Moose in Michigan: History, Biology, and Considerations for Hunting

Report to the Michigan Department of Natural Resources and Environment
Moose Hunting Advisory Council

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Executive Summary

Moose are native to Michigan but numbers declined as settlement progressed. The State granted moose full legal protection in 1889; however, this protection did not lead to long-term recovery. Moose disappeared from the Lower Peninsula in the 1890s and only a few scattered individuals remained in the Upper Peninsula. The State attempted to reintroduce moose in the Upper Peninsula mainland in the 1930s by releasing 63 moose from Isle Royale. This reintroduction attempt failed. The State made a second attempt to reintroduce moose in the mid 1980s by releasing 59 moose from Algonquin Provincial Park (Ontario, Canada) into Marquette County. The goal of this reintroduction was to produce a self-sustaining population of free ranging moose. An optimistic objective of 1000 moose by the year 2000 was established but not reached.

In addition to Isle Royale in Lake Superior, currently (2011) moose are found in two general areas of the Upper Peninsula. The herd which originated from the releases in the mid 1980s ranges across parts of Marquette, Baraga and Iron counties. Moose also occur in the eastern Upper Peninsula ranging across parts of Alger, Schoolcraft, Luce, and Chippewa counties. Both the western and eastern ranges have remained relatively stable over the last decade.

Biologists working in the eastern Upper Peninsula believe there are currently fewer than 100 animals in this area, but the only formal survey attempt was in 1991. Since 1997, the Department of Natural Resources and Environment (DNRE) has estimated moose abundance in the western Upper Peninsula with aerial surveys. Survey results indicate the population grew from about 130 animals in 1997 to over 430 animals in 2011. There is considerable statistical variance associated with the population estimates because moose abundance is relatively low and moose have a clumped distribution on the landscape. These factors make it difficult to achieve estimates with high statistical precision. The abundance estimates from 2009 and 2011 are notable in that they suggest population growth may have slowed. However, due to the width of the confidence intervals, it is not possible to state with statistical certainty whether population growth has increased, decreased, or remained stable over this 2-year period. Given the statistical precision of the moose population estimates, small changes in population growth rate cannot be detected on a short-term basis.

The growth (positive, negative, or zero) of the moose population is the result of the interaction of the rates of birth, death, immigration, and emigration. Estimates of these rates can aid understanding of the factors which may be influencing the population. The annual pregnancy rates of adult cows in the western Upper Peninsula are low compared to average rates of moose throughout North America and represent an important limitation to population growth. In addition, there is evidence pregnancy rates may have declined from 1999 to 2004 and twinning rates are also generally low in this population. Survival rates of calves in the western Upper Peninsula are high and suggest predation and winter stress are not important mortality factors for this age class. Survival rates of yearling and adult moose in the western Upper Peninsula are similar to other moose populations that are not harvested, but higher than moose survival rates in northwestern and northeastern Minnesota where populations are declining. A variety of diseases and trauma associated with accidents are the leading causes of death for moose in the western range. Brainworm has not been an important mortality factor over the last decade, yet the parasitic liver fluke is. About 5-6% of moose emigrate from the western Upper Peninsula range each year, and this loss is not offset by immigration and must be taken into account.

Climate change, in particular increasing temperatures, is an important concern since the southern distribution of moose throughout the world appears to be controlled by temperature. Moose are easily heat stressed and climate change projections suggest conditions in Michigan may be unsuitable for moose by the end of this century. An information/education program on this topic will be important. Harvesting moose when a population decline related to climate change is possible may present two challenges. First, if a population decline occurs it will be difficult to know the specific cause without extensive and expensive monitoring and research. Second, the public may blame any population decline on hunting, which could result in negative impacts to this important cultural and wildlife management activity.

Moose are on the list of Michigan game species and Public Act 366 of 2010 allows the establishment of the first moose hunting season since the late 1800s, and authorized the Natural Resources Commission to pass moose hunting regulations. Public Act 366 also created the Moose Hunting Advisory Council (MHAC). The MHAC has one year to make recommendations on expanding moose hunting, the economics of moose hunting, and proposed season dates and quotas.

The range of moose in the Upper Peninsula falls within two Native American treaty areas. Approximately 96% of the western Upper Peninsula moose range occurs within the 1842 Treaty of LaPointe ceded territories, and the remainder within the 1836 Treaty of Washington ceded territories. The entire range of moose in the eastern Upper Peninsula is located within the 1836 Treaty of Washington ceded territories. In 2007, Michigan signed a consent decree with the 1836 tribes that describes the consultation process to follow before moose may be hunted. The 1842 Treaty of La Pointe ceded territories extend into Wisconsin and the 1842 tribes' hunting and fishing rights have been adjudicated in federal circuit court in Wisconsin. However, since that ruling was in circuit court, there is no formal agreement which defines the extent of 1842 treaty rights within Michigan.

Factors to consider when evaluating the sustainability of a moose hunting season include:

- Information on distribution, abundance and vital rates exists to evaluate the sustainability of moose hunting in the western Upper Peninsula range but not the eastern range.
- Harvesting of cows would not be sustainable because of the small size of the western Upper Peninsula herd and the disproportionate importance of each female to the reproductive potential of the population.
- Any harvest prescription must ensure an adequate bull to cow ratio to maintain pregnancy rates.

- A reproductive (compensatory) response to a harvest is not expected because the western Upper Peninsula population is not limited by the amount of available food.
- The mortality of bulls from hunting will not likely substitute for other forms of mortality (i.e., the harvest of bulls will be additive to other forms of mortality).
- With no reproductive response and additive harvest mortality, hunting will reduce the rate of population growth.

Using the abundance estimates and population dynamic data for the western Upper Peninsula moose population, Michigan State University and the DNRE developed a population model to evaluate the dynamics of this population and response to various hypothetical harvest levels. Key findings from the simulation modeling include:

- Harvests of 10 or fewer bulls per year does not appear to reduce the bull to cow ratio to unsustainable levels.
- A harvest of 10 bulls per year reduces the growth rate of the population by about 2% the first year of harvest when pregnancy rates average 70%. This level of harvest lowers growth rate closer to zero if the actual pregnancy rate is reduced below 70%.
- If reproductive rates and survival rates of moose in Michigan decline to levels observed in the declining populations in Minnesota, the growth rate of Michigan's population would approach zero.
- Harvests of 20 bulls or more per year are unlikely to be sustainable because the number of cows per bull would exceed 1.5, possibly leading to lower pregnancy rates and thus, lower population growth.

Apart from hunting, per se, other decisions to be made include: season timing, season length, hunt frequency (annual or otherwise), antler restrictions, single hunters vs. group hunting, hunt unit boundaries, hunting access, tag drawing logistics, and harvest monitoring.

History

The moose (*Alces alces*) is the largest member of the deer family and occurs in Europe, Asia, and North America. Moose are native to Michigan and occurred throughout all except the southwestern Lower Peninsula prior to European settlement (Verme 1984, Baker 1983). The Lower Peninsula is at the southern edge of moose range and moose were probably never abundant in this region (Dodge 2002). The influx of settlers resulted in increased hunting pressure and habitat changes which caused moose numbers to decline, and moose were given full legal protection in 1889. However, this protection did not lead to long-term recovery. Moose disappeared from the Lower Peninsula in the 1890s, and only a few scattered individuals remained in the Upper Peninsula. It is not known if moose disappeared from the Upper Peninsula in the early 1900s because historical records are scant. It is possible that a small remnant population persisted in the Upper Peninsula, although moose could have died out and then reestablished through immigration from Ontario (Dodge 2002).

The interaction of several factors probably caused the decline of moose in Michigan. First, extensive logging during the early 20th century eliminated millions of acres of moose habitat. Loggers, miners, and other settlers also took these large animals for food. Another factor thought to have contributed to the decline of the population was brainworm (*Parelaphostrongylus tenuis)*, a nematode carried by white-tailed deer.

Although the brainworm has little effect on white-tailed deer, it can cause a fatal neurological disease in moose. Infected moose display weakness, circling, blindness, and paralysis. Infected moose often die, although recent evidence indicates that the disease is not always fatal as previously thought (Lankester and Samuel 1998). The Michigan deer population was generally low before European settlement. However, deer numbers expanded rapidly in the more open and brushy habitat created by the logging and forest fires that followed settlement. As a result, the incidence of brainworm in the moose population likely increased.

The state's first attempt to reintroduce moose in the Upper Peninsula mainland occurred from 1934-1937 when biologists trapped and transported 71 moose from Isle Royale to the mainland (Hickie, ca 1943). Most of these moose (n = 63) were released in Keweenaw, Marquette, and Schoolcraft counties. Of the remaining moose, officials sent two to the Detroit Zoo, and six to the Cusino Wildlife Experimental Station for study of basic moose biology. These studies revealed information on the dates of the rutting season, gestation period, rate of growth from birth to maturity, types of food eaten and food preferences, and antler development.

At the time of capture, the Isle Royale moose population was very high and moose had depleted the forage on the island. As a result, moose brought to the mainland were in poor physical condition and some developed serious infections after release. Many of the introduced moose died from what was described at the time as "circling disease," most likely caused by the brainworm parasite. Although citizens reported observing moose across the Upper Peninsula in 1941, poaching continued as a threat to the population.

The poor condition of the translocated moose combined with poaching and high deer numbers all contributed to the failure of this initial attempt to reintroduce moose on the mainland.

During the 1950s and 1960s, citizens occasionally observed moose in the Upper Peninsula, primarily in the eastern counties. In the 1970s, biologists recognized changes in the Upper Peninsula that were promising for moose. Most notable was a decline in deer numbers in the northern portions of the Upper Peninsula. On two different occasions, the DNRE brought moose management specialists from Ontario to evaluate potential moose habitat in the Upper Peninsula. The Ontario moose specialists confirmed that Michigan had habitat capable of supporting breeding populations of moose.

The DNRE debated the pros and cons of introducing moose during the 1970s. One concern was the potential impact of brainworm on a reintroduced population. In the early 1980s, the Wildlife Division conducted several surveys to determine deer densities and the proportion of deer carrying brainworm. These surveys indicated that although a majority of deer carried brainworm, a large portion of the Upper Peninsula had fewer than 10 deer/mi^2 (4 deer/km^2). Moose experts advised that if deer populations were below 10 deer/mi^2, the frequency of transmitting the parasite to moose would be low enough that the moose's reproductive potential would outweigh deaths due to brainworm.

Because of the experts' recommendations, the DNRE explored potential sources for obtaining moose to reintroduce into the Upper Peninsula. After considering several sources, officials selected the Province of Ontario. A team of Ontario and Michigan biologists considered three sites to obtain the animals, and selected Algonquin Provincial Park, located east of Lake Huron. The biologists also reviewed several potential reintroduction sites in the Upper Peninsula and selected an area north of Lake Michigamme, about 40 mi (64 km) west of Marquette. Some of the funding for the reintroduction project came from private funds. The Michigan Involvement Committee of the Michigan chapters of Safari Club International was the major private contributor. Other groups that provided support include Michigan's Loyal Order of the Moose, the Upper Peninsula Sportsmen's Alliance, several Lions Club chapters, the Michigan United Conservation Clubs, and the Michigan Wildlife Habitat Foundation.

Biologists scheduled the translocation for midwinter to take advantage of several factors. First, the frozen lakes provided open areas for capturing and handling moose by helicopter in the roadless reaches of Algonquin Provincial Park. Second, most cow moose would be carrying calves as small embryos. In effect, this meant getting two and sometimes three moose in Michigan after calves were born with only the effort required to capture and move one animal. Finally, the colder temperature would help moose cope with the drugs used for their capture and the general stress of capture.

The original plan was to deliver 30 moose from Algonquin to Michigan over two winters. The Michigan and Ontario teams initiated the first of two planned transfers during late January 1985; this effort became known as "Moose Lift." The timing of the second effort would depend on how well the first effort went. Despite public education campaigns and careful planning and testing of all phases of the operation, biologists did not want to implement the second phase unless the first phase was successful. Unanticipated problems could occur in drugging the moose, using a helicopter to lift and transport moose under wilderness conditions, and transporting moose 600 mi (965 km) in crates on trucks during the winter when snowstorms often restricted travel for days. Experience also had shown that poachers could have devastating impacts on a small population, so the public's acceptance and cooperation in protecting moose was extremely important.

The first effort resulted in the release of 29 moose; 10 bulls and 19 cows. Calf production and survival that spring were excellent with the 19 cows producing 21 calves. During the following spring three bulls died of unknown causes and another bull wandered east across the Peninsula, leaving six widely scattered bulls to breed the 19 cows. In the spring of 1986, only 14 cow moose remained and they produced only ten calves. The good news was that there were no suspected poaching losses. The DNRE decided to conduct a second translocation the following winter to improve the ratio of bulls to cows in the population.

The second phase, "Moose Lift II," took place in early February 1987 and resulted in the translocation of 30 additional moose, 15 bulls and 15 cows. These moose were released in the same area as the first group.

All of the moose in both "lifts" were fitted with mortality-sensing radio collars to help monitor the outcome of the reintroduction. The translocated moose population increased through the late 1980s and early 1990s in spite of a few losses each year to brainworm and several other natural causes, including falls off cliffs, fights during the rut, and complications while giving birth. Calf production and survival through the first year of life were very good, confirming the habitat was suitable. Poaching losses were virtually nonexistent, perhaps because the citizens of the Upper Peninsula were involved with the project and had adopted the new moose population as their own.

Moose Management Goal

The goal of Michigan's moose management program is a self-sustaining population of free-ranging moose. An Ontario moose expert who surveyed the Upper Peninsula in the early 1970s thought the area could support a population of 1000 animals. Based on his assessment and a simple simulation model, some thought a population of 1000 moose could be reached by the year 2000 and the slogan "1000 by 2000" was born. It is important to note the objective of 1000 moose by the year 2000 was the highest population size achieved in the simulations (Table 1). The moose population grew slower than the maximum rate predicted by the simulations, and as a result, the herd did not meet those initial expectations.

Status of the Moose Population

Moose Distribution

Although citizens have observed moose in every county of the Upper Peninsula, the range of resident moose is more restricted (Fig. 1). In addition to the population on Isle Royale in Lake Superior, moose are found in two general areas in the Upper Peninsula. The western moose range includes parts of Marquette, Baraga, and Iron counties and is approximately 1,400 mi^2 (3,700 km^2). The eastern moose range includes parts of Alger, Schoolcraft, Luce, and Chippewa counties and is about 1,200 mi^2 (3,100 km^2). Other than a translocated bull that traveled from the release area in the western Upper Peninsula to the eastern Upper Peninsula, biologists have not documented movements of radio-collared moose between the two ranges.

In 1982, Ontario moose biologist M. L. Wilton evaluated potential moose habitat in the Upper Peninsula. To his credit, the areas of suitable habitat he identified (with the exception of the Keweenaw Peninsula) are the places where moose currently occur. The distribution of moose appears closely related to the distribution of wetlands, in particular, areas where forested and shrub wetlands are interspersed with forested uplands. The terrain in the eastern range is relatively flat and supports large continuous areas of uplands and wetlands with less interspersion and edge. This lack of interspersion and edge reduces habitat suitability for moose. In contrast, the terrain in the western Upper Peninsula is more broken which creates smaller areas of uplands and wetlands, greater amounts of edge, and subsequently better habitat for moose.

Based on aerial and ground observations and movements of radio-collared moose, the range of moose in the western Upper Peninsula has not changed significantly in the last decade. In addition, based on Wilton's assessment and the distribution and interspersion of forested and shrub wetlands, the western range of moose is not expected to expand significantly. Although detailed information on moose in the eastern Upper Peninsula range is lacking, biologists working in this area believe the eastern range has also remained relatively stable over the last 10 years.

The majority (87%) of the western Upper Peninsula moose range is privately owned; 54% commercial forest and 33% private nonindustrial. Public lands make up the remainder and include state (11%) and federal (2%) forests. In contrast, 64% of the eastern Upper Peninsula range is in state (49%) and federal (15%) ownership. Commercial forest companies own only 12% of the eastern range with private nonindustrial landowners holding the remaining 24%.

The range of moose in the Upper Peninsula falls within two Native American treaty areas. Approximately 96% of the western Upper Peninsula moose range occurs within the 1842 Treaty of LaPointe ceded territories, and the remainder within the 1836 Treaty of Washington ceded territories. The entire range of moose in the eastern Upper Peninsula is located within the 1836 Treaty of Washington ceded territories (Fig. 1).

Moose Abundance

Initially the size and growth of the reintroduced population in the western Upper Peninsula were determined through a simple accounting process. All of the released animals were radio-collared, and biologists simply monitored how many died and how many calves were born to radio-collared cows. Tracking the growth of the population was as simple as adding reproduction and subtracting mortality.

As the population grew and the sample of radio-collared of moose declined through mortalities and collar attrition, an increasing proportion of the population was not marked with radio-collars. This caused biologists to shift from a simple accounting process to a "population model" to determine population growth using estimates of reproduction and mortality derived from the sample of radio-collared animals. The accuracy of a population model is dependent on having an adequate and representative sample of moose collared. Through time the radio-collared sample of moose probably did not adequately represent the age structure of the moose population. This could influence model results because cows of different ages may have different rates of survival and calf production. In the early 1990s, the number of radio-collared animals was small and with reduced sample size, estimates of mortality and reproduction became less certain. In addition, calf counts in 1992 and 1993 were not conducted. Because of these factors, biologists had to incorporate estimates of reproduction and mortality from previous years in the model. It is quite likely that this introduced additional error in the population estimates because rates of reproduction and mortality vary annually. In addition, estimates for the rate of emigration were not available and this loss from the population was not included in the model, adding another potential source of error in the population estimates.

It was clear a less intensive method to monitor moose numbers was needed, as the DNRE could not afford to maintain an adequate sample of radio-collared animals indefinitely. The most common method of estimating moose numbers throughout the species' range is an aerial survey. Due to cost and time constraints, only a portion of the total range is typically surveyed, and statistical extrapolation is used to derive a population estimate for the entire land area. There are many variations of aerial survey techniques, however regardless of the technique, it is unlikely that observers will see all of the moose in an area. This is particularly true in landscapes that have extensive cover of conifer trees, such as in the Upper Peninsula. Consequently, aerial surveys have been refined to incorporate "sightability correction factors" for moose that are missed by observers. Correction factors most commonly take the form of a sightability model. Wildlife managers commonly use sightability models to estimate abundance of large cervids (Samuel et al. 1987, Bodie et al. 1995, Anderson and Lindzey 1996).

In 1991, the DNRE conducted an experimental aerial moose survey. Survey procedures followed the "Standards and Guidelines for Moose Population Inventory in Ontario" developed by Oswald (1982). Biologists identified approximately 7,200 mi^2 (18,648 km^2) of the Upper Peninsula as potential moose range. The identified range was stratified into high and low moose density plots. Plots were 3 mi (4.8 km) long and 3 mi

(4.8 km) wide. Biologists selected a random sample of 70 plots in the western Upper Peninsula and 29 plots in the eastern Upper Peninsula to survey. By comparing the number of radio-collared moose known to be on the plots to the number of radio-collared moose counted by observers, biologists corrected the aerial counts to account for moose that were not observed. In the western Upper Peninsula, biologists estimated a population of 210 animals. However, calculation of statistical confidence intervals was not possible because observers found zero moose on the low-density stratum plots. Observers did not see any moose on the 29 plots in the eastern Upper Peninsula, thus moose abundance in this region could not be determined.

After the 1991 survey, the DNRE, in collaboration with Michigan Technological University and Michigan State University, developed and refined a sightability model constructed specifically for the western Upper Peninsula moose population (Drummer and Aho 1998, T. D. Drummer, unpublished data). The initial model was completed in 1995 and refined in 2005. The refined model takes the following form:

$$\text{logit(Detection)} = 0.64 - 1.26*\text{Canopy Cover} + 0.5*\text{Group Size}$$

The sightability model contains two statistical "covariates" believed to influence the probability of observers sighting a moose group; group size and canopy cover. To put the model in simpler terms; larger moose groups are easier to spot than smaller groups and moose in hardwood cover are easier to spot than are moose in conifer cover.

For all surveys (1997-2011), biologists classified portions of the moose range as either high moose density or low moose density using information from previous surveys and the movements of radio-collared moose and then divided these high and low "strata" into survey plots. From 1997-2009 there were 28 high-density plots and 29 low-density plots. In 2011, the classification of 3 plots was changed from low-density to high-density based on pre-survey flights. Thus in 2011, there were 31 high-density plots and 26 low-density plots. Survey plots were rectangular and typically 2 mi (3.2 km) wide and 12 mi (19.3 km) long. A few plots were larger or smaller, as necessary, to ensure compete coverage of the moose range in each density stratum.

Biologists estimated moose abundance in the western Upper Peninsula using the refined sightability model in 2006, 2007, 2009, and 2011, and retrospectively applied the model to survey data from 1998 and 2001. Moose abundance in 1997 was estimated with the first version of the sightability model. Survey results indicate the population grew from about 130 animals in 1997 to over 430 animals in 2011 (Fig. 2). There is considerable statistical variance associated with the population estimates because moose abundance is relatively low and moose have a clumped distribution on the landscape. These factors make it difficult to achieve estimates with high statistical precision (Thompson 2004). The mean percent error of the estimates (abundance estimate plus or minus some percentage), ranged from 26 to 50% with 95% confidence. However, most of the moose are found in the high-density stratum where the mean percent error is lower. During the 2006, 2007, 2009, and 2011 surveys, 81-93% of the moose were located in the high-density stratum, and mean percent error ranged from 17 to 26%.

The abundance estimates from 2009 and 2011 are notable in that they suggest population growth may have slowed considerably over this period. However, due to the width of the confidence intervals, it is not possible to state with statistical certainty whether population growth has increased, decreased, or remained stable over this 2-year period. Given the precision of the moose population estimates in general, short-term changes in population growth cannot be determined with confidence. The trend in the population is best judged by examining the population estimates over a longer timeframe. Additional surveys are needed to determine if the growth rate of the population has changed since 2009.

Using the abundance estimates from 1997-2011, the growth rate of the western Upper Peninsula population can be estimated by fitting an exponential growth model to the estimates. This analysis suggests the population grew at an annual rate of about 8% from 1997-2011 (Fig. 3).

Aerial surveys to estimate the abundance of moose in the eastern Upper Peninsula have not been conducted since 1991. Based on citizen's reports and observations in the field, biologists working in the eastern Upper Peninsula believe there are fewer than 100 moose in that area.

Population Dynamics

The growth (positive, negative, or zero) of any population is the result of the interaction of the rates of birth, death, immigration, and emigration. By estimating these rates, biologists can better understand the factor or factors that may be influencing a population. A cooperative study between the DNRE and Michigan State University examined the dynamics of the moose population in the western Upper Peninsula from 1999-2005. Estimates of these vital rates for the western Upper Peninsula moose population are presented below. These data are useful inputs for population modeling to examine the growth of the population and to evaluate the effects of any proposed harvest.

Reproduction

Researchers determined the pregnancy status of moose cows at the time of capture through assays of blood serum for pregnancy-specific protein B (PSPB; Haigh et al. 1993, Stephenson et al. 1995) and progesterone levels (Haigh et al. 1982, Stewart et al. 1985). In years after capture, researchers estimated pregnancy status of radio-collared cows by assays of fecal material for fecal progesterone levels (Monfort et al. 1993, Schwartz et al. 1995).

In healthy populations, pregnancy rates of adult cows are generally high (Gasaway et al. 1992) and appear to be relatively insensitive to year-to-year changes in environmental conditions (Boer 1992, Modaferri 1992). Pregnancy rates of adult cow moose (breeding at $\geq$ 2 years) in the western Upper Peninsula averaged 71% from 1999-2004 (Fig. 4). Few, if any, yearling cows in this population breed. Compared to the North American average of 84% (Boer 1992), pregnancy rates in the western Upper Peninsula are low and represent an important limitation to population growth. A second order polynomial regression fit to the pregnancy data suggests the pregnancy rate may have declined from 1999 to 2004 (Fig. 4), although inferences are limited by low sample size and the truncated time-series. The only recent insight into the reproductive rate of the population comes from calf:cow ratios based on observations during aerial surveys in 2009 and 2011. The number of calves per 100 cows was 64 and 56 in 2009 and 2011, respectively.

The production of calves in the population is a function of the number of cows that are pregnant and the number that produce singletons vs. twins. During most years from 1999-2005, the number of calves per adult cow was about 0.7, but in 1999 and 2005 the number of calves per adult cow was > 1.0 (Fig. 5). The twinning rate, calculated as the number of births involving twins divided by the number of females giving birth, was generally low, averaging about 18%. Twinning rates have been associated with body size and fat levels (Heard et al. 1997) with cows in better condition producing more twins (Keech et al. 2000). Twinning rates appear to be related to habitat quality and the size of the population relative to the habitat's carrying capacity (Gasaway et al. 1992). However, low twinning rates may be observed in populations affected by weather or disease, independent of the population size (Heard et al. 1997, Sand 1996).

Survival and cause-specific mortality

Researchers monitored the survival of radio-collared moose in the western Upper Peninsula 1-2 times per week from fixed-wing aircraft and the survival of calves of radio-collared cows monthly by observation (Dodge 2002).

Calf survival from birth to 6 months of age was about 85%, while survival from 6-months to 1-year of age averaged 94% (n = 48; 95% CI = 85–100%) during 1999-2005. Calf survival did not differ by sex. Annual survival rates of calves vary among moose populations depending on predation levels and winter conditions and range from 16 – 100% (Murray et al. 2006, Dodge et al. 2004, Bertram and Vivion 2002, Keech et al. 2000, McLaren et al. 2000, Stubsjoen et al. 2000, Osborne et al. 1991, Aho and Hendrickson 1989, Larsen et al. 1989, Albright and Keith 1987, Gasaway et al. 1983, Hauge and Keith 1981, Mytton and Keith 1981). Low annual survival is often associated with high levels of neonate predation (Bertram and Vivion 2002, Gasaway et al. 1992, Ballard et al. 1991, Osborne et al. 1991, Larsen et al. 1989, Gasaway et al. 1983, Hauge and Keith 1981), while the highest reported rates of annual calf survival are from systems with low levels of natural predation (Murray et al. 2006, Dodge et al. 2004, McLaren et al. 2000, Stubsjoen et al. 2000, Aho and Hendrickson 1989, Albright and Keith 1987, Mytton and Keith 1981). Calves may also be susceptible to higher rates of mortality during severe winter weather (Stubsjoen et al. 2000, Ballard et al. 1991, Gasaway et al. 1983). In northeastern Minnesota, annual calf survival averaged 40%, similar to other areas with wolves (*Canis lupus*) and black bears (*Ursus americanus*) (Lenarz et al. 2010). The relatively high rate of calf survival in the western Upper Peninsula suggests predation and winter stress are not important mortality factors for this age class.

Annual survival of yearling moose (those between 1 and 2 years old) averaged 85% from 1999-2005 (n = 50; 95% CI = 74–95%). Yearling cow (n = 26) survival averaged 91%, while yearling bull (n = 24) survival averaged 79%. Annual adult survival (1 June – 31 May) averaged 88% (n = 85; 95% CI 84–92%). Annual adult bull survival (n = 21; 85%) did not differ from annual adult cow survival (n = 64; 88%). The probability of surviving from birth to age 5 is estimated to be about 51%. Annual survival of yearling and adult moose varies among moose populations and ranges between 47 and 100% (Murray et al. 2006, Scarpitti et al. 2005, Dodge et al. 2004, Bertram and Vivion 2002, McLaren et al. 2000, Stubsjoen et al. 2000, Kufeld and Bowden 1996, Stenhouse et al. 1995, Gasaway et al. 1992, Ballard et al. 1991, Bangs et al. 1989, Larsen et al. 1989, Boer 1988, Hauge and Keith 1981, Mytton and Keith 1981). The lowest survival rates for adult moose are for bulls (47–58%) in areas where human hunting pressure is high (Bangs et al. 1989, Boer 1988, Albright and Keith 1987). Survival of adult cows is generally high (75–100%), and may be lowest where human hunting occurs at high levels (Stubsjoen et al. 2000, Boer 1988). In most cases, however, annual cow survival exceeds 85% and often approaches 100% for prime-age animals (Scarpitti et al. 2005, Dodge et al. 2004, Bertram and Vivion 2002, McLaren et al. 2000, Stubsjoen et al. 2000, Kufeld and Bowden 1996, Stenhouse et al. 1995, Gasaway et al. 1992, Ballard et al. 1991, Bangs et al. 1989, Larsen et al. 1989, Albright and Keith 1987). Survival rates of moose in Michigan are higher than survival rates in northwestern and northeastern Minnesota where populations are declining (Murray et al. 2006, Lenarz et al. 2010). In addition, annual survival rates in northeastern Minnesota were much more variable than those documented in Michigan (Lenarz et al. 2010).

Moose radio collars were equipped with mortality sensors that signaled when the collar remained motionless for 4-6 hours. Once researchers received this mortality signal, they located the dead moose and performed a field necropsy. Researchers sent the carcass, or more commonly, specimens from the carcass to the DNRE Diagnostics Laboratory for further study. Laboratory scientists used the results of the field necropsy and laboratory analyses to assign a cause of death.

From 1999-2005, researchers monitored 109 radio-collared moose and investigated the deaths of the 50 animals that died during this period. The DNRE Diagnostic Lab identified the cause of death in 43 of the 50 mortalities (Fig. 6). Diseases such as pneumonia, bacterial infections, pulmonary congestion, and pericarditis accounted for about 30% of the mortality. Nearly 25% of moose died from trauma associated with mishaps such as breaking through ice on waterways or being stuck in mud.

Liver flukes (*Fascioloides magna*), a parasite common in white-tailed deer, were the primary cause of 14% of moose deaths. Of the 43 mortalities where cause of death could be determined, 16% had liver flukes listed as the primary cause of death and 66% had some level of liver fluke infestation. Researchers studying moose in northwestern Minnesota attributed a long-term decline in moose numbers, in part, to liver flukes.

Starvation accounted for 10% of mortality. Although biologists were concerned about losses due to brainworm, this parasite accounted for only 2% of total mortality. Predation by wolves and bears was not an important source of mortality. Researchers did find winter ticks (*Dermacentor albipictus*) on moose; although there was no evidence the infestations were causing mortality. Losses by drowning and vehicle strikes were low.

Immigration

There is no evidence to suggest moose are immigrating into the western Upper Peninsula moose range. The only radio-collared moose documented moving between the western and eastern ranges of the Upper Peninsula was a bull released during the 1985 reintroduction. In addition, there are no records of non-collared moose moving between the two ranges, nor has there been any evidence of moose from Minnesota making their way to the western range. Although researchers have documented the movement of moose back and forth from Michigan to Wisconsin, the small population in Wisconsin (~20-40 animals) is not large enough to provide many immigrants. The St. Mary's River separating Michigan from Ontario, Canada is not a barrier to moose, thus it is likely moose occasionally move between Ontario and the eastern Upper Peninsula. For the purposes of modeling population dynamics, immigration into the western Upper Peninsula moose range does not appear to be an important factor.

Emigration

Researchers estimated the rate at which moose emigrated out of the western Upper Peninsula moose range by monitoring the radio-collared animals and determining how many animals left and did not return. The results indicate about 5-6% of moose emigrate from this range each year. Because the loss of animals through emigration is not offset by immigration, this loss needs to be taken into account when modeling the dynamics of the population.

Moose and Climate Change

Moose are circumpolar, occurring around the world in the northern hemisphere. Metabolic research suggests moose are well adapted to cold but maladapted to heat (Renecker and Hudson 1986). Indeed, the southern limit of moose distribution appears related to temperature. Throughout the world, the southern edge of moose range occurs near the 68° F (20° C) July isotherm (Tefler 1984). Moose found farther south occur in cooler mountainous regions. Michigan is at the southern edge of moose range in North America.

The climate of the Great Lakes region is changing; shorter winters, increasing temperatures, and more common extreme heat events (Kling et al. 2003, Karl et al. 2009). Long-term climate change may have the most pervasive influence on moose near the southern extent of their range where temperatures are warmest and overlap with white-tailed deer is greatest (Maskey 2008, Murray et al. 2006). Moose are easily heat stressed and must actively thermoregulate when temperatures exceed 23° F (-5° C) in winter and 57° F (14° C) in summer (Renecker and Hudson 1986). Modeling suggests that high temperatures would reduce moose activity and preempt foraging and that moose could not make up the resultant energy loss the following day (Renecker and Hudson 1992). Researchers studying moose in northwestern Minnesota correlated a moose population decline to increasing summer temperatures (Murray et al. 2006). These researchers speculated that energetic costs of thermoregulation combined with decreased foraging in warm weather might have lowered the physical condition of moose, resulting in increased susceptibility to pathogens and malnutrition. In northeastern Minnesota, researchers concluded that temperatures greater than the identified physiological thresholds were important for explaining variation in moose survival rates (Lenarz et al. 2009). In particular, this study found that January temperatures above the 23° F (-5° C) threshold were inversely related to spring, fall and annual survival.

Projections of climate change suggest that temperatures in Michigan will rise by 6–10° F (3.3–5.5° C) in winter and 7–13° F (3.9–7.2° C) in summer by the end of the 21st century (Kling et al. 2003). This would mean that Upper Peninsula winters would be similar to current winters in the southern Lower Peninsula and Upper Peninsula summers would be similar to current summers in Missouri. Given what biologists know about the limits to the southern distribution of moose, moose are unlikely to persist in Michigan if these projections are realized.

Considerations for Hunting Moose

Authorities and responsibilities

Moose were given complete protection in Michigan in 1889 and no legal harvest of moose has occurred since that time. Public Act 366 of 2010, signed by the Governor on December 22, 2010, allows the establishment of the first moose hunting season since the late 1800s, and authorized the Natural Resources Commission (NRC) to pass moose hunting regulations. Prior to the passing of this legislation, moose were on the list of game species. Public Act 366 also created the Moose Hunting Advisory Council (MHAC). The MHAC must make a report to the Department, NRC and legislature within 12 months, which will include recommendations on whether or not to expand moose hunting, the economics of moose hunting, and proposed season dates and quotas.

Section XXV of the 2007 Consent Decree for the 1836 Treaty contains the following provision that pertains to consideration of hunting moose in this treaty area:

> "…For species designated as game species under Michigan law as of October 2006 (as also set forth in Appendix K), the issue shall be whether the State has a reasonable basis for prohibiting such harvests taking into consideration the Tribes' interest in allowing such harvests, *provided* that no harvest of moose shall be permitted by the State or the Tribes unless the State and the Tribes agree that such harvest is appropriate and agree on an allocation of such harvest..."

Important biological considerations

Wildlife Division's strategic plan emphasizes sustainable management of the state's wildlife populations. Listed below are a number of factors related to the biology and population dynamics of moose to consider when evaluating the sustainability of a moose hunting season.

- Information on distribution, abundance and vital rates exists to evaluate the sustainability of moose hunting in the western Upper Peninsula range. Information does not exist to characterize the population or evaluate the sustainability of hunting moose in the eastern Upper Peninsula range.
- Given the relatively small size of the western Upper Peninsula moose population, low rate of growth, and the disproportionate importance of each female to the reproductive potential of the population, harvesting of cows would not be sustainable.
- Given the comparatively low rates of pregnancy in the western Upper Peninsula population and a bull:cow ratio close to 1:1, a harvest that reduced the number of bulls per cow could lower the pregnancy rate, which in turn would lower the growth rate of the population. Unfortunately, the threshold or number of bulls per cow needed to ensure adequate levels of breeding in the Great Lakes region is unknown. A Moose Advisory Committee convened by the Minnesota Legislature in response to declining moose abundance recommended a ratio of at least one bull per 1.5 cows (Crete et al. 1981, Peterson et al. 2009).
- There is no evidence to suggest the western Upper Peninsula moose population is limited by the quantity of food available. Because the population is not food limited, a reproductive response (compensatory) to a harvest is not expected. In other words, cows will not produce more calves if moose numbers are reduced through hunting.
- There is no evidence to suggest that the harvest of bulls will be compensatory, i.e., harvest mortality will not likely substitute for other forms of mortality. Thus, the harvest of bulls will be additive to other forms of mortality. This is an important point because it follows that without a reproductive response any harvest will reduce the rate of population growth. For example, if a population of 400 moose was growing 10% each year, without a harvest the population would grow to 440 animals. If 10 bulls were harvested, the population would grow to 430 animals. With this harvest, the growth rate declines from 10% to 7.5%.

Simulation model

Wildlife managers often use population models to predict the response of a wildlife population to proposed harvests or changes in vital rates. Using the abundance estimates and population dynamic data for the western Upper Peninsula moose population, Michigan State University and the DNRE developed a population model to evaluate the dynamics of this population and response to various hypothetical harvest levels.

The population model spans the years 2001– 2050. Years 2001 – 2009 are historic and serve to calibrate the model against the results of the aerial surveys. Years 2010 – 2050 are projections based upon the model inputs. The model inputs and the basis for these estimates are:

- Population age structure was determined by reconstructing the population (in a life table format) based on age at death from necropsies and histories of radio-collared animals.
- Age specific survival rates for ages calf to 5 were based on survival analysis from radio collared moose (standard errors and confidence intervals are available).
- Age specific survival rates for ages 6 to 16+ were based on age distribution reconstruction, estimates from the literature, and model calibration.
- Percent adult cows reproducing was based on survey data of radio collared females, and blood serum and fecal progesterone analyses (standard errors and confidence intervals are available).
- Calves per breeding adult female was based on survey data (standard errors and confidence intervals are available).
- Males per 100 calves; no data exist to estimate the true value of this variable for the western Upper Peninsula moose.
- Yearlings emigrating per 100 yearlings was based on data from radio collared moose; between 4% and 6% annually.
- Ratio of emigrants (bulls:cows) was based on data from radio collared moose; between 1:1 and 3:1 (bulls:cows).

Age specific survival rates for ages 6 to16+ and the number of males per 100 calves are the only variables for which there are not research-based values for the western Upper Peninsula moose herd. Once specified for a particular model run, all variables are held constant (i.e., a deterministic model).

To study the population response to various harvest levels, the total number of bulls harvested is entered. In the simulations, the first hunting season was set for 2012. The bulls are “harvested” proportional to the availability of the yearling to16+ age classes; no calves are harvested.   Based on the discussion above on important biological considerations, the model does not allow the harvest of cows.

A more complete description of the model is provided in Appendix A.

Modeling results

The base run of the deterministic model (i.e., no harvest) suggests the western Upper Peninsula moose population would reach 1000 animals in 2023 if the vital rates remain constant (Fig 7). However, it is important to recall the uncertainty in the trend of population growth based on the abundance estimates in 2009 and 2011.

As discussed previously, the reproductive output of the western Upper Peninsula moose population is relatively low and represents an important limitation to population growth.

In addition, there was some indication that the reproductive rates may have declined from 1999-2004. In the declining northwestern Minnesota moose population only about 48% of adult cows were pregnant (Murray et al. 2006). Simulations suggest a similar reduction in pregnancy rates in Michigan, would by itself, reduce the growth rate of the population to zero (Fig. 8). Similarly, if survival rates of adult cows in Michigan declined to the average annual survival observed in the declining northeastern Minnesota population (79%; Lenarz et al. 2010), the western Upper Peninsula population's growth rate would approach zero.

Although there is uncertainty regarding the current rate of growth for the western Upper Peninsula moose population, modeling population responses to varying harvest levels can provide managers with a general understanding of the population's response to a proposed harvest. The modeling results must be viewed cautiously because the deterministic model assumes that vital rates do not change annually, an unrealistic assumption. In addition, the deterministic model does not account for the occasional year with very high mortality. In the past 2 decades, there have been 2 years in which significant continent-wide mortality occurred (R. Peterson, Michigan Technological University, personal communication).

There are two important metrics to examine when evaluating the population response to a bull harvest: the annual growth rate and the bull to cow ratio. Simulations indicate that a harvest of ≥ 20 bulls per year will result in more than 1.5 cows per bull in the population. As discussed above, exceeding this threshold could reduce the pregnancy rate, and thus, the population's growth rate. A harvest of 15 bulls per year would maintain a bull:cow ratio below this threshold but only if the pregnancy rate is ≥ 70%. If the pregnancy rate of adult cows drops below the average rate of 70%, the number of cows per bull could exceed 1.5. Harvest of 10 or fewer bulls per year appears to maintain an adequate bull: cow ratio across pregnancy rates ranging from 70 to 55%.

A harvest of 10 bulls per year reduces the growth rate of the population by 2% at a pregnancy rate of 70% (Fig. 9). Simulations show this level of harvest lowers the growth rate closer to zero as the pregnancy rate declines.

Hunting season structure

Other considerations regarding how to implement a moose hunt include: season timing (post-rut would ensure breeding is not disrupted), season length, hunt frequency (annual hunt vs. every other year), antler restrictions (for example, target older and growth retarded bulls), single hunters vs. group hunting, hunt unit boundaries, hunting access, the logistics and opportunity for drawing a permit (e.g., once-in-a-lifetime, a weighted draw, preference points, etc.), and mandatory vs. voluntary harvest checking.

Management Issues

- Michigan's moose range is near the southern edge of moose range in the non-mountainous regions of North America. There is good evidence the southern boundary of moose range is controlled by temperature. Climate change, especially warming temperatures, may have a direct effect on moose by limiting their ability to forage effectively. This may be one reason why reproductive rates of Michigan moose are low. Warmer temperatures may benefit white-tailed deer allowing populations to increase which may indirectly affect moose by increasing the incident rates of brainworm and liver flukes. Moose populations in northwestern Minnesota have declined to near zero numbers and the population in northeastern Minnesota is declining. Researchers have suggested these declines may be related to increasing temperatures. If current climate change projections are accurate, moose are unlikely to persist in Michigan. An information/education program on this topic will be important.

- Harvesting moose when a population decline related to climate change is possible may present two challenges. First, if a population decline occurs it will be difficult to know the specific cause without extensive and expensive monitoring and research. Second, the public may blame any population decline on hunting, which could result in negative impacts to this important cultural and wildlife management activity.
- Much of the moose range in the western Upper Peninsula is in private ownership. Currently, there are no mechanisms to consider moose habitat needs on these private lands.
- There are two general habitat trends in the western Upper Peninsula that may be important to moose. The first is that the proportion of mesic conifer stands (i.e., white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*)) has been greatly reduced over time. Mesic conifers provide cover and shade for moose. Management plans for state land in the western Upper Peninsula have a goal of doubling the area covered by mesic conifers, yet these are slow-growing trees and this management goal does not apply to private lands. The second trend relates to the age class distribution of aspen. The age class distribution of aspen is skewed with a large proportion of aspen in the 20-39 year age class. Young aspen provides forage for moose, but little aspen 0-20 years old will be available in the next 20 years.
- Given the statistical precision of the moose population estimates, biologists will not be able to discern small changes in population growth rate on a short-term basis. This becomes most critical if the population growth rate approaches zero.
- The 1842 Treaty of La Pointe ceded territories encompass most of the western Upper Peninsula moose range with a small area of the 1836 Treaty of Washington ceded territories in the eastern side of the range. In 2007, Michigan signed a consent decree with the 1836 tribes that describes the consultation process to follow before moose may be hunted. The 1842 Treaty of La Pointe ceded territories extend into Wisconsin and the 1842 tribes' hunting and fishing rights have been adjudicated in federal circuit court in Wisconsin. However, since that ruling was in circuit court, there is no formal agreement which defines the extent of 1842 treaty rights within Michigan. Two of the 10 Federally-recognized 1842 tribes are in Michigan (Keweenaw Bay Indian Community and the Lac Vieux Desert Band of Lake Superior Chippewa Indians) and currently they exercise their

hunting rights in the 1842 area of Michigan following tribal regulations consistent with the Wisconsin court cases.

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Table 1. Results of moose population simulations, 1985 to 2000, used in the development of the original population projection of 1000 moose by the year 2000.

Mortality rate[1]		Reproductive	Population	
Males	Females	rate[2]	in 2000	Comments
30%	22%	71	45	Current reproductive rate
30%	22%	71 to 116	106	Gradual reproductive rate increase
30%	22%	71 to 150	194	Gradual reproductive rate increase – 50% twinning rate
30%	22%	71 to 176	269	Gradual reproductive rate increase – 75% twinning rate
30%	22%	71 to 120	165	Best guess reproductive rate
20%	16%	71	122	Current reproductive rate
20%	16%	71 to 116	276	Gradual reproductive rate increase
20%	16%	71 to 150	493	Gradual reproductive rate increase – 50% twinning rate
20%	16%	71 to 120	424	Best guess reproductive rate
15%	11%	71	254	Current reproductive rate
15%	11%	71 to 116	565	Gradual reproductive rate increase
15%	11%	71 to 150	998	Gradual reproductive rate increase – 50% twinning rate
15%	11%	71 to 120	860	Best guess reproductive rate

[1]Mortality rate of adult moose ($\geq$ 2 years).
[2]Calves per 100 cows.

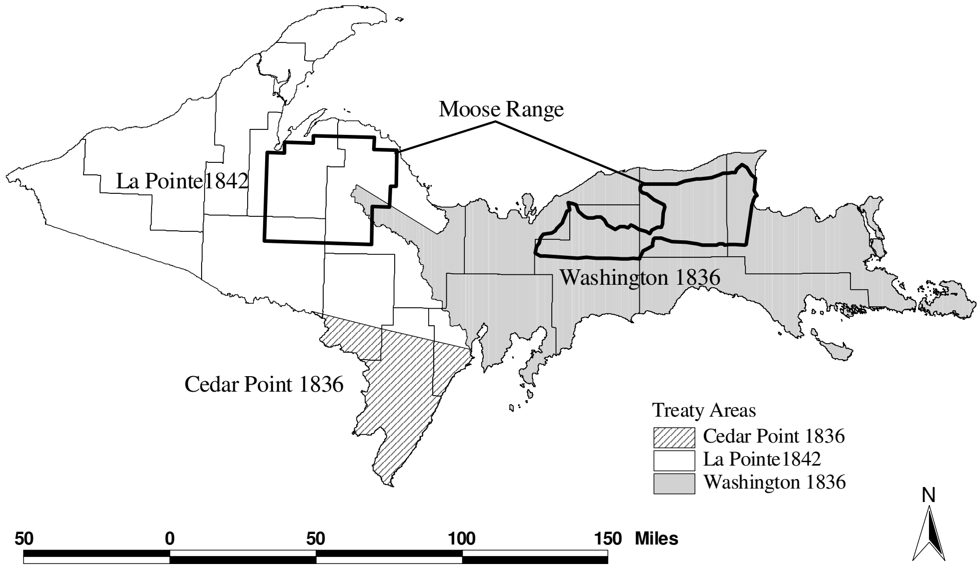

Figure 1. Approximate range of moose in the western and eastern Upper Peninsula of Michigan (excluding Isle Royale) in relation to Native American Treaty (land only) areas.

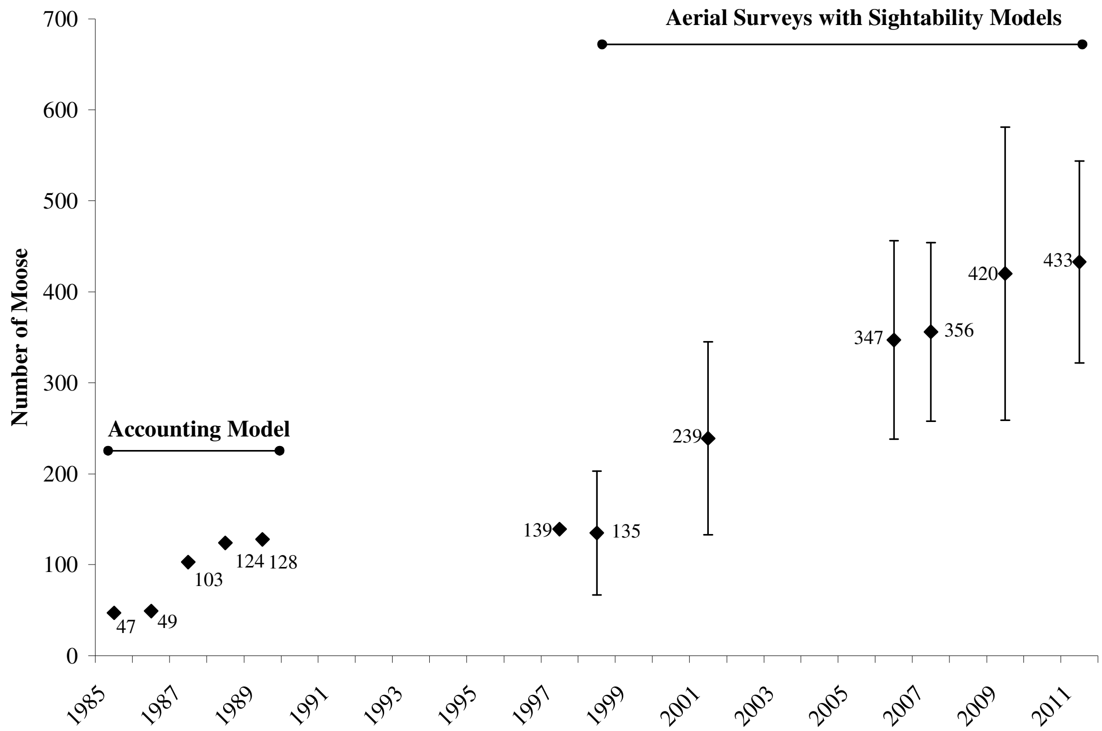

Figure 2. Winter population estimates and 95% confidence intervals (for 1999-2011) of moose in the western Upper Peninsula, 1985-2011. Estimates from 1985-1989 were based on an accounting model and estimates from 1997-2011 were based on aerial surveys corrected with sightability models (see text for details).

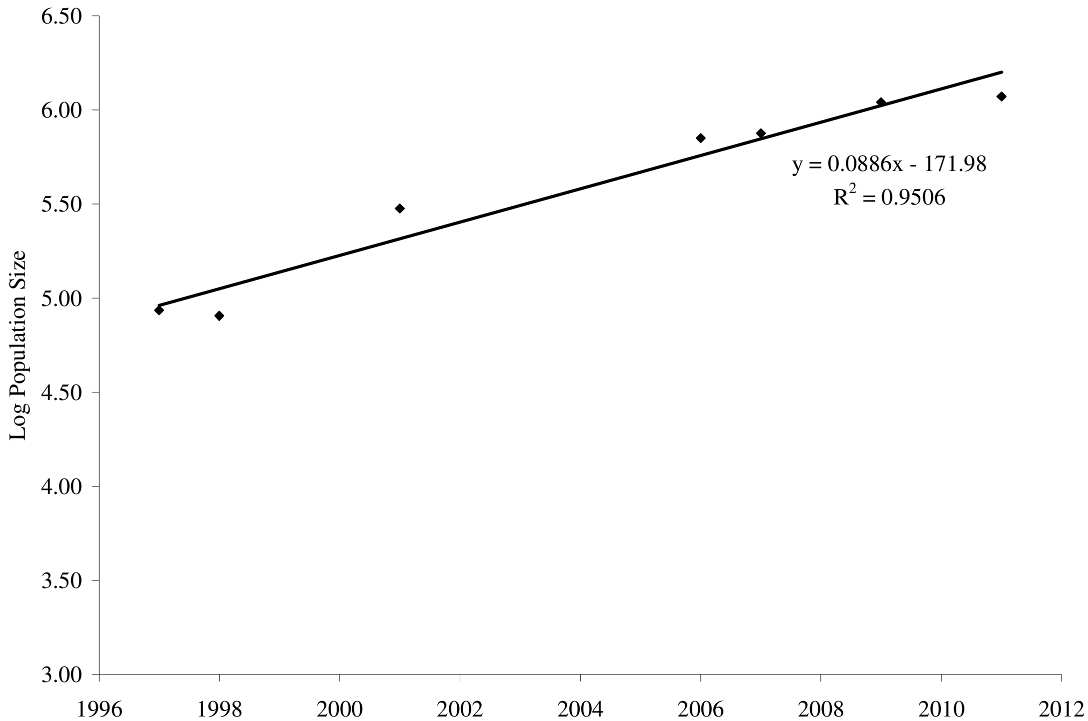

Figure 3. Exponential growth model (logarithmic form) fitted to moose abundance estimates (aerial counts corrected for visibility bias) from the Western Upper Peninsula of Michigan, 1997-2011. The results of this model can be used to estimate the annual growth of the population.

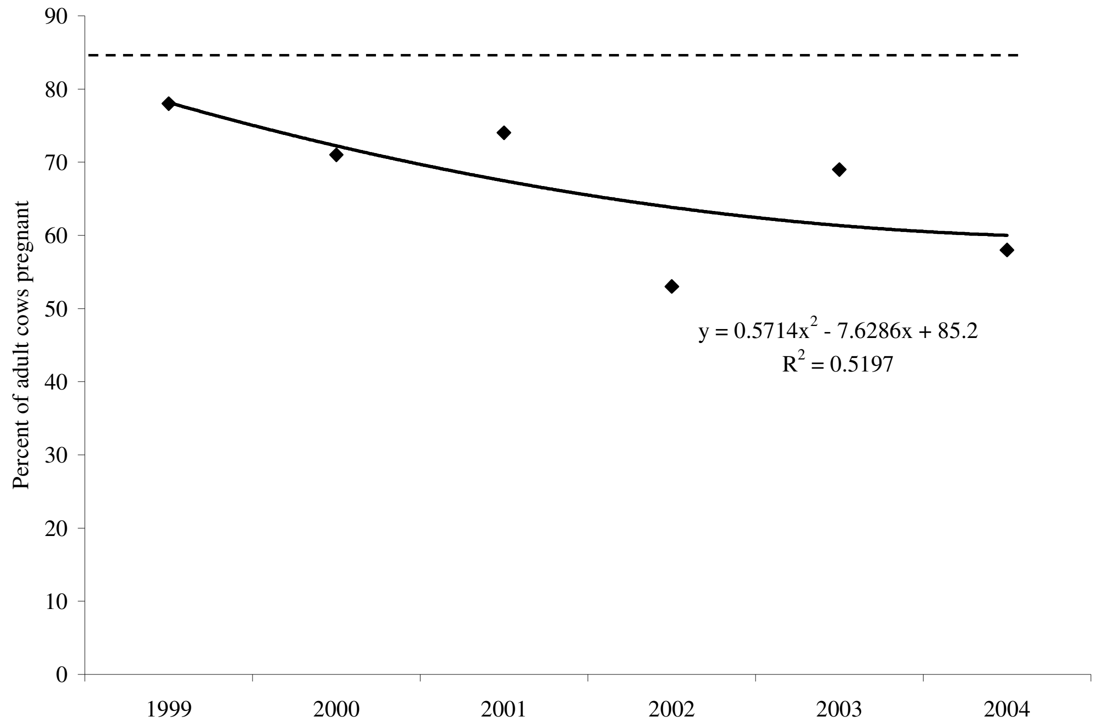

Figure 4. Percentage of pregnant adult cow moose in the western Upper Peninsula of Michigan, 1999-2004. The dashed line shows the North American average pregnancy rate of adult cows (84%). The solid line is a regression equation (2nd order polynomial) fit to the pregnancy data.

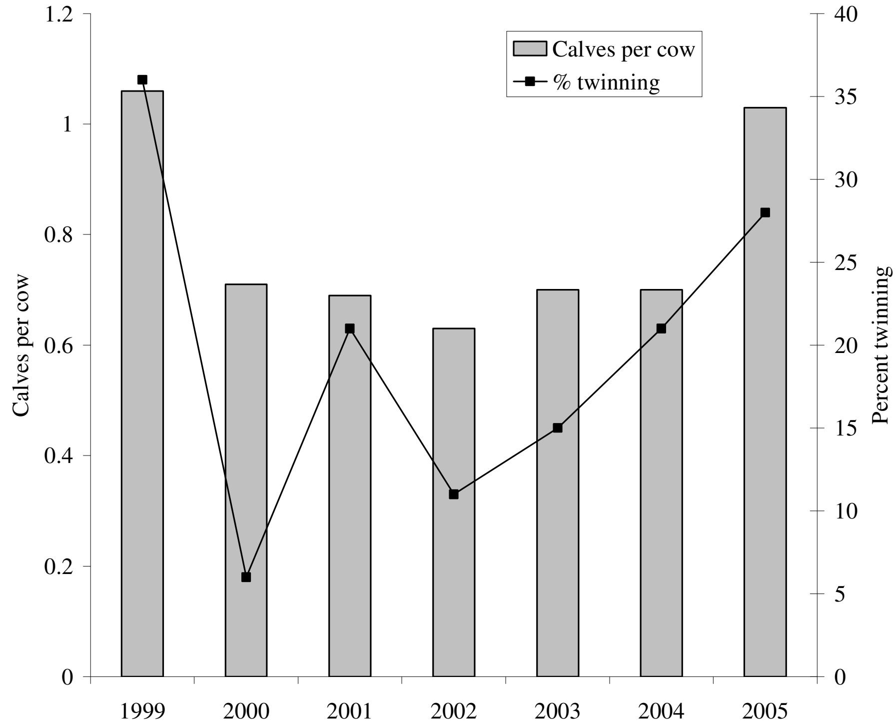

Figure 5. Number of calves per adult cow and percentage of cows with calves that produced twins in the western Upper Peninsula, 1999-2005.

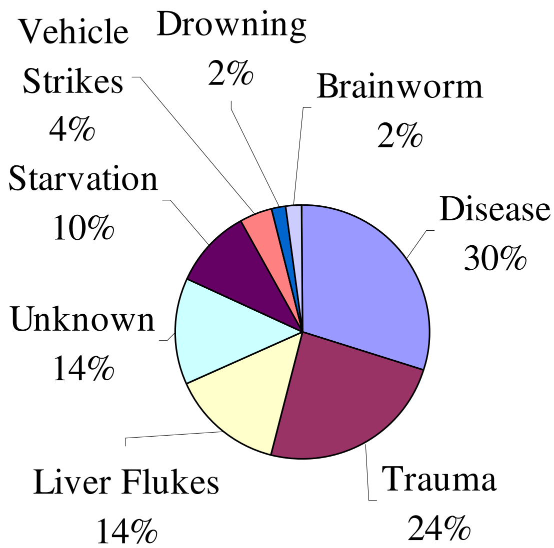

Figure 6. Proportion of radio-collared moose dying from various causes in the western Upper Peninsula, 1999-2005.

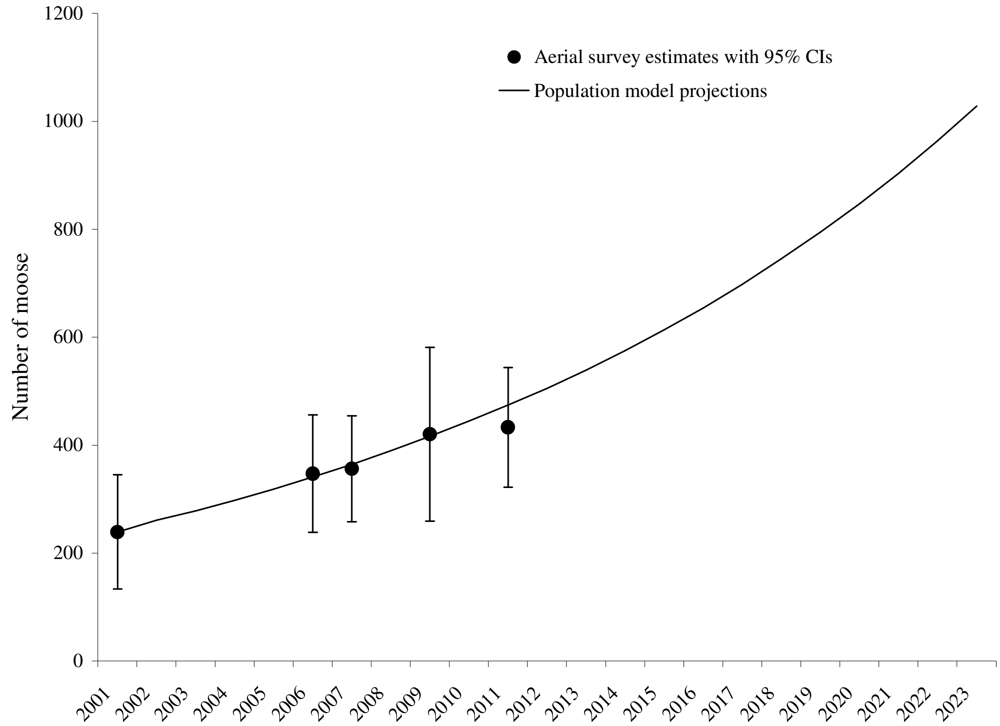

Figure 7. Aerial survey estimates and 95% confidence limits (2001, 2006, 2007, 2009, and 2001) for the western Upper Peninsula moose population relative to estimates based on simulation modeling. Modeling assumes vital rates (see text) remain constant and no harvest. The simulation model was calibrated to the 2001-2009 survey estimates.

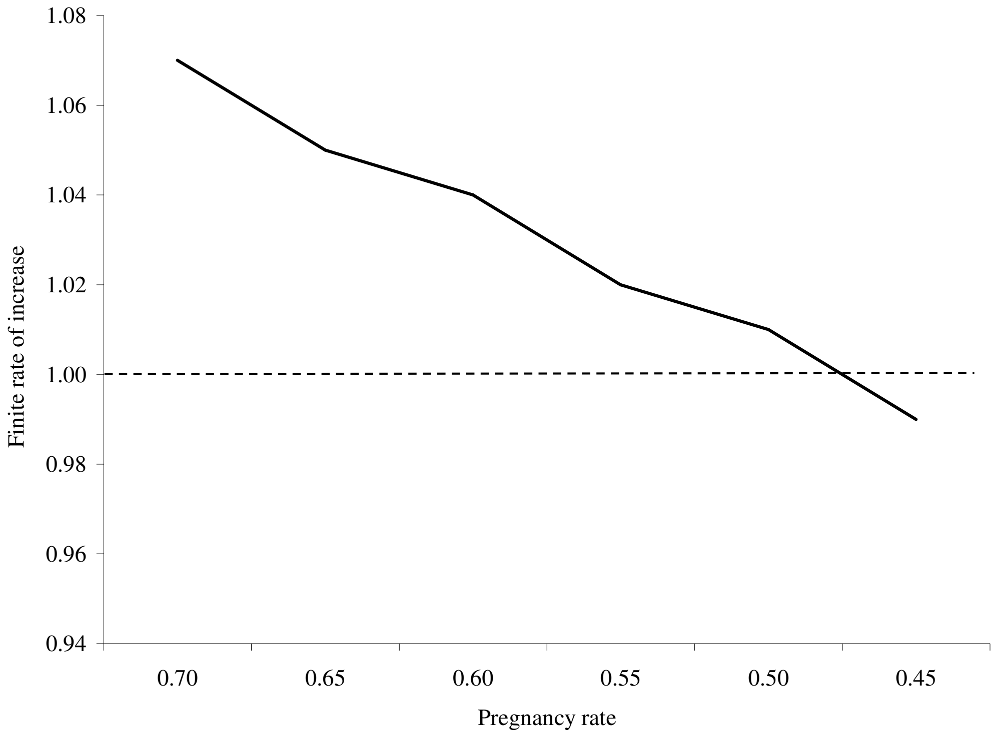

Figure 8. Relationship between the western Upper Peninsula moose population's annual growth rate (finite rate of increase) and the pregnancy rate of adult cows based on a deterministic simulation model. The dashed line represents zero population growth, values above the line indicate positive growth and values below the line indicate negative growth.

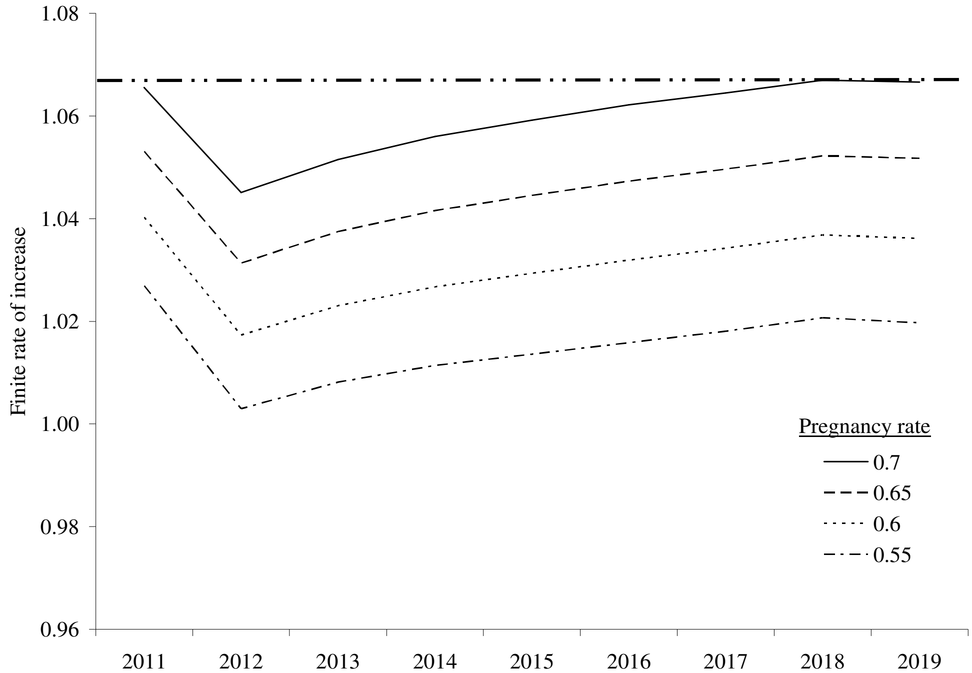

Figure 9. Simulated response of the western Upper Peninsula moose population's annual growth rate (finite rate of increase) to an annual harvest of 10 bulls across a range of adult cow pregnancy rates. The first harvest occurs in 2012. The long dash-dot-dot line represents sustained population growth with no harvest and a pregnancy rate of 70%.

Appendix A

Moose population projection model

The model was built as a spreadsheet with the following features:

- Males and females are tracked separately
- There are 17 age classes: calf – 16+
- Once specified for a particular model all variables are deterministic
- Hunting begins in 2012
    - Only males are harvested
    - Males are harvested proportional to availability for age classes Yearling – 16+
    - No calves are harvested
- All adult cows (2 – 16+) are equally likely to reproduce.
    - The % of cows that reproduce is controlled by the model
    - Calves produced per adult cow is specified by the model & does not change with age
- Years 2001 – 2009 are considered historic with
    - % adult cows breeding = 0.70
    - Calves per breeding adult cow = 1.0
    - Beginning in 2010 these values change as per the model inputs

1. Age Structure determination (age structure tab in the spreadsheet)

Population age structure was determined by reconstructing the population (in a life table format) based on age at death from necropsies and radio-collaring histories.

- Table A. is based on the necropsy records for the Western UP (WUP) for 1999 – 2007. These data include moose with and without radio collars.

- Table B. is based on the necropsy records for the WUP (1999 – 2007) for radio collared moose only and data for individuals of known age at trapping in the WUP.

- Table C. reflects that minimum age at death based on individuals trapped in the WUP. These data are not known age at death.

- Table D. reflects the combined data from tables B and C and is for radio-collared moose in the WUP only.

- Table E. is based on the necropsy records for moose found dead in the WUP (1999 – 2007). None of these moose were radio collared.

- Table F. is a combination of tables B and E. So, it is based on the necropsy data for WUP moose (radio collared and not radio collared) for 1999 – 2007 and those moose for whom we knew the age at trapping. THESE ARE THE

DATA THAT WERE USED TO SET THE AGE DISTRIBUTION IN THE MODEL.

- Table G. is a combination of Tables D. and E.

The data in Table F. were used to reconstruct a population age distribution under the assumptions that (1) age at death was properly identified and (2) the population was at stable age distribution (SAD).

A survivorship curve (lx) was calculated based on the reconstructed population age distribution.

2. Calculating the initial population size and age distribution for the model (model starting N tab)

The initial year in the population projection model is 2001. The aerial survey of the WUP moose population in that year yielded a population size estimate of 239 animals. Using the survivorship schedule from Table F. (above) an age distribution was calculated such that the bull calf to cow calf ratio was 1:1 and the total population equaled 239.

Bull calf to cow calf sex ratio was set to 1:1, by matching the number of male calves to the number of female calves (80) from the population reconstruction data. Based on 80 initial male calves, the male survivorship schedule was used to generate the remainder of the age distribution (step 3). Note that since they began with 80 calves, the female distribution will match the reconstructed age distribution. (This same procedure could have been done with the initial number of female calves set at 56 to match the males; simulation results in the projection model would not have been impacted).

There is a male bias in the number of male calves (55) per 100 calves in the current model (though this can be changed). The primary impact of starting with an age distribution based on a 1:1 ratio, but running the model with a slightly male biased calf ratio is that it takes the model a few years to reach SAD. If the calf sex ratio in the initial year of the model is matched to the sex ratio used in the model, the population will immediately be at SAD. See the model parameterization section below for more information on the calf sex ratio.

The age distribution of the population is standardized to 239 individuals based on the percentage of individuals by gender in each age class (steps 4 and 5)

3. Population projection model (Projection model tab)

- The model spans the years 2001 – 2050.
- The first hunting season is 2012.
- Years 2001 – 2009 are historic and serve to calibrate the model against the results of the aerial surveys.
- Years 2010 – 2050 are projections based upon the model inputs.

- Because of the sparse number of individuals in the older age classes, the oldest age class has been truncated at 16+.

Inputs:

- Initial age class distribution – calculated as described above
- Age specific survival rates for ages calf to 5 – based on survival analysis from radio collared moose, standard errors and confidence intervals available
- Age specific survival rates for ages 6 – 16+ -- estimates based on the literature, age distribution reconstruction, and model calibration. These are not statistically derived values and are highlighted in red.
- % adult cows reproducing (deep purple) – based on survey data of radio collard females and blood serum analysis and fecal progesterone analysis, standard errors and confidence intervals available
- Calves per breeding adult female (light purple) – based on survey data, standard errors and confidence intervals available
- Total number of males (Juv & adult) harvested (green) – value determined by modeler
- Males per 100 calves (blue) – value determined by modeler, no data exist for the true value of this variable for the WUP moose
- Yearlings emigrating per 100 yearlings (tan) -- value determined by modeler, but should be between 4% and 6%, based on data from radio collared moose
- Ratio of emigrants: bulls to cows (tan) -- value determined by modeler, but should be between 1:1 and 3:1 (bull:cow) based on data from radio collared moose.

Age specific survival rates for ages 6 – 16+ and males per 100 calves are the only variables for which we do not have research-based values for the WUP moose herd.