

Proximity to Established Populations Explains Moose (*Alces alces*) Occurrence in Northern Wisconsin

LUCAS O. OLSON¹

Department of Forest and Wildlife Ecology, University of Wisconsin, Madison 53706

TIMOTHY R. VAN DEELEN AND JOHN D. J. CLARE

Department of Forest and Wildlife Ecology, University of Wisconsin, Madison 53706

AND

MAXIMILIAN L. ALLEN

Illinois Natural History Survey, University of Illinois, Champaign 61820

ABSTRACT.—Wildlife conservation and management requires an understanding of patterns and changes in the populations and distributions of wildlife. Moose (*Alces alces*) population trends vary within regions of North America, such as in the upper Midwest region of the United States where sub-populations are declining in Minnesota, but are stable or increasing in Michigan. The population and distribution of moose in Wisconsin, which shares a border with Minnesota and Michigan, is unknown. We examined community scientist observations of moose collected by the Wisconsin Department of Natural Resources from 1991–2017 to determine the trends of moose occurrence in Wisconsin and the relationship to potential drivers. We used a binomial generalized linear mixed model in a Bayesian framework to understand how variables affect county-level occurrence of moose. We found moose occurrence was greater in counties closer to Minnesota and Michigan, but the effect of distance to Minnesota on moose occurrence has decreased over time. We also found counties with higher habitat suitability and proximity to Michigan are more likely to have a moose occurrence than those with low habitat suitability. This study offers insight for moose populations at the southern fringe of their circumpolar distribution and a foundation for understanding the moose population in Wisconsin and the upper Midwest.

INTRODUCTION

Conservation and management of large ungulate populations relies on knowing their distribution and abundance (Fryxell *et al.*, 2004; Dussault *et al.*, 2005; Timmerman and Rodgers, 2017). Identifying factors impacting distributional limits to a species' range may explain factors affecting individual fitness (Dussault *et al.*, 2005; Lowe *et al.*, 2010; van Beest *et al.*, 2012; van Beest and Milner, 2013). The distribution of large ungulate populations may be dictated by forage availability (Fryxell *et al.*, 2004), climate (van Beest and Milner, 2013), or competition (Schmitz and Nudds, 1994), and understanding these factors informs conservation and management efforts.

Moose (*Alces alces*) show contrasting declining and increasing sub-population trends throughout their circumpolar distribution across Europe, Asia, and North America (Safronov, 2009; Smith *et al.*, 2011; Wattles and DeStefano, 2011; Murray *et al.*, 2012; van Beest and Milner, 2013; Decesare *et al.*, 2014). Similar variable patterns in sub-population trends also exist within regions, such as in the upper Midwest region (including Minnesota, Wisconsin, and Michigan) of the United States (U.S.A.). The moose population in Minnesota has declined by more than half since 2006 and currently has a distribution

¹ Corresponding author: Telephone: (715)-218-7056; E-mail: lolson@azgfd.gov

limited to the northeastern panhandle (DelGiudice, 2017). In contrast 59 moose were re-introduced to the Upper Peninsula of Michigan in the late 1980s, and surveys indicate the population has grown to approximately 400 individuals with a stable distribution (Beyer *et al.*, 2011; Largent *et al.*, 2015).

The ecoregion that northern Wisconsin shares with northern Minnesota and the Upper Peninsula of Michigan contains the southern limit of moose distribution in the upper Midwest, U.S.A. (Karns, 2007). Factors that appear to be regulating the region's moose populations include forage availability (Murray *et al.*, 2006), disease (Lankester, 2010; Vanderwaal *et al.*, 2015), and warming temperatures (Murray *et al.*, 2006; Lenarz *et al.*, 2010). Forage availability and habitat quality impacts the distribution of moose, which require large (*i.e.*, >93km²) areas composed of shrub, wetland, deciduous mix, and conifers for sustainable populations (Allen *et al.*, 1987; Thompson and Stewart, 2007). Meningeal worm (*Parelaphostrongylus tenuis*), carried by white-tailed deer (*Odocoileus virginianus*), is linked to moose mortality (Wünschmann *et al.*, 2015). Better winter survival and high deer abundance have the potential to increase the transmission rate of the disease, which can possibly have population level effects in Minnesota (Anderson, 1972; Lankester, 2010). The effect of warming temperatures in the upper Midwest U.S.A. can also impact moose habitat preference (Lowe *et al.*, 2010; van Beest and Milner, 2013) and survival (Lenarz *et al.*, 2009, 2010). Despite on-going research in the ecoregion, it is currently unknown how these factors affect moose distribution in Wisconsin.

We used records of verified moose observations from community scientists (also called "citizen-scientists", *i.e.*, amateur data collectors) across 34 counties and 27 y in northern Wisconsin. Our objective was to determine the trend of moose occurrence over time and determine correlates of moose occurrence including proximity to neighboring populations, deer density, habitat, and climate. We developed and tested combinations of variables within *a-priori* competing models to determine potential drivers of the moose population in Wisconsin.

METHODS

STUDY AREA

Our study area was northern Wisconsin (Fig. 1A), defined by the areas north of the habitat gradient known as the "tension zone" in which southern broadleaf forest transitions to northern mixed broadleaf-conifer forest (Curtis, 1959). The 34 counties within the study area ranged in size from 918 km² (Menominee County) to 4082 km² (Marathon County). Northern Wisconsin has thousands of lakes and extensive wetland habitat important for moose (Allen *et al.*, 1987). The most common forest cover type throughout the region is maple-basswood, including dominant tree types of sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), American basswood (*Tilia americana*), white ash (*Fraxinus americana*), northern red oak (*Quercus rubra*), aspen/poplar (*Populus* spp.), yellow birch (*Betula alleghaniensis*), and eastern hemlock (*Tsuga canadensis*) (Curtis, 1959). Other forest communities included aspen-birch, oak-hickory, spruce-fir, northern dry-mesic, and lowland hardwoods (Wisconsin Department of Natural Resources, 2015). Early seral browse, preferred moose forage, was primarily produced through disturbances such as logging activity. The seasonal climate throughout the study area was classified by cold winters, followed by warm and humid summers. The mean summer (July) temperature across all counties was 26.42C, whereas the mean winter temperature (January) was -5.26C (cli-MATE MRCC Application Tools Environment).

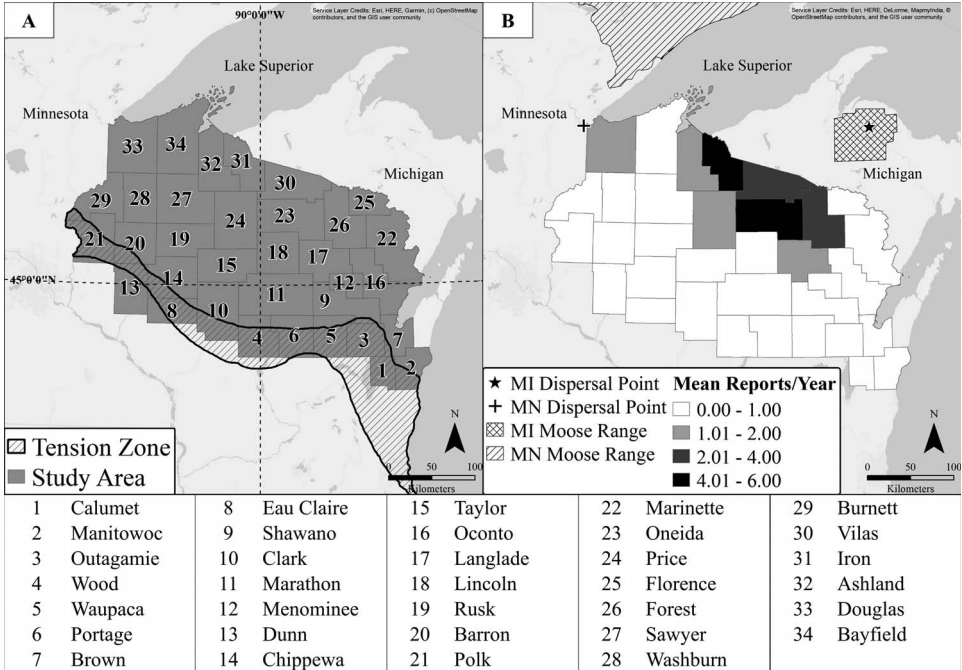


FIG. 1.—(A) indicates the study area in northern Wisconsin, U.S.A (45°33'09.38"N; 90°02'34.52"W). which includes 34 counties. The tension zone marks a gradient where southern broadleaf forest transition to northern mixed-coniferous and deciduous forests (Curtis, 1959). (B) includes a heat map of mean annual moose (*Alces alces*) observations by county within the study area from 1991–2017

DATA COLLECTION

From January 1991 to December 2017, the Wisconsin Department of Natural Resources (WDNR) used moose observations across the state that were reported by community scientists. Reports of moose were collected through multiple methods, including in-person reporting at WDNR offices, phone calls, e-mails, and online through a large mammal observation form (Appendix I). Each report was verified by WDNR staff through verbal descriptions or photos to ensure it was a moose or a moose track that was observed, and the county and year of the observation was recorded in a database. Since 2012 moose observations were censored for double counting of the same individual. For example if a unique moose (based on antler branching or other unique identification) was independently reported multiple times within the same year, this was recorded as one observation. The verified observation reports are assumed to be reliable given moose are easy to identify by their unique size and appearance (Wiedenhoef, 2015).

MODEL COVARIATES

Moose require sizable areas of habitat (~93 km²) that include deciduous shrubs, conifers, forbs, aquatic plants for food, and mature forest stands for shelter (Allen *et al.*, 1987; Thompson and Stewart, 2007). To estimate suitable habitats, we used the Public Land Survey System (PLSS; gridded survey lines used as a standardized geographic reference system in

the United States) at the township level that were $>77.7 \text{ km}^2$ (mean = 92.86 km^2 ; range 77.7 km^2 to 113.96 km^2). To quantify land and vegetative cover within each township, we used an open access raster layer, Wisland 2.0, which is a Wisconsin land cover dataset generated from classified aerial land cover images from 2010–2014 (available from: <https://data-wi-dnr.opendata.arcgis.com/datasets?q=wisland>). We used Wisland 2.0 at classification level 2 (the level indicates the classification detail), which met relevant cover descriptions of suitable moose habitat (Appendix II), and provided 86% overall classification accuracy (Wisconsin Department of Natural Resources, 2016). Using ArcMAP 10.3 (ESRI, 2014) and Geospatial Modelling Environment (GME; Beyer, 2009), we converted the percent cover of four habitat categories to Suitability Index Variables (SIV), using graphical projections and piecewise functions (Allen *et al.*, 1987; Appendix II). We used each SIV to inform a habitat suitability model derived by Allen *et al.* (1987):

$$HSI = (SIV10 \times SIV11 \times SIV12 \times SIV13)^{0.25}$$

to create an index of relative habitat suitability (HSI) on a scale from 0 (least suitable) to one (most suitable). SIV10 indicates optimal shrub cover < 20 y old, SIV11 indicates optimal spruce/fir > 20 y old, SIV12 indicates optimal upland deciduous/mixed forest > 20 y old, and SIV13 indicates optimal suitable wetland (Allen *et al.*, 1987). We then calculated the area-weighted mean township HSI value within each county to account for partial townships in given counties. Mean county HSI was 0.28 and ranged from 0.03 in Calumet County to 0.52 in Burnett County.

At coarse scales road networks may negatively influence moose occurrence (Laurian *et al.*, 2008); however, roads may be positively associated with moose observations that are submitted by the community. We calculated density of major and minor roads in ArcMAP and GME using US Census Bureau TIGER line file shapefiles (TIGER feature codes S1200, S1300, and S1400; U.S. Census Bureau, 2010). We calculated road density as km road/ km^2 within each PLSS township, which is a spatial scale representative of the area required for moose habitat (Allen *et al.*, 1987; Thompson and Stewart, 2007). We then took the area-weighted mean of township road density within each county. Mean road density was $1.64 \text{ km}/\text{km}^2$, and ranged from the lowest in Iron County at $0.89 \text{ km}/\text{km}^2$ to the highest in Brown County at $3.4 \text{ km}/\text{km}^2$.

Moose are thought to emigrate to Wisconsin from either the western Upper Peninsula of Michigan (Beyer *et al.*, 2011) or northern Minnesota (Parker, 1990). We used ArcMAP to calculate the distance from the geometric center of each county to fixed dispersal points in Michigan and Minnesota in order to investigate whether occurrence is being driven by proximity to established populations (Fig. 1B). For Michigan the fixed point was near the late 1980s moose re-introduction area in Marquette County of the Upper Peninsula ($46^\circ 38' 14.93'' \text{N}$, $88^\circ 1' 33.6'' \text{W}$). Dispersal from Minnesota's moose population is partially obstructed by the western tip of Lake Superior. Therefore, we identified a point past the western tip of Lake Superior ($46^\circ 38' 28.01'' \text{N}$, $92^\circ 19' 34.1'' \text{W}$), where it is most reasonable for a moose to move from Minnesota into Wisconsin.

The natural southern limit of moose is believed to be climate mediated (Dussault *et al.*, 2004; Murray *et al.*, 2006), and heat stress in moose may have a cumulative effect on moose survival given it causes malnutrition and immunosuppression (Murray *et al.*, 2006; Lenarz *et al.*, 2009). January temperatures warmer than -5°C predict short and long term survival of moose, with a negative relationship between January temperature greater than -5°C and survival (Lenarz *et al.*, 2009). We collected mean maximum January and July temperatures for each year from weather stations within each county through the Midwestern Regional

Climate Center (cli-MATE MRCC Application Tools Environment). For cases in which weather station data were incomplete or missing within the county boundary, we used the mean temperatures from weather stations from adjacent counties. Maximum mean temperatures in January ranged from -17.78°C (Price County, 2008) to 2.61°C (Dunn County, 2006). Maximum mean temperatures in July ranged from 20.27°C (Forest County, 1992) to 32.38°C (Eau Claire County, 2006). Mean maximum temperature across all counties during January and July was -5.36°C and 26.42°C , respectively.

White-tailed deer host and transmit parasites that can cause mortality when contracted by moose (Vanderwaal *et al.*, 2015). Deer density has been suggested as a potential reason for the decline of moose in Minnesota (Lankester, 2010; Wünschmann *et al.*, 2015). We calculated county level deer density using deer population estimates calculated by the WDNR from 1991–2017 (Stenglein and Wallenfang, 2017), divided by the total amount of deer range within each county (land available to deer). Because Menominee County falls under tribal jurisdiction and does not have deer abundances estimated by WDNR, we used the mean density from the adjacent Langlade County. White-tailed deer densities from 1991–2017 had a mean of 11.66 deer/ km^2 , ranging from 1.23 deer/ km^2 in Iron County (2014) to 35.02 deer/ km^2 in Brown County (2017).

STATISTICAL ANALYSES

We performed our statistical analyses using program R (Version 3.5.1) (R Core Team, 2018). We fit binomial generalized linear mixed models (GLMM; Bolker *et al.*, 2009) with a logit-link function in a Bayesian framework, using the binary response variable of moose being observed (1) or not observed (0) within a given county in a given year (*i.e.*, an occurrence). We used GLMMs (assuming perfect detection) over alternative models (*i.e.*, occupancy) as they provide a relative measure of moose occurrence and reduce bias within opportunistically collected moose observations without restrictive assumptions (*e.g.*, closure). We used observations from 34 counties across 27 y, giving us a total of 918 county-year samples. We considered 10 individual variables (Table 1) in a series of 12 *a-priori* models (Table 2). We included a first-order autoregressive term to assess temporal autocorrelation (whether moose observed in year t affects observation in year $t+1$). We centered and standardized all continuous covariates to a mean of zero and standard deviation of one to estimate relative effects between covariates. Before model fitting we assessed collinearity between all fixed variables. To reduce over-parameterization of global models, we excluded fixed variables that had a correlation coefficient $r \geq |0.70|$. Fixed effects in our models included the linear independent variables of each of our *a-priori* models, and we included a random effect for counties to account for longitudinal data structure.

We fit models and estimated parameters using Hamiltonian Monte Carlo with NO-U-Turn-Sampling simulations (Hoffman and Gelman, 2014), with randomly generated initial values and relatively uninformative prior values within the package ‘rstanarm’ (Version 2.18.2, Stan Development Team, 2016). Each model was run on four parallel chains of 2000 iterations each, with the first 1000 iterations discarded as warmup, which is a sufficient number of simulation draws for many real-world settings (Hoffman and Gelman, 2014; Vehtari *et al.*, 2017). We used Gelman-Rubin statistics to determine convergence (Gelman and Rubin, 1992), with values < 1.1 considered to indicate convergence (Allen *et al.*, 2018). Goodness of fit and model selection was calculated adopting a leave-one-out information criterion (LOOIC) and using Pareto-smoothed importance sampling leave-one-out cross-validation (PSIS-LOO; Vehtari *et al.*, 2017). LOOIC was calculated using the $\widehat{\text{elpd}}_{\text{loo}}$ (expected log pointwise predictive density) multiplied by -2 to be on the deviance scale, in which smaller

TABLE 1.—Individual variables considered in *a-priori*, models of moose (*Alces alces*) occurrence in 34 Northern Wisconsin Counties, U.S.A., 1991–2017

Covariate name	Symbol	Unit	Description
Road Density	RDDN	km road/km ²	Density of US Census Bureau roads classified as S1100, S1200, and S1400.
Deer Density	DRDN	deer/km ²	Deer population estimate per square kilometer of deer range.
Habitat Suitability Index	HBSI	%	Area weighted mean of HSI within counties (Allen <i>et al.</i> , 1987).
Distance to Upper Peninsula	DIUP	km/100	Scaled linear distance to fixed point, Upper Peninsula of Michigan*.
Distance to Minnesota	DIMN	km/100	Scaled linear distance to fixed point, Minnesota†.
July Temperature	JULY	C	Mean maximum July temperature.
January Temperature	JANU	C	Mean maximum January temperature.
Year	YEAR	Year	Year of observation (<i>i.e.</i> , 1 = 1991, . . . , 27 = 2017).
Autoregressive Term	AURI	–	Indicates moose occurrence at time (<i>t</i> -1).
County	CNTY	–	County of moose occurrence, included as random intercept in all candidate models.

* Distance to moose reintroduction area in Marquette County, Michigan, U.S.A.

† Distance to point near western tip of Lake Superior near St. Louis Estuary, Minnesota, U.S.A.

values indicate a better supported model (Vehtari *et al.*, 2017). LOOIC is interpreted similarly to conventional information criterion (*i.e.*, AIC). In cases where the tail shape parameter of the generalized Pareto distribution (\hat{k}) was >0.7 , we resampled directly from the LOO posterior for the problematic observation (Vehtari *et al.*, 2017). We compared models using LOOIC weight (wLOOIC), considering any model within a cumulative wLOOIC < 0.95 to have substantial support. Among top models, we checked residuals for spatial autocorrelation of inverse distance weights within each year using Moran's I (Gittleman and Kot, 1990).

RESULTS

COMMUNITY SCIENCE OBSERVATIONS

The WDNR documented 762 total moose observations by community scientists from 1991–2017. Observations were reported every year of the study, with a mean of 28.2 moose observations/year (SE = 2.64). The greatest number of moose observations was in 2010 ($n = 65$), and the least was in 1997 ($n = 3$). Moose were reported most frequently in Oneida ($\bar{x} = 5.4 \pm 0.76$ SE moose observations/year), Iron ($\bar{x} = 4.25 \pm 0.67$ SE moose observations/year), Vilas ($\bar{x} = 3.67 \pm 0.68$ SE moose observations/year), and Forest ($\bar{x} = 3.03 \pm 0.63$ SE moose observations/year) counties (Fig. 1B).

There was a total of 36 observations of calves (singlet or twins), but the observations did not include the estimated age of the calves (*i.e.*, young of the year, yearling). Calf observations occurred in 21 of the 27 y, with a maximum of three in 2002, 2009, and 2012. From 1991–2017 calf observations were most frequent in Forest ($n = 8$), Florence ($n = 5$), Oneida ($n = 5$), Vilas ($n = 4$), and Iron ($n = 4$) counties.

Among 918 county-years, there were in 243 (26.5%) moose occurrences. Within counties occurrence was most frequent in Oneida (96%), Iron (93%), Vilas (77%), and Forest (77%).

TABLE 2.—*A-priori*, candidate models for predictors of moose (*Alces alces*) occurrence in 34 northern Wisconsin Counties, U.S.A., 1991–2017. Provided are the variables and our reasoning behind each candidate model

Model name	Model variables	Reason
Observability	RDDN	Road density increases the amount of community science observations.
Habitat and observability	RDDN+HBSI+(RDDN×HBSI)	Moose occurrence will increase with road density because road disturbance increases available forage (Beyer <i>et al.</i> , 2013).
Deer survival	JANU+JULY+DRDN+DRDN×(JANU+JULY)	Moose occurrence will decrease in warmer climates because it provides conditions conducive to increased winter survival of white-tailed deer and increased transmissibility of meningeal worm (Lankester, 2010; Vanderwaal <i>et al.</i> , 2015).
Deer density and habitat	DRDN+HBSI+(DRDN×HBSI)	High deer density within moose habitats will increase transmission rate of the brain worm that is lethal to moose (Lankester, 2010; Vanderwaal <i>et al.</i> , 2015).
Movement	DIUP+DIMN	Moose disperse and migrate from source populations, and occurrence probability is a function of distance to the Upper Peninsula of Michigan and Minnesota (Parker, 1990; Beyer <i>et al.</i> , 2011).
Habitat	HBSI	Moose will be more likely to occur in better habitat (Allen <i>et al.</i> , 1987).
Movement and habitat	DIUP+DIMN+HBSI+HBSI×(DIUP+DIMN)	Moose occurrence probability is a function of the distance to the Upper Peninsula of Michigan and Minnesota and habitat suitability (Parker, 1990; Dodge <i>et al.</i> , 2004; Beyer <i>et al.</i> , 2011).
Temperature	JANU+JULY	Moose occurrence probability will decrease when mean January and July maximum temperatures increase (Renecker and Hudson, 1986; Lenarz <i>et al.</i> , 2009; Monteith <i>et al.</i> , 2015).
Thermal behavior	JANU+JULY+HBSI+HBSI×(JANU+JULY)	During warm periods suitable habitat becomes more important for forage accessibility and thermal cover (Dussault <i>et al.</i> , 2004; Lenarz <i>et al.</i> , 2009; van Beest <i>et al.</i> , 2012; van Beest and Milner, 2013).
Movement across time	YEAR+DIUP+DIMN+YEAR×(DIUP+DIMN)	The effect of distance to Michigan and distance to Minnesota depends on the year.
Global	YEAR+DIUP+DIMN+DRDN+HBSI+JANU+JULY+AURI+RDDN	Moose occurrence is a complicated process dependent on all variables.
Null	–	Moose occurrence is independent of county-level covariates.

TABLE 3.—Model selection results of *a-priori*, models for moose (*Alces alces*) occurrence in Wisconsin, U.S.A, 1991–2017. Included in the table is the model name, effective parameters (K_{eff}), and LOOIC. LOOIC is calculated using the $\widehat{\text{elpd}}_{\text{loo}}$ (expected log pointwise predictive density) multiplied by -2 to be on the deviance scale

Model name	K_{eff}	LOOIC	ΔLOOIC	wLOOIC	Cumulative wLOOIC
Movement across time	23.36	705.71	0.00	0.49	0.49
Movement	19.92	706.96	1.25	0.26	0.76
Movement and habitat	19.76	707.89	2.18	0.17	0.92
Global	25.40	710.29	4.58	0.05	0.97
Observability	25.63	714.28	8.57	0.01	0.98
Temperature	30.37	714.65	8.94	0.01	0.98
Thermal behavior	32.22	714.98	9.27	0.00	0.99
Habitat and observability	26.61	715.17	9.46	0.00	0.99
Habitat	27.68	715.75	10.04	0.00	1.00
Deer density and habitat	29.36	717.37	11.66	0.00	1.00
Null	28.21	717.91	12.20	0.00	1.00
Deer survival	32.45	718.14	12.43	0.00	1.00

Across years the greatest number of counties with moose occurrence was in 15 in 1994 (42%), whereas the least number of counties with moose occurrence was three in 1997 (9%).

MODEL SELECTION

Our model selection results indicated the ‘movement across time’ model had the best out-of-sample predictive accuracy for moose occurrence (wLOOIC = 0.49; Table 3), followed by the ‘movement’ model (cumulative wLOOIC = 0.76), and the ‘movement and habitat’ model (cumulative wLOOIC = 0.92). Parameters in the ‘movement across time’ model showed occurrence probability decreased as the distance from Michigan or Minnesota increased ($\hat{\beta}_{\text{DIUP}} = -1.79$, 95% CrI² = -2.19 to -1.41 ; $\hat{\beta}_{\text{DIMN}} = -1.66$, 95% CrI = -2.11 to -1.21), whereas the interaction terms showed the effect of distance to Minnesota became weaker over time ($\hat{\beta}_{\text{DIMN} \times \text{YEAR}} = 0.38$, 95% CrI = 0.11 to 0.66). Parameters within the ‘movement’ model were similar in effect, showing moose occurrence probability decreased as the distance from Michigan or Minnesota increased ($\hat{\beta}_{\text{DIUP}} = -1.75$, 95% CrI = -2.15 to -1.36 ; $\hat{\beta}_{\text{DIMN}} = -1.59$, 95% CrI = -2.04 to -1.15). Parameters within the ‘movement and habitat’ model showed moose occurrence probability decreased as the distance from Michigan or Minnesota increased ($\hat{\beta}_{\text{DIUP}} = -1.80$, 95% CrI = -2.00 to -1.41 ; $\hat{\beta}_{\text{DIMN}} = -1.45$, 95% CrI = -1.98 to -0.97) and there was a moderate, negative interaction effect between the distance from Michigan and habitat suitability ($\hat{\beta}_{\text{DIUP} \times \text{HBSI}} = -0.39$, 95% CrI = -0.76 to -0.03).

DISCUSSION

Our objective was to determine trends in moose occurrence with respect to time and ecological factors in Wisconsin. Our results indicate proximity to Michigan and Minnesota had the greatest effect on the probability of moose occurrence, supporting the hypothesis movement (which could include dispersal or migration) from established moose

² Credible Interval

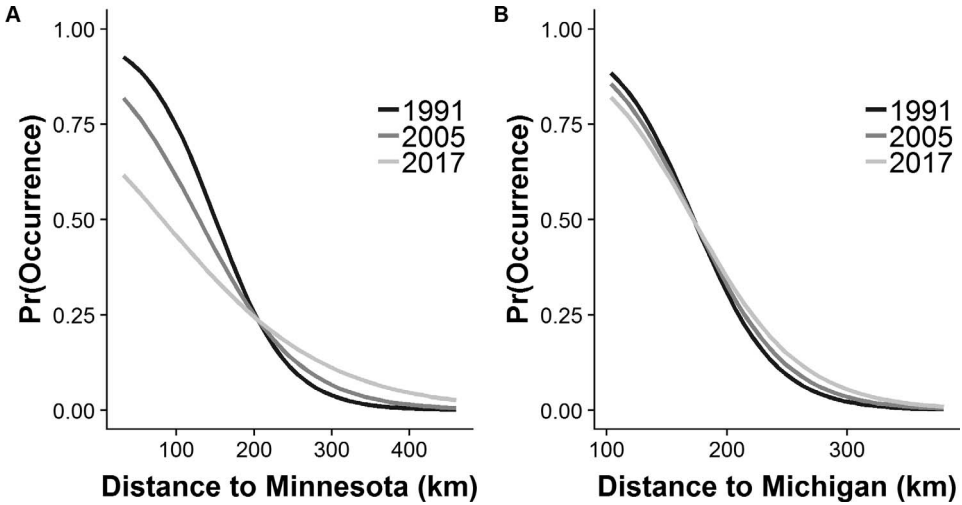


FIG. 2.—Posterior density distribution for the ‘movement across time’ model for mean predicted moose (*Alces alces*) occurrence probability in relationship to (A) Minnesota and (B) the Upper Peninsula of Michigan, 1991–2017

populations is driving Wisconsin’s moose distribution at the county level. This suggests the distribution of moose in Wisconsin will likely fluctuate with respect to broader regional population dynamics (Pulliam, 1988; Hanski, 1998). We found evidence the effect of proximity to Minnesota has diminished over time (Fig. 2A). This is potentially because the moose population in Minnesota has experienced significant declines in the last decade, and their distribution is now limited to the far northeast portion of the state (DelGiudice, 2017). The moose population in the Upper Peninsula of Michigan appears to be stable or increasing with respect to time (Largent *et al.*, 2015), which is consistent with our findings (Fig. 2B). Within all of the supported models, the individual effect of the distance from Michigan on probability of occurrence was greater than Minnesota. Given current trends we expect the moose population in the Upper Peninsula of Michigan to be the primary driver of the moose population and distribution in Wisconsin.

Counties with higher habitat suitability close to Michigan had a greater probability of moose occurrence, suggesting movement varies as a function of habitat dispersion and connectivity (Addison *et al.*, 1980). We detected this relationship at a relatively large (county-level) spatial extent, suggesting further investigation of habitat productivity indicators (Franzmann and Schwartz, 1985; Aitken and Child, 1992) at biologically meaningful spatial extents may be warranted (Thompson and Stewart, 2007). In addition habitat assessments may consider integrating dispersal pathways between populations, migration corridors, and the potential barriers. Because the Wisconsin population appears subject to regional trends, identifying and protecting productive habitats and their connectivity may be important for conservation of the regional moose population.

We found no support for our hypothesis of negative effects between moose occurrence and deer density, or ambient temperature. The unclear relationship with deer density may be attributed to the complex life cycle of the brain worm, and the environment may have a more important role in predicting patterns of disease transmission than deer density alone

(Lankester, 2010; Vanderwaal *et al.*, 2015). Future research should consider the relationship between disease transmission and environments favorable to moose, deer, and gastropods (the intermediate host of the brain worm). The relationship with moose occurrence and ambient maximum temperatures in January or July was unclear. Although the southern distribution of moose is often attributed to climate, our results may indicate at broad scales moose adapt behaviorally to thermal stress (van Beest *et al.*, 2012) or alternatively moose in their southern range may be more resilient to heat stress than previously thought (Lowe *et al.*, 2010). Alternative scales of assessment are necessary to further understand this relationship.

Here we show community science moose observations are valuable for understanding large-scale patterns of moose occurrence at the periphery of their range, but more information is required to understand changes in population demographics and abundance in Wisconsin. We recommend agency personnel promote their interest in community monitoring of the moose population and continue to collect detailed data on moose observations. Certainly, the widespread use of trail cameras, personal cellular devices, and social media among the public will continue to provide a valuable monitoring tool (Newman *et al.*, 2012). Georeferenced community science observations combined with detailed demographic information such as twinning rates and cow to calf ratios may provide necessary productivity indicators and habitat associations (Franzmann and Schwartz, 1985; Aitken and Child, 1992), giving insights to the status and future of this species throughout the region.

Acknowledgments.—We are grateful for the assistance of K. Wallenfang and J. Wiedenhoft of the WDNR for providing the moose observation data and their useful advice. We thank S. Crimmins for his reviews of earlier versions of the manuscript. We also thank A. Ketz, V. Radeloff and D. Helmers at the University of Wisconsin-Madison. We thank the Department of Forest and Wildlife Ecology at UW-Madison for supporting this research.

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SUBMITTED 15 MARCH 2019

ACCEPTED 11 JULY 2019

Description	
Species	Moose ▾
If other, please specify	<i>(not required unless you select other above)</i>
Number of adults	<input type="text"/>
Number of young	<input type="text"/>
Sex	-- Choose gender -- ▾
Estimated size	<input type="text"/>
Tail length	-- Choose tail length -- ▾
Track length	<input type="text"/>
Track width	<input type="text"/>
Coloration:	<input type="text"/>
Other descriptions	<input type="text"/>
General comments	<input type="text"/>

APPENDIX I.—An example of the current Wisconsin Department of Natural Resources large mammal observation form. This form is found online at <https://dnr.wi.gov/topic/wildlifehabitat/mammalobsform.asp> and can be filled in by any member of the public

APPENDIX II.—Wiscland 2.0 classification used to measure moose (*Alces alces*) Habitat Suitability Index. The user guide for Wiscland 2.0 may be found online at ftp://dnrftp01.wi.gov/geodata/landcover/wiscland2/user_guide/Wiscland_2_User_Guide_September_2016.pdf

Optimal cover type based on Allen <i>et al.</i> (1987)	Optimal cover percentage	Wiscland 2.0 class designation	Description (Wiscland 2.0 user guide)
Shrub <20 y old (SIV10)	40 – 45%	Lowland Scrub/Shrub	Areas with 30% or more woody vegetation, less than 20 feet tall, with a tree cover of less than 10%, occurring in wetland areas.
		Shrubland	Vegetation with a persistent woody stem, generally with several basal shoots, low growth of less than 20 feet, and coverage of at least one-third (33%) of the land area. Less than 10% tree cover interspersed.
Spruce/Fir > 20 y old (SIV11)	5–10%	Coniferous Forest	Upland areas whose canopies have a distinct crown closure of which no less than two-thirds (67%) should be of the coniferous tree group. If the broad-leaved deciduous species group is present, it should not exceed one-third (33%) of the canopy
Upland deciduous/mixed forest >20 y old (SIV12)	35–40%	Broad-Leaved Deciduous	Upland areas whose canopies have a distinct crown closure of which no less than two-thirds (67%) should be of the broad-leaved deciduous tree group. If the coniferous species group is present, it should not exceed one-third (33%) of the canopy.
		Mixed Deciduous/Coniferous	In the case of mixed broad-leaved deciduous/coniferous forest, canopy percent must have a distinct crown closure, of which no more than two-thirds (67%) should be from either of the species group (coniferous or deciduous).
Suitable Wetland (SIV13)	5–10%	Floating Aquatic Herbaceous Vegetation	Floating herbaceous plants growing entirely on or in a water body and covering 30% or more of the area. Includes rooted floating, free floating, and submerged plants
		Emergent/Wet Meadow	Persistent and non-persistent herbaceous plants standing above the surface of the water or wet soil and covering 30% or more of the area