but logging is not permitted. Presumably the lower density and population growth rate in New York, as compared to that in Vermont and New Hampshire, reflects less forest harvesting and early successional habitat. The few reports of moose south of the Interstate 90 corridor are usually young bulls presumably dispersing. The NYDEC does not expect moose to establish in southern New York because of the high level of development and warmer climate. State biologists predicted the population to exceed 1,000 animals by 2010; however, population growth was lower than expected and the 2010 population was estimated at 500-800 (C. Dente and E. Reed, NYDEC, pers. comm.).

The goal of NYDEC is to increase the population in northern New York, and it monitors the population through reports of mortalities, reproduction, and public sightings. Aerial surveys have been conducted to document range distribution but not to estimate the population. The population was monitored with a survey of successful deer hunters conducted by the Wildlife Conservation Society that documented moose sightings and sign; response to these surveys was low (10%). The NYDEC has conducted surveys since 2008 and the response rate has increased to 30%. Due to the overlap of moose and deer in New York, there is concern about the effect of *P. tenuis* and several cases of brainworm have been documented (C. Dente and E. Reed, pers. comm.).

Due to concern about increasing MVCs (Fig. 2), the NYDEC and the New York Department of Transportation (NYDOT) have increased signage and public information about MVCs; NYDOT is investigating moose road crossings and MVCs in the state. In densely populated southern New York (north of New York City) concern about increasing MVCs and the need for a hunt have been raised in the popular press; however, it is believed that moose involved in local MVCs dispersed from adjacent Connecticut and Massachusetts, not northern New York (C. Dente, pers. comm.).

Moose-human conflicts are increasing and the state has developed a plan to coordinate and standardize response actions, including relocation of moose considered a threat to public safety. Most response actions result from moose wandering into developed areas in the greater Albany region and the Interstate 90 corridor. Management options are limited because moose are fully protected by state law; therefore, NYDEC is evaluating the possibility of securing regulatory change to allow broader management actions (e.g., hunting season). Public opinion about moose recovery in New York remains positive despite increasing moose-human conflicts (E. Reed, pers. comm.).

Connecticut - Moose began to re-colonize Connecticut in the late 1980s with young bulls dispersing from Massachusetts (Kilpatrick et al. 2003). Sightings of females occurred by 1990, and evidence of a resident breeding population was confirmed with the first cow-calf sighting in 2000; cow-calf sightings are consistent since. The increase in cow-calf sightings corresponded with increased public sightings in the late 1990s, from ≤5 in the early 1990s to 32 in 2002 (Kilpatrick et al. 2003). Similarly, there were no MVCs in Connecticut before 1995; the frequency of MVCs has increased to 1-4 annually since 2003 (Fig. 2; Kilpatrick et al. 2003; H. Kilpatrick, CDEP, pers. comm.) and the first human fatality occurred in 2007 (Table 1; A. Labonte, CDEP, pers. comm.).

Most moose are located in the more rural and forested northern third of the state, with higher density in the northwest than northeast (H. Kilpatrick, pers. comm.). These 2 areas are largely separated from each other by the heavily developed portion of the Connecticut River Valley between Springfield, Massachusetts and Hartford, Connecticut; however, each is contiguous with moose habitat in Massachusetts.

In 2008 the population was estimated at >100 animals and increasing (H. Kilpatrick, pers. comm.). Continued growth was expected despite the belief that high summer temperatures, range overlap with white-tailed deer and threat of brainworm, and marginal habitat should all limit population growth. With a more conservative method, the population was estimated at ~75 animals in 2010 (A. Labonte, pers. comm.). These estimates were based largely on observation rates and public reports, but the latter may be decreasing as moose are less of a novelty. This general stabilizing trend after a slight population reduction matches what seemingly occurred in Massachusetts and southwest New Hampshire (S. Christensen, pers. comm.; K. Rines, New Hampshire Fish and Game Department [NHFG], pers. comm.).

Connecticut is the fourth most densely populated state in the nation with 271 people/km^2 (U.S. Census Bureau n.d.). This high human population, dense road network, and high traffic volume make a large moose population potentially dangerous to human safety. Several moose entering highly developed or high traffic areas are relocated or euthanized annually, and CDEP is concerned about continued growth of the moose population as it desires to minimize MVCs. As a result, Connecticut is conducting public and hunter opinion surveys, preparing a moose management plan, and considering the possibility of initiating a moose hunt to limit population growth. Any initiation of a hunt will likely be met by opposition from anti-hunting groups in the state. The CDEP has also deployed GPS radio-collars on moose to investigate habitat use and movement patterns (H. Kilpatrick, pers. comm.).

Northern New England

Maine, New Hampshire, and Vermont have well established moose populations of social, ecological, and economic importance. Wildlife viewing, tourism revenue, and hunting permits and related expenditures generate millions of dollars annually in these states. Moose populations have been actively managed with hunting seasons since 1980 in Maine, 1988 in New Hampshire, and 1993 in

Vermont. The respective histories of moose recovery and development of hunting seasons are found in Morris (2007), Bontaites and Guftason (1993), and Alexander (1993) as well as in annual state reports. Public participation with varied stakeholder groups has played an important role in determining state management goals (C. Alexander, Vermont Fish and Wildlife Department [VFWD], pers. comm.; L. Kantar, MDIFW, pers. comm.; K. Rines, pers. comm.). Certain management issues are similar to those in southern New England, (e.g., MVC; Fig. 3) but state-specific management is often related to balancing sometimes conflicting goals of different interest groups.

Maine – The moose population was estimated at 30,000-60,000 in 2010. Highest density occurs in the forested interior with lower density along the coast. Density ranges from 0.2-0.6 moose/km^2 in the southern and 1.0-1.7 moose/km^2 in the northern forested interior (Morris 2007; L. Kantar, pers. comm.).

Management goals and objectives were revised by a public working group after the state legislature granted the MDIFW full authority for moose management in 2000 (L. Kantar, pers. comm.) . The working group created a more comprehensive set of goals compared to the previous goal of maintaining the population at the 1985 level (Morris 2007). Goals and objectives continue to be developed through a public process involving representative stakeholders, including potentially conflicting groups associated with expanding moose watching and moose hunting, both of economic importance in Maine (Morris 2007). The goal is to strike a balance between moose viewing, public safety, and recreational opportunities (L. Kantar, pers. comm.). The management guidelines developed in 2000 set population objectives specific to each of 29 Wildlife Management Districts (WMD) and fall into 3 main categories: 1) recreation management which seeks to maintain the population at 60% of carrying capacity to maximize hunting and viewing opportunities, 2) road safety which seeks to reduce the population to decrease MVCs, and 3) compromise which seeks to reduce the population by a third to both reduce MVCs and maintain quality recreational opportunities (Morris 2007; L. Kantar, pers. comm.).

In the remote and heavily managed forests in northern and central western Maine where human population is minimal, WMDs are in the recreation management category (1), WMDs along the northeast-eastern and southwest borders of the state are in the compromise category (3), and WMDs along the more densely populated southern interior and southeastern coastline of Maine are in the road safety category (2; L. Kantar, pers. comm.). Despite the risk of MVCs, public opinion indicates that the majority do not favor a large reduction of the moose population along the

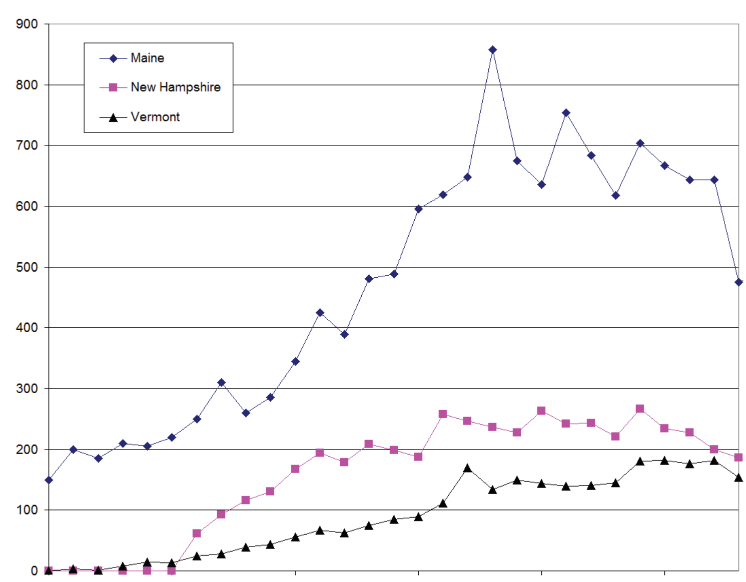

Fig. 3. Reported moose vehicle collisions in northern New England, 1980-2008.

coast (Morris 2007).

New Hampshire - The moose population was estimated at ~6,000 in 2008 based upon analyses of deer hunter surveys and infrared thermal imagery surveys (Bontaites et al. 2000), but was reduced to ~4,500 by 2010 (K. Rines, pers. comm.). Moose density declines from north to south in New Hampshire, ranging from 1.2/km^2 in the northern third of the state to <0.01/km^2 along the more densely human populated coastline; numbers are considered relatively stable throughout most of the state. The population decline occurred in the northern third of the state due to increased hunting pressure proposed in the 2006-2015 New Hampshire Big Game Plan and to mortality related to winter tick parasitism (K. Rines, pers. comm.). Musante et al. (2010) found that body weight, survival, and reproduction of adult cows were high, but winter ticks caused measurable mortality of calves in years of high infestation and probably affected productivity of yearling cows. As a result, parasitism rather than habitat is believed more limiting to the population growth rate of moose in northern New Hampshire.

The New Hampshire Big Game Plan 2006-2015 (NHFG 2005) states the goal for moose management as:

"New Hampshire will regionally manage moose populations by balancing and incorporating social, economic, public safety and ecological factors, using the best available science."

Management in each of 6 regions seeks balance among multiple and somewhat opposing goals of limiting browsing impacts, maximizing wildlife viewing and hunting opportunities, and limiting MVCs. Management goals vary with regional priorities that are determined largely by the public. For instance, limiting MVCs is a priority in the southeastern region of highest human density, whereas balancing maximal recreational opportunity and limiting browsing impacts are priorities in the north where lower human density makes MVCs less of a concern (NHFG 2005). Since 1999 the number of annual moose hunting permits has ranged from 482-678 in response to change in observation rates, hunter success, adult sex ratio, fall calf recruitment, and population growth rates; annual harvest has ranged from 333-482 (K. Rines, pers. comm.).

Vermont - The 2008 population was estimated at 4,000-5,000 animals with densities of 1/km^2 in the northeast to ≤0.2/km^2 elsewhere. An estimated statewide population of 3,000-4,000 moose in 2010 reflects the success of the effort to reduce density in the northeast portion of Vermont (C. Alexander, pers. comm.). A conservative hunt with limited permits was initiated in 1993 to allow increase of moose throughout the state, with the exception of Wildlife Management Unit (WMU) E in the northeastern corner where stabilization/reduction of the population was desired because moose had or were nearly exceeding cultural carrying capacity. Other goals were to monitor the population relative to biological and cultural carrying capacity to determine when and if expansion of the hunt was needed, maximize recreational opportunities, minimize moose-human conflicts, and provide funding for Vermont's Moose Management Program (Alexander 1993).

As the population grew throughout the state, additional WMUs were opened to hunting and permits increased; hunting now occurs in most of Vermont. By 2003 the number of annual permits was 440 statewide and harvest was 298 animals. Despite the increase in permits, the high moose density in northeastern Vermont was causing heavy browse damage as body condition and productivity declined. Hunting permits in the northeast were increased annually in an attempt to control the population; permits jumped to 833 in 2004 and 1250 in 2008 when 75% of permits and harvest statewide occurred in the 4 northeastern WMUs. Population reduction was achieved by allocating half the permits as antlerless only

(Vermont Moose Management Team 2008a, b; C. Alexander, pers. comm.).

Management goals in 2008 were to further reduce the moose population in northeastern WMUs, stabilize the population in most other WMUs, and allow for controlled growth in a few WMUs. It was believed that after several years of high permit numbers, permits would decline to ~500 statewide (Vermont Moose Management Team 2008b). Harvest levels in 2009, hunter sighting rates, and a reduction in MVCs and non-hunting mortality all indicated that population goals in the northeastern WMUs were being met. As a result, permits in WMU D2 were reduced from 337 in 2009 to 90 in 2010, and permits in WMUs E1 and E2 were reduced about 30% from 600 combined permits in 2009; further reductions are anticipated in 2011 (C. Alexander, pers. comm.; Darling and Alexander 2010; VFWD 2010).

Rhode Island, New Jersey, and Pennsylvania

Annual moose sightings in Rhode Island are relatively rare (1-2 annually with no cow-calf sightings) and are usually north of Scituate. The RIDFW has not responded to a moose incident since the early 1990s when a moose was removed from inside the Highway 295 corridor; the moose died in transit to New Hampshire. It is believed that more sightings would occur if resident moose existed (L. Gibson, RIDFW, pers. comm.). There have been no reports of moose in New Jersey, other than one animal observed crossing into the northwest corner (C. Condolf, NJDFW, pers. comm.). Similarly, in the past 5 years there has been only a single sighting in northeastern Pennsylvania, a young bull in a pasture with domestic cows (B.Wallingford, Pennsylvania Game Commission, pers. comm.). It is presumed that New Jersey and Pennsylvania are isolated from established moose populations either by distance or dense human development barriers.

DISCUSSION

Population Trends

Since 2001 the Massachusetts moose population appears stable at 850-950 animals. The frequency of MVCs, responses to problem moose, relocations, and public safety kills in Massachusetts peaked in 2004-05, followed by sharp decline (MDFW, unpublished data). A similar temporal trend toward stability occurred in Connecticut (75-100 animals) and in southwest New Hampshire where numbers increased sharply during range expansion when moose exploited unoccupied habitat. Eventually these populations declined and stabilized at a lower level. It is speculated that brainworm might act as a limiting factor given the relatively high deer density in these areas (K. Rines, NHFG, pers. comm.).

Moose in Massachusetts and Connecticut are at relatively low density and viewing moose is difficult due to their tendency to inhabit contiguous forest blocks. Further, the few carcasses found are usually too deteriorated for necropsy or to determine cause of death; most animals afflicted with brainworm or heavy tick loads likely die unobserved. Although no cases of brainworm are confirmed in Massachusetts, neither have animals been tested, and several cases of brainworm have been confirmed in Connecticut; many suspected cases are noted in both states. Winter ticks are observed on captured and free-ranging moose in Massachusetts, but the infestation level is not considered as severe as in northern New England (MCRU, unpublished data; K. Rines, pers. comm.; D. Scarpitti, MDFW, pers. comm.).

Comparison of the heat stress index in Ely, Minnesota, where Lenarz et al. (2009) speculated that warm temperatures were a mortality factor of moose, to that calculated in central Massachusetts indicates that moose in southern New England are subjected to more prolonged periods of temperatures above the estimated thermoneutral zone of moose (Renecker and Hudson 1986). Data from GPS radio-collared moose in Massachusetts show reduced use of early successional habitats and a corresponding increase in use of conifer stands and wooded wetlands at spring and summer temperatures associated with thermal stress (MCRU, unpublished data), an example of thermoregulatory behavior. If such behavior lead to reduced body condition (e.g., through stress and inefficient foraging), productivity and survival could be compromised. However, conflicting evidence of such includes high pregnancy rates and twinning by radio-collared adult cows (MCRU, unpublished data).

Mortality related directly to winter tick (Musante et al. 2007) and brainworm (Lankester 2010), and mortality correlated with increasing temperatures (Murray et al. 2006, Lenarz et al. 2009) are associated with moose on the southern edge of their range. These factors and MVCs likely account for most mortality in southern New England where no hunting exists and predators of moose are few. Moose may be at or near carrying capacity in deciduous forest habitat in southern New England, but no relative or comparator estimate of population density exists. Despite evidence of heavy use of preferred browse species in regenerating sites, damage causing permanent forest change and/or nutritional impacts on moose has not been measured. The initial irruptive phase of population growth appears to have shifted to a slight decline and stabilization phase in Massachusetts and Connecticut. Research needs include improved population estimation and related techniques, and further study of the influence of habitat, parasitism, MVCs, and temperature on this southern-most population in New England.

Habitat

The long-term future of moose in southern New England is debatable. It is unknown how many moose are sustainable in the fragmented, deciduous forests of southern New England, if long-term occupation by moose will affect forest plant communities, and the impact of continued human development on forest resource availability. Preliminary data from the GPS radio-collar study in Massachusetts indicate that moose (as elsewhere) use early successional forests created by logging. Eastern hemlock substitutes for balsam fir, which is typical winter browse in northern New England but uncommon in most of western Massachusetts and absent in eastern Massachusetts and Connecticut.

Forest harvesting has created a shifting mosaic of small patches of early successional habitat in southern New England where small privately-owned wooded parcels predominate (Kittredge et al. 2003, McDonald et al. 2006). Further, public perception of logging in southern New England is often negative, and has lead to societal pressure in Massachusetts to limit or eliminate logging on state lands. In fact, creation of new forest management plans in 2010 for state lands has greatly reduced the acreage for, and the types and extent of logging. These restrictions will require that private lands provide most early successional habitat in the state, with no guarantee that logging will continue at current levels. Eastern hemlock is threatened with decline due to the hemlock woolly adelgid (*Adelges tsugae*) with outbreaks causing widespread mortality of hemlock in Connecticut and elsewhere in the Appalachian Mountains (Orwig et al. 2003); it has recently spread into southern Maine. The decline of hemlock in southern New England will presumably limit important winter browse and seasonal thermal cover for moose, and the relative impact may be related directly to higher temperatures associated with climate change.

Habitat in northern New England will likely not be a primary limiting factor of moose. Although early successional habitat in Maine is less than after the spruce budworm (*Choristoneura fumiferana*) outbreak of the 1970s and 1980s, availability of commercial forestland and forest harvesting that produces early successional habitat is relatively constant in the northern areas of Maine, New Hampshire, and Vermont (Morris 2007). As in northeastern Vermont, cultural carrying capacity influenced by public safety concern about MVCs and regeneration of commercial forests will mean that certain populations are managed at levels below nutritional carrying capacity.

A growing human population with increased development is considered a potential limiting factor for the moose population in southern New Hampshire (NHFG 2005). Continued human development and urban sprawl probably pose the greatest threat to moose in southern New England and coastal New Hampshire and Maine. Direct habitat loss from development of forested lands is occurring rapidly in Massachusetts (DeNormandie and Corcoran 2009), and the combination of habitat loss to development and increased forest fragmentation will likely result in more MVCs as moose move among habitat patches throughout the region.

Management and the Public Role

Public opinion and involvement in the management process has and will continue to drive moose management policies and population goals in the northeastern United States. For example, public meetings and public advisory groups composed of members from various stakeholder groups shaped Vermont's management goals and plan when the initial hunting season was under consideration. Providing the public a voice in the decision-making process and proactive efforts to address the social issue of morality of moose hunting likely helped to minimize the anti-moose hunting sentiment that existed in Vermont (Alexander 1993; C. Alexander, VFWD, pers. comm.); public involvement also plays an important role in moose management in New Hampshire and Maine. In Massachusetts the policy for response to problem moose was influenced by public sentiment (Vecellio et al. 1993), and public opposition in New York factored into the decision to not augment the moose population (Lauber and Knuth 1997). Public opinion will obviously play a large role in whether moose hunting occurs in New York, Massachusetts, and Connecticut.

Moose Vehicle Collisions

While relatively rare, MVCs are a primary public safety concern throughout the region because of their devastating nature and the possibility of human fatality. Increasing moose populations in densely populated Massachusetts and Connecticut have led to a corresponding increase in MVCs (Fig. 2). Likewise, MVCs in New York have increased but the distribution of moose in the lightly roaded northern third of the state has presumably limited the relative number. Higher moose density in northern New England has lead to more MVCs and related human fatalities, despite lower human population and traffic density (Fig. 3). Since 1996 there have been >1,000 MVCs annually in the northeastern United States resulting in >50 human fatalities, or about 1 in 250 (Table 1; Fig. 2, 3). The 600-700 annual MVCs in Maine result in estimated damages of $17.5 million (Danks 2007).

Unfortunately, MVC data in Massachusetts have become increasingly unreliable. The number of reported collisions has declined in recent years to 24 and 18 in 2007 and 2008, respectively (Fig. 2); however, this decline is at least partially due to inconsistent reporting from conflict over ownership of a moose carcass, lack of communication among state agencies, and the simple fact that a MVC in Massachusetts is less novel. Anecdotal and second-hand reports of MVCs now outnumber official reports, and comparison of Division of Law Enforcement and MDFW records indicates that only a fraction of MVCs are reported to MDFW. The decline in collisions may represent an actual trend in the population, but any use of MVC data as a population index is compromised. By comparison, in 1999 the New York State Legislature amended the law concerning the disposition of the moose carcass in a MVCs; people whose vehicle has been damaged can obtain a permit from a law enforcement officer to possess the carcass (NYDEC 2010). Connecticut adopted a law in 2008 that allows motorists to claim deer, moose, and bears killed in collisions (H. Kilpatrick, CDEP, pers. comm.); a similar approach in Massachusetts may improve reporting of MVCs.

Research is continuing to better understand how habitat associations, landscape characteristics, road features, speed limits, moose density, and traffic volume influence MVCs. Flexible management policies in northern New England provide for population reduction through hunting to reduce risk of MVC. Wildlife managers in southern New England and New York are without this option and attempt to reduce collisions through signage, public education, and response to problem moose.

Hunting

The number of moose hunting permits has been ~2,900 in Maine and 400-700 in New Hampshire over the past decade. The number fluctuates by management unit relative to evolving management goals and observation rate, hunter success, adult sex ratio, fall calf recruitment, and population growth rate. The number of permits in Vermont fluctuates with change in observation rate to meet WMU-specific population goals and has increased statewide in recent years; however, the greatest increase was in the northeastern section to reduce and stabilize the population below ecological carrying capacity to address concern about forest impacts (Vermont Moose Management Team 2008b). In response to the population reduction, more conservative permit levels were established in the northeastern section in 2010. Connecticut and New York are exploring the option of instituting moose hunts; however, in both cases legislation is required. It is also unlikely that moose hunting will occur in Massachusetts in the near future.

Research

Regional cooperation among state moose biologists and managers is high. An annual meeting is held to share information and address management issues within northeastern U.S. states and Canadian provinces. Other meetings and collaborations are used specifically to help produce regional methods to index and estimate moose populations, and construct a uniform system to classify habitat. Despite extensive studies throughout moose range, important regional questions remain regarding biology, foraging ecology, habitat use, life history, and population dynamics.

In southern New England where most information about moose biology, habitat interactions, and forest interactions is scarce to non-existent or anecdotal and speculative, current research includes use of GPS radio-collared moose and forest exclosures (Wattles and DeStefano 2009, unpublished data). Other research needs include methods to estimate population size and growth, causes of and factors influencing mortality and population growth, and ecological carrying capacity in this unique moose environment (H. Kilpatrick, CDEP, pers. comm.). In northern New England there is considerable interest in the role of black bear (*Ursus americanus)* and coyote (*Canis latrans*) predation, and parasitism (winter tick, lung worm, and brainworm) in population dynamics, especially with regard to calf mortality and recruitment. Recent studies have focused on methods to monitor and predict infestation level of winter ticks and associated impacts on moose (Musante et al. 2007, Bergeron 2011). Moose-deer interactions are of interest from the standpoint of interspecific competition for browse and the role of deer density on parasitism (brainworm) in moose. The impact of moose on forest regeneration and production is also a focal area of management and research (e.g., Bergeron et al. 2011).

The Future

The recovery of moose in the northeast is widely heralded as a unique example of successful wildlife management. Moose are the largest native mammal of the region and they recovered naturally due to ecological change largely associated with forest management and regulation of hunting. Moose appear to have a stable future in the region, with the population well established in northern New England and relatively stable or growing in southern New England. However, the presence and ecological impact of such a large, charismatic mammal in the highly populated northeastern United States creates unique management issues for researchers and managers, particularly because its range has extended well southward in the past 20 years. The greatest concern and challenge for managers will be how to manage such a large animal in an increasingly human-dominated landscape that also has highly productive commercial forestland. Moose management in this region will demand unique approaches due to the interconnected ecological, economic, social, and political factors in this diverse region.

ACKNOWLEDGMENTS

We would like to thank the following for their great assistance in making this manuscript possible: Cedric Alexander, VFWD; Kristine Rines, NHFG; Lee Kantar, MDIFW; Ed Reed and Chuck Dente, NYDC, Bureau of Wildlife; Howard Kilpatrick and Andrew Labonte, CDEP; Sonja Christensen and Dave Scarpitti, MDFW; Lori Gibson, RIDFW; Carrol Condolf, NJDFW; and Bret Wallingford, Pennsylvania Game Commission. The information provided by the individual state managers was invaluable. The MDFW has provided long-term funding for moose research in Massachusetts through the Federal Aid in Wildlife Restoration program (W-35-R). The Massachusetts Department of Conservation and Recreation, U. S. Geological Survey, U. S. Forest Service, and University of Massachusetts-Amherst have also provided funding and logistical support. We would like to thank Todd K. Fuller, John E. McDonald, Jr., Thomas O'Shea, and Sonja Christensen for their careful review and comments on drafts of this manuscript.

REFERENCES

Alexander, C. E. 1993. The status and management of moose in Vermont. Alces 29: 187-195.

Allen, J. A. 1870. The distribution of moose in New England. American Naturalist 4: 535-536.

Bergeron, D. H. 2011. Assessing relationships of moose populations, winter ticks, and forest regeneration in northern New Hampshire. M. Sc. Thesis, University of New Hampshire, Durham, New Hampshire, USA.

_____, P. J. Pekins, H. F. Jones, and W. B. Leak. 2011. Influence of moose population density on forest regeneration in northern New Hampshire. Alces 47: 39-51.

Bontatites, K. M., and K. Guftason. 1993. The history and status of moose management in New Hampshire. Alces 29: 163-167.

_____, _____, and R. Makin. 2000. A Gasaway-type moose survey in New Hampshire using infrared thermal imagery: preliminary results. Alces 36: 69-75.

Compton, J. A., and S. DeStefano. 2009. Experimental exclosures and the regeneration of forest vegetation in response to moose and deer browsing. USGS Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts, Amherst, Massachusetts, USA.

Danks, Z. D. 2007. Spatial, temporal, and landscape characteristics of moose-vehicle collisions in Maine. M. Sc. Thesis. State University of New York, Syracuse, New York, USA.

Darling, S., and C. Alexander. 2010. 2010 Moose season proposal. Vermont Department of Fish and Wildlife, St. Johnsbury, Vermont, USA.

DeGraaf, R. M., and M. Yamasaki. 2001. New England Wildlife; Habitat, Natural History, and Distribution. University Press of New England, Hanover, New Hampshire, USA.

DeNormandie, J. and C. Corcoran. 2009. Losing ground: beyond the footprint, patterns of development and their impact on the nature of Massachusetts. Mass Audubon, May 2009.

Faison, E. K., G. Motzkin, D. R. Foster, and J. E. McDonald. 2010. Moose foraging in the temperate forests of southern New England. Northeast Naturalist 17: 1-18.

Garner, D. L., and W. F. Porter. 1990. Movement and seasonal home ranges of bull moose in a pioneering Adirondack population. Alces 26: 80-85.

Goodwin, G. G. 1936. Big game animals of the northeastern United States. Journal of Mammalogy 17: 48-50.

Hicks, A. 1986. The history and current status of moose in New York. Alces 22: 245-252.

_____, and E. McGowan. 1992. Restoration of moose in northern New York State. Draft Environmental Impact Statement. New York Department of Environmental Conservervation, Albany, New York, USA.

Karns, P. D. 1997. Population distribution, density, and trends. Pages 125-139 *in* A.W. Franzmann and C.C. Schwartz, editors. Ecology and Management of the North American Moose. Smithsonian Institution Press, Washington, D.C., USA.

Kilpatrick, H. J., R. Riggs, A. Labonte, and D. Celotto. 2003. History and status of moose in Connecticut. Connecticut Department of Environmental Protection, Hartford, Connecticut, USA.

Kittredge, D. B., Jr., A. O. Finley, and D. R. Foster. 2003. Timber harvesting as ongoing disturbance in a landscape of diverse ownership. Forest Ecology and Management 180: 425-442.

Lankester, M. W. 2010. Understanding the impact of meningeal worm, *Parelaphostrongylus tenuis*, on moose populations. Alces 46: 53-70.

Lauber, T. B., and B. A. Knuth. 1997. Fairness in moose management decision-making: the citizens perspective. Wildlife Society Bulletin 25: 776-787.

Lenarz, M. S., M. E. Nelson, M. W.Schrage, and A. J. Edwards. 2009. Temperature mediated moose survival in northeastern Minnesota. Journal of Wildlife Management 73: 503-510.

McDonald, J. E., Jr. 2003. Bears and moose in Massachusetts: the past, the present and the future possibilities. Transactions of the North American Wildlife and Natural Resources Conference 68: 225-234.

McDonald, R .I., G. Motzkin, M. S. Bank, D. B. Kitteridge, J. Burke, and D. L. Foster. 2006. Forest harvesting and land-use conversion over two decades in Massachusetts. Forest Ecology and Management 227: 31-41.

Morris, K. I. 2007. Moose assessment. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine, USA.

Murray, D. L., E. W. Cox, W. B. Ballard, H. A. Whitlaw, M. S. Lenarz, T. W. Custer, T. Barnett, and T. K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. Wildlife Monograph 166: 1-30.

Musante, A. R., P. J. Pekins, and D. L. Scarpitti. 2007. Metabolic impacts of winter tick infestations on calf moose. Alces 43: 101-110.

_____, _____, _____. 2010. Characteristics and dynamics of a regional moose *Alces alces* population in the northeastern United States. Wildlife Biology 16: 185-204.

New Hampshire Fish and Game Department (NHFG). 2005. New Hampshire big game plan; species managment goals and objectives 2006-2015. New Hampshire Fish and Game Department Concord, New Hampshire, USA.

New York State Department of Environmental Conservation (NYDEC). 2010. Moose. <http://www.dec.ny.gov/animals/6964.html> (accessed June 2010).

Orwig, D. A., D. R. Foster, and D. L. Mausel. 2003. Landscape patterns of hemlock decline in New England due to the introduced hemlock woolly adelgid. Journal of Biogeography 29: 1475-1487.

Peek, J. M., and K. I. Morris. 1998. Status of moose in the contiguous United States. Alces 34: 423-434.

Renecker, L. A., and R. J. Hudson. 1986. Seasonal energy expenditures and thermoregulatory responses of moose. Canadian Journal of Zoology 64: 322-327.

Samuel, W. M. 2007. Factors affecting epizootics of winter tick and mortality of moose. Alces 43: 39-48.

U.S. Census Bureau. n.d. Census 2000. Population Housing Units, Area and Density for States: 2000. <http://www.census.gov/population/www/censusdata/density.html.> (accessed June 2010).

Vecellio, G. M., R. D. Deblinger, and J. E. Cardoza. 1993. Status and management of moose in Massachusetts. Alces 29: 1-7.

Vermont Fish and Wildlife Department (VFWD). 2010. 2009 Vermont wildlife harvest report; moose. Vermont Department of Fish and Wildlife, St. Johnsbury, Vermont, USA.

Vermont Moose Management Team. 2008a. 2008 moose season proposal. Vermont Department of Fish and Wildlife, St. Johnsbury, Vermont, USA.

_____. 2008b. Executive summary, 2008 moose season proposal. Vermont Department of Fish and Wildlife, St. Johnsbury, Vermont, USA.

Wattles, D., and S. DeStefano. 2009. Movement and landscape pattern use of a colonizing moose population in Massachusetts. USGS Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts, Amherst, Massachusetts, USA.

Whitlaw, H. A., and M. W. Lankester. 1994. A retrospective evaluation of the effects of parelaphostrongylosis on moose populations. Canadian Journal of Zoology 72: 1-7.