DEMOGRAPHIC STATUS OF MOOSE POPULATIONS IN THE BOREAL PLAIN ECOZONE OF CANADA

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ABSTRACT: Broad scale analyses of winter population survey data collected between 1985 and 2015 were conducted to provide a synthesis of the current status and historical performance of 14 moose (*Alces alces*) populations residing in the Boreal Plain Ecozone of Saskatchewan and western Manitoba. Population time series models indicated a broad scale decline averaging 30% in moose populations across the Boreal Plain Ecozone since 2000 relative to the long-term (1985 to 2015) cumulative mean population size. Demographic patterns and rates of population change were variable among and within populations across years. We found an inverse relationship between adult sex ratio (bull:cow) and population density ($R^2 = 0.48$, $P < 0.001$), which suggests negative population growth ($\lambda < 1.0$) when the adult sex ratio falls below a density-dependent threshold for population growth. Winter calf recruitment (calves/cow) was positively correlated ($R^2 = 0.12$, $P = 0.027$) with adult sex ratio. Stable or increasing populations ($\lambda \geq 1.0$) tended to have lower adult sex ratios relative to winter calf recruitment ratios than declining populations. Population state and vital rate relationships are useful to assess population performance and guide science-based moose management strategies in a Management-by-Objective decision-analytic framework.

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Moose (*Alces alces*) population density in North America varies geographically and temporally (Messier 1994, Timmermann and Rodgers 2017). Divergent trends in abundance include an apparent decline across much of the continental moose range (Laliberte and Ripple 2004, Murray et al. 2006, DelGiudice 2013, McCann et al. 2013, Kuzyk 2016) that is in contrast with increase of certain populations along the southern periphery of moose range and on both coasts (Foster et al. 2002, Darimont et al. 2005, Faison et al. 2010, Musante et al. 2010, Murray et al. 2012, LaForge et al. 2016, Timmermann and Rodgers 2017). However, there is limited detailed information regarding the magnitude and trend of population change at regional scales including in the Boreal Plain Ecozone.

Demography of a given moose population is strongly influenced by metrics of population state (abundance, age/sex structure), vital rates (annual finite rate of population change [λ], survival, and recruitment), and movement dynamics (immigration, emigration). Adult female survival and calf recruitment are well studied in ungulate populations and have a dynamic influence on ungulate population demography, λ, and abundance (Gaillard et al. 2000, Eberhardt

2002, Raithel et al. 2007, Environment Canada 2012, Monteith et al. 2015). Landscape (configuration, dynamics), habitat (condition, availability), and temporal (seasonal) effects also contribute to the complexity of interacting variables that govern population performance. Consequently, the dynamics of one population can substantially differ from those characterizing another. Reliable information on regional moose population dynamics is central to identifying drivers of population change and informing management and conservation action (Taber and Raedeke 1979). Surveying winter populations across multiple years provides a sequential time series of population state and vital rate metrics useful to model abundance trends and demographic changes that provide inference about population performance (Taber and Raedeke 1979, Eberhardt 2002).

Moose populations in the Boreal Plain Ecozone of Saskatchewan and Manitoba are more exploited by hunting and incur greater harvest levels relative to Boreal Shield Ecozone populations further north (Arsenault 2000, Government of Manitoba 2014). However, neither province monitors hunting mortality consistently or accurately at the local scale because of low response rate to harvest questionnaires; Manitoba recently ceased using these questionnaires. In addition, harvest by rights-based hunters has never been monitored in either province. Poorly managed harvest mortality can have substantial effects on the sex and age structure of a population, especially if age or sex classes are selectively harvested (Slalski et al. 2005). For example, selective and excessive harvest can influence productivity through skewed sex ratio and age class distribution. Therefore, management strategies should consider maintenance of appropriate adult sex ratios to ensure maximum reproductive efficiency in hunted moose populations (Raedeke et al. 2002).

Given the numerous factors that affect the performance of moose populations, the challenge for managers is to interpret the various relationships identified with survey data and other information in a structured, decision-making process to provide science-based recommendations for population management. Management-by-Objective is a results-based performance appraisal approach accomplished through strategic planning and population modeling (Strickland 1985, Arsenault 2000, Thiele 2007). The establishment of numerical population metrics (i.e., abundance, population structure, recruitment, and λ) from long-term data sets and subsequent demographic modelling helps to develop appropriate, biologically sustainable management strategies and a means to evaluate management prescriptions through population performance monitoring. Management-by-Objective requires development of area-specific management goals and numerical population objectives that are biologically and ecologically sound. This requires systematic population data collection, analysis, and evaluation of population performance relative to goals and objectives. As a prerequisite to management actions, it is important to understand the relationships among these various aspects to apply biological principles appropriately in a structured decision-making process (Sauer and Knutson 2008, Artelle et al. 2018).

The objectives of our analyses in the absence of reliable harvest data for the Boreal Plain Ecozone were to: 1) estimate and evaluate long-term demographic trends of our study populations, 2) present an overview of moose population status in the Boreal Plain Ecozone, and 3) provide suggestions for evaluating population demographic performance within a Management-by-Objective framework.

STUDY AREA

Our study area was within the Boreal Plain Ecozone of Saskatchewan and western Manitoba (Fig. 1) that lies south of the Precambrian Shield (Boreal Shield Ecozone) and north of the Aspen Parkland Ecoregion of the Prairie Ecozone (Ecological Stratification Working Group 1995, Padbury et al. 1998, Smith et al. 1998, Marshall et al. 1999), and where continuous moose population survey data were available and hunting occurs. The local topography is influenced by underlying glacial deposits and characterized by closed-crown mixed wood and coniferous forest, interspersed with peatland complexes, riparian watercourses, wetlands, and lakes. The forested landscape incurs substantial timber harvesting and wildfire suppression. The temperate climate is characterized by long, cold ($\bar{x}_{\text{January}} = -15$°C) and snowy winters and shorter warm ($\bar{x}_{\text{July}} = +15$°C) and moist summers; average annual precipitation is 450 mm.

The Boreal Plain Ecozone is more productive moose range than the adjacent Boreal Shield Ecozone and can support higher population densities (Arsenault 2000), but it also contains more linear access development for resource extraction and recreation.

The 14 discrete moose populations in our study area were subject to predation

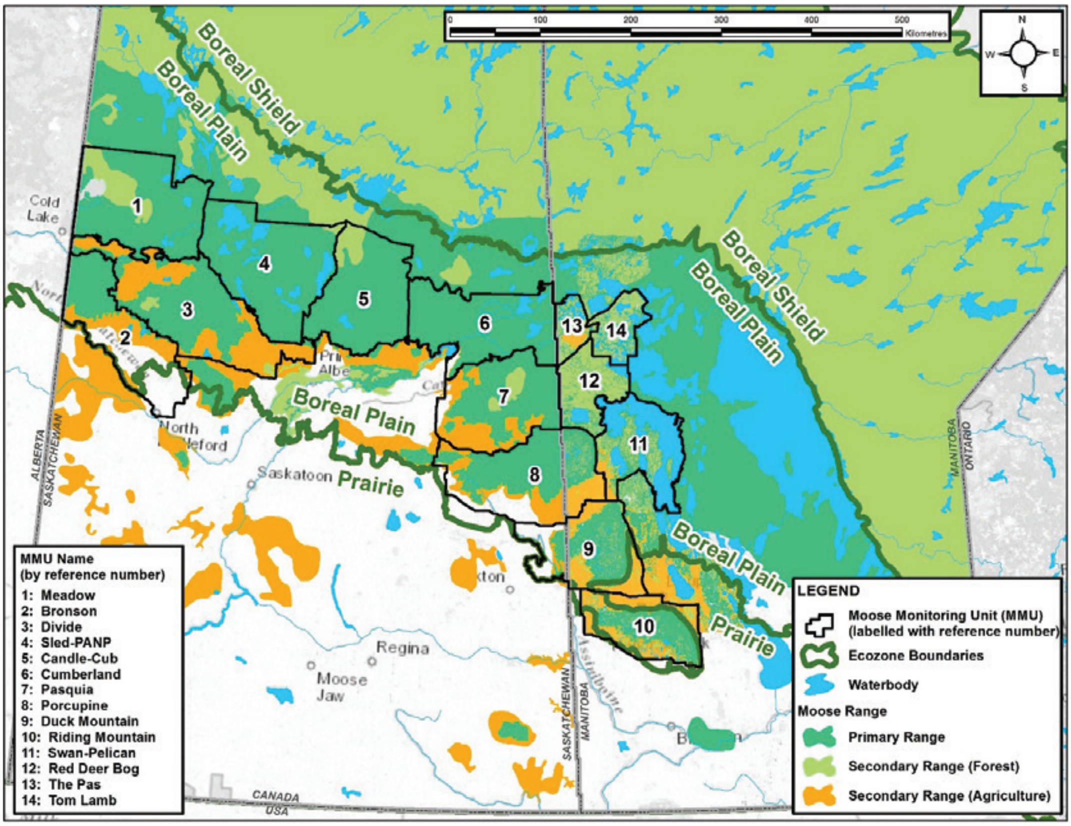

Fig. 1. Study area and Moose Management Units (MMU) delineated within the Boreal Plain Ecozone of Saskatchewan and western Manitoba. The primary range represents core moose distribution and high-quality habitats; secondary range represents lower quality habitats and/or discontinuous moose distribution.

from wolves (*Canis lupus*) and black bears (*Ursus americanus*). Population survey data were available for all, and each incurred harvest mortality from licensed and rights-based hunting. Three populations had portions of their range that provided refuge from hunting within a national park (Sled-Prince Albert National Park, Riding Mountain) or an air-weapons range (Meadow). Four populations (Candle-Cub, Duck Mountain, Meadow, and Porcupine) had areas of restricted harvest in portions that were provincial parks. All populations were subject to the effects of landscape disturbance and fire suppression. These are open populations that likely mix along the periphery of adjacent boundaries, but each is unique in the configuration, quality, and amount of moose habitat, as well as magnitude or type of landscape scale, anthropogenic disturbances including agriculture, forestry, mining and exploration, recreation, linear development, and urban development.

METHODS

Survey data

All population survey data were acquired from publicly funded wildlife survey programs implemented by the Saskatchewan and Manitoba governments. Prior to 1984, population structure and trend in Saskatchewan were monitored with a strip transect sampling design. A habitat-stratified random block quadrat sampling design (Stewart 1983) was used to obtain winter population structure and density estimates from 1984 to 1995; a >10% sightability error was maintained 95% of the time (i.e., estimates within a 95% CI). In 1996, Saskatchewan transitioned to the Gasaway et al. (1986) sampling design, as modified by Lynch and Shumaker (1995), that used 5.0 × 5.0 km survey units (UTM grid system) to assess winter population structure and density corrected for sightability (90% CI).

Manitoba monitored moose populations with a strip transect method prior to 1992, and subsequently adopted the modified Gasaway survey method that used 3.5 × 5.5 km survey units based on 3-minute grid cells (WGS 84) to obtain winter population structure and density estimates (95% CI; Knudsen 2007). The Gasaway surveys were conducted when snow conditions (>30 cm snow cover) and timing (January to early February) optimized sightability. One exception was the annual Cervid survey in Riding Mountain National Park and adjacent farmland that employed a strip transect design with ~25% coverage of the area (Tarleton 1992).

Population trend and demographic analyses

Survey data were acquired for all moose populations regularly sampled in both provinces within the Boreal Plain Ecozone over a 31-year period (1985 to 2015). Because the survey data were collected with different methods, our analyses were constrained to those that produced winter population structure and density estimates with known confidence limits (i.e., modified Gasaway surveys conducted between 1992 and 2015 inclusive; n = 41). Abundance estimates with known confidence limits obtained from habitat-stratified random block quadrat sampling (1985 to 2005 inclusive; n = 12) were used only to inform population trend models, and were excluded from demographic analyses because sample size of classified animals was limited. All survey data were spatially partitioned into 14 moose management units composed of combinations of Saskatchewan wildlife management zones (WMZs) and Manitoba game hunting areas (GHAs) (Fig. 1) that are the administrative units used to allocate hunting licenses, but do not (in most cases) delineate individual moose populations. Moose management units present an ideal landscape scale at which population assessment, management strategies, and policies are implemented (Arsenault 2000, Funk et al. 2012) because they share contiguous geophysical landscapes and similar ecological characteristics. Importantly, they encompass the core and fringe distribution of local populations based on spatial distribution from interpolation of aerial survey data and landscape features.

Each management unit population (n = 14) was reconstructed in Microsoft Excel© from survey data spanning the 31-year period to discern patterns of population structure, abundance, and trend as a time series model (White 2000). Model construction involved linear interpolation of abundance and demographic structure data between survey years. A third-degree polynomial was used to fit a long-term population trend line to the 3-year moving average of abundance estimates for each management unit. The polynomial was used because it is more sensitive to fluctuations in population size than a linear or log-linear trend line (Kuzyk 2016). The objective of model fitting was to identify periods of population increase and decline within each management unit and to enable assessment of population performance metrics both within and among management units with respect to changes over time in: 1) population state (winter abundance and demographic composition), 2) vital rates (λ, calf recruitment, sex ratio), and 3) historical range of variability.

The time series population reconstruction models were used to generate annual estimates of λ in each management unit to determine whether each Gasaway population estimate occurred during a period of increase, stability, or decline as well as to determine if the estimate was above or below the long-term mean for that population. We calculated the annual finite rate of population change as $\lambda = N_{t+1}/N_t$.

Investigation of demographic relationships between population structure and density relied solely on survey data collected using the Gasaway method to minimize potential for confounding effects of multiple survey methods in the analyses. Linear regression analyses of winter survey data (n = 41) were used to examine the relationships between population composition metrics (calf:cow and bull:cow ratios) and population density (moose/km²) relative to λ. We used multiple regression with calf:cow and bull:cow ratios as covariates to examine the relative effects of these variables on moose density in the same model. Annual harvest data by licensed or rights-based hunters were not available from either province for our analyses that were performed in Excel (Microsoft Corporation, Redmond, Washington, USA) or R (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Population trend

The time series modelling revealed a common trend of general decline in all 14 management units, although the rates and temporal patterns varied by unit (Fig. 2). Cumulative abundance estimates obtained by combining the model results for all 14 management units indicated a steady decline since the early 1990s in the absolute annual winter population (Fig. 3) that is currently estimated as ~30% less than the 31-year average. No cumulative estimate was above this average since the winter of 2010–2011 (Fig. 4). It is important to note that although surveys are designed to achieve population estimates with a precision level of ±10–20% (i.e., within the Manitoba 95% and Saskatchewan 90% CI), a >10–20% difference is required to detect a significant change in abundance between surveys (Gasaway and DuBois 1987, Lenarz et al. 2010).

Moose demography

No significant relationship was detected between population density and winter calf recruitment that varied between 0.3 and 0.6 calves/cow (Fig. 5A), indicating that winter calf recruitment was not density dependent. A significant negative relationship was found between the adult sex ratio

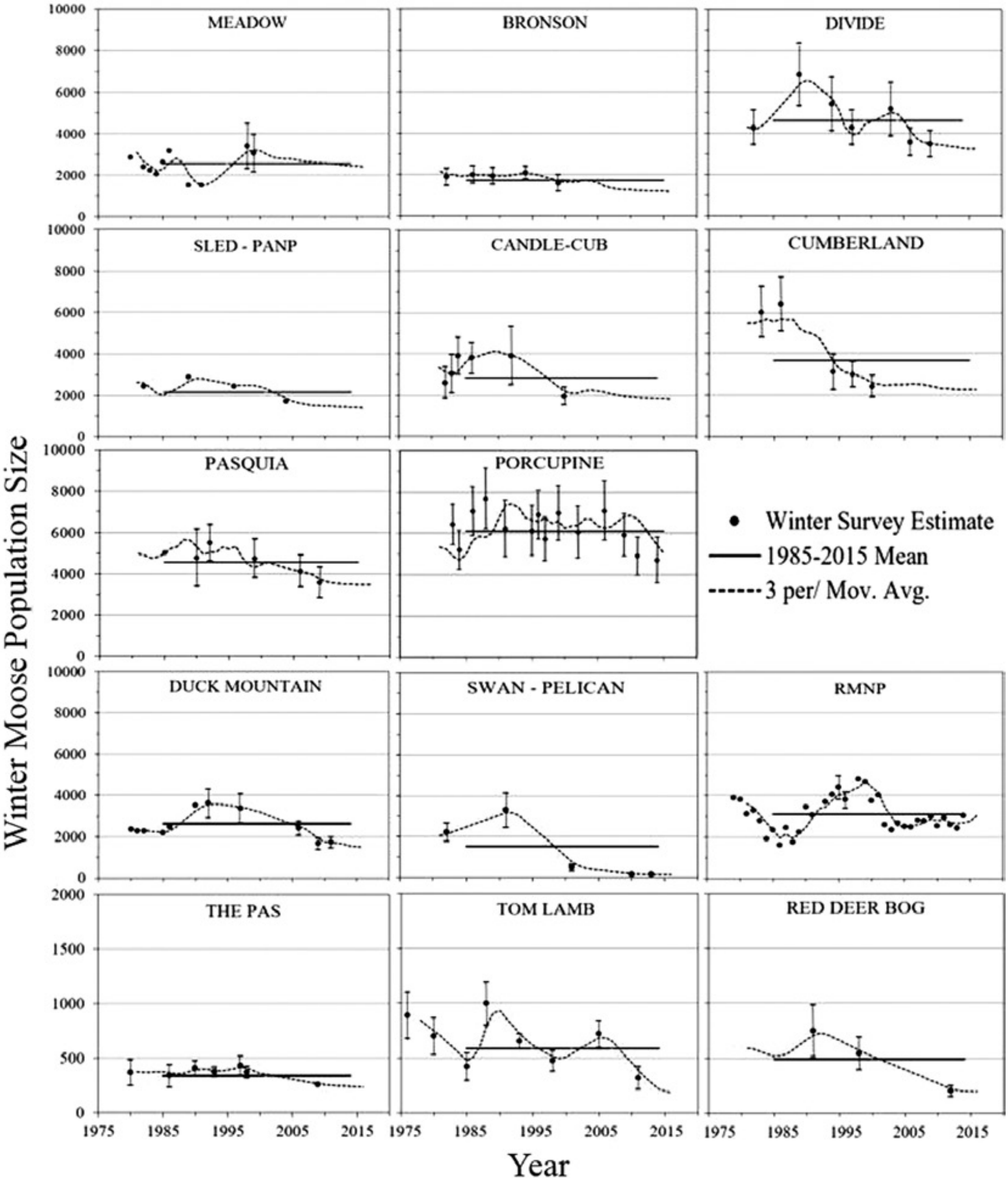

Fig. 2. Annual estimates of population abundance for 14 moose populations in the Boreal Plain Ecozone in Saskatchewan and Manitoba. Eight populations in Saskatchewan (top 3 rows – Meadow to Porcupine; 90% CI) and 6 populations in Manitoba (bottom 2 rows – Duck Mountain to Red Deer Bog; 95% CI) are illustrated relative to the average abundance estimate across 1985–2015.

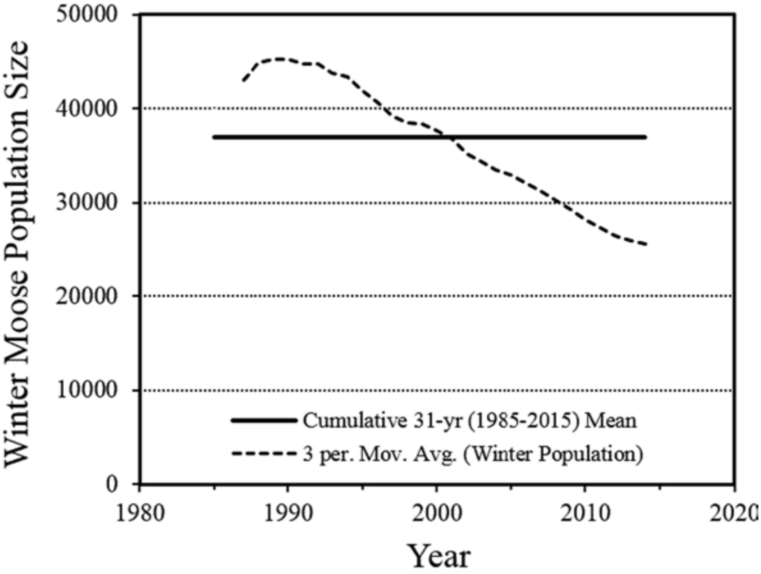

Fig. 3. The annual change in moose population abundance in 14 populations (pooled) in the Boreal Plain Ecozone in Saskatchewan and Manitoba, 1985–2015.

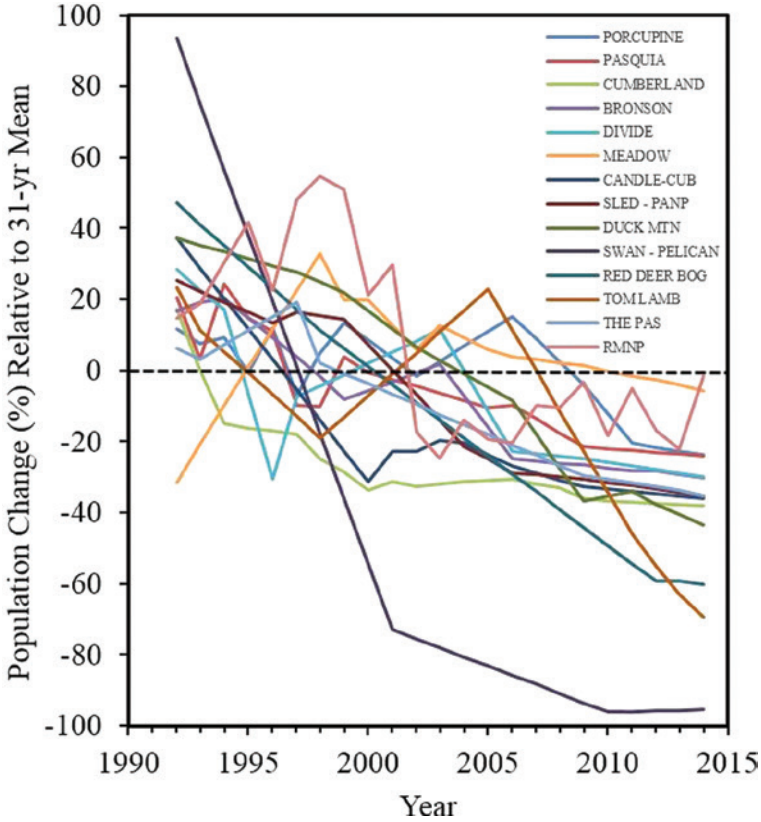

Fig. 4. The annual population change (%) in 14 moose populations in the Boreal Plain Ecozone in Saskatchewan and Manitoba relative to their respective 31-year (1985 to 2015) average abundance.

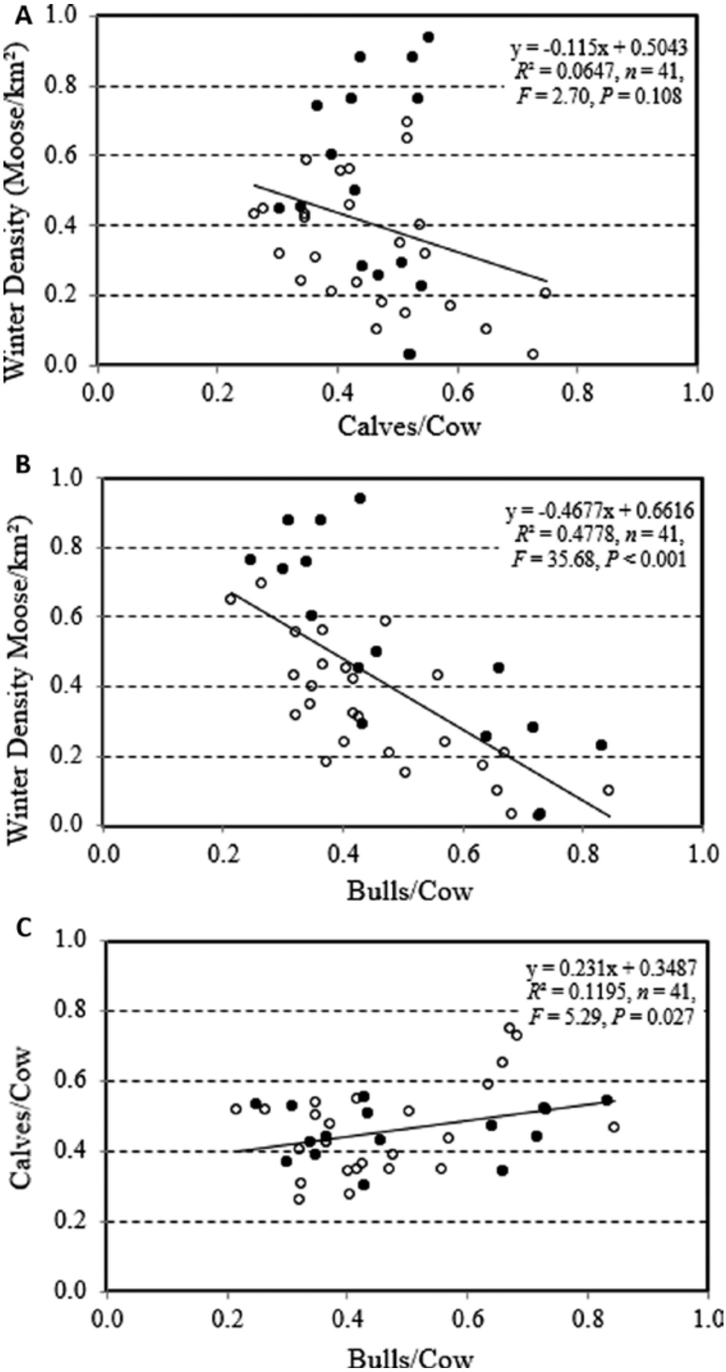

Fig. 5. The relationship of population structure, population density, and λ for moose populations residing in the Boreal Plain Ecozone in Saskatchewan and Manitoba. Solid symbols = Gasaway surveys where λ ≥ 1.0 and the population estimate was above the long-term average (1985–2015). Open symbols = Gasaway surveys where λ ≤ 1.0 and the population estimate was below the long-term average (1985–2015). (A) winter density versus winter recruitment (calves/cow); (B) winter density versus winter sex ratio (bulls/cow); and (C) winter recruitment (calves/cow) versus winter sex ratio (bulls/cow).

(bull:cow) and population density (Fig. 5B). For a given bull:cow ratio, population density was higher when λ was increasing than when declining (Fig. 5B). A significant positive linear relationship was detected between the calf:cow and bull:cow ratios (Fig. 5C), suggesting that calf production and recruitment increase with an increasing adult sex ratio. When included as covariates in the same model ($R^2 = 0.478$, $P < 0.001$), winter calf recruitment ($\beta = -0.018$) had no effect on moose density relative to the adult sex ratio ($\beta = -0.685$).

DISCUSSION

Our modelling indicates a broad scale, 30% average decline since 2000 in the study populations across the Boreal Plain Ecozone. Low moose density can influence population demographics (e.g., bimodal parturition reducing calf survival, fitness, population growth) and cause genetic effects (e.g., reduced heterozygosity, bottlenecks, founder effects) that influence long-term population viability (Broders 1998, Gaillard et al. 2000, Eberhardt 2002). Further, persistence of isolated and small, low-density populations is particularly susceptible to demographic stochasticity (Skalski et al. 2005, Broms et al. 2010) that increases the probability of extinction from the amplified effects of random annual fluctuations in vital rates of small populations (Snaith and Beazley 2002). Environmental stochasticity occurs less frequently and may cause decline in populations of any size (Lande et al. 2003). Valuable reference information is provided from consistent and repetitive population surveys that estimate abundance and sex and age structure of moose populations. Comparisons with long-term averages and historical variances are useful to evaluate current conditions, assess potential of and threats to a population, and determine population performance relative to management decisions or habitat change (Haufler et al. 2002).

A multitude of factors and pathways potentially affect long-term viability, demographic trends, and range occupancy of moose. The functional pathways of drivers of population change occur at spatial and temporal scales that affect habitat suitability (Karns 1998, van Beest and Milner 2013, Monteith et al. 2015), habitat selection (Schwab and Pitt 1991, Fahrig and Rytwinski 2009, Herfindal et al. 2009, Bjorneraas et al. 2012, Van Beest et al. 2012), population demography (Murray et al. 2006, 2012, Brown 2011), abundance (Van Ballenberghe 1983, Timmermann 1992, Sylvén 2003), mortality risk (Hebblewhite 2008, Laurian et al. 2008, Wasser et al. 2011), behaviour patterns (Dussault et al. 2004, Bjorneraas et al. 2011, Broders et al. 2012, Street et al. 2015), fitness (Renecker and Hudson 1990, Crichton 1992, Wilton 1992, Lowe et al. 2010, McCann et al. 2013), predator-prey dynamics (Stewart et al. 1985, Messier 1994, Rayl et al. 2015), pathogen burdens (Murray et al. 2006, Lenarz et al. 2009, Doak and Morris 2010), and population viability (Popescu et al. 2016). Although there is a paucity of empirical data to quantify the relative effects of these drivers of population change (e.g., comprehensive hunter harvest statistics) in the Boreal Plain Ecozone, there are common probable causes of moose population decline (Table 1). We consider hunting mortality and to a lesser extent predation to be proximate (immediate) drivers of decline in these populations. We consider habitat alteration from anthropogenic effects of linear and polygonal disturbance, wildfire suppression, sensory disturbance, and climate change effects (e.g., shorter winters, increased temperature, extreme weather events, or drought-altered wetland phenology) to be ultimate (critical/definitive) drivers of population change in the Boreal Plain Ecozone.

Table 1. Hypothesized drivers of population change by Moose Management Unit (MMU) in the Boreal Plain Ecozone of Saskatchewan and western Manitoba, 1985–2015. Winter population abundance and density (in brackets) are modelled estimates projected from the available survey data.

MMU	Winter population (moose/km²)		Hypothesized driver(s)[4]
	31 yr ave. (1985–2015)	Current (2015)	
Meadow[1]	2554 (0.208)	2407 (0.201)	CC, HC (fire suppression)
Bronson[1]	1719 (0.424)	1174 (0.241)	CC, UHH, HC (increased access, oil and gas disturbance, forest cattle grazing, fire suppression)
Divide[1]	4627 (0.462)	3238 (0.282)	CC, UHH, HC (increased access, fire suppression)
Sled-PANP[1]	2142 (0.142)	1385 (0.091)	CC, UHH, HC (increased access, fire suppression)
Candle-Cub[1]	2834 (0.273)	1811 (0.157)	CC, UHH, HC (increased access, fire suppression)
Cumberland Delta[1]	3678 (0.401)	2553 (0.223)	CC, UHH, HC (hydroelectric development altering delta ecology and allowing increased human and predator access, and vegetation succession)
Pasquia[1]	4555 (0.603)	3500 (0.411)	CC, UHH, HC (increased access, anthropogenic disturbance, fire suppression)
Porcupine[2]	6160 (0.658)	4705 (0.496)	CC, UHH, HC (increased access, anthropogenic disturbance, fire suppression)
Duck Mtn.[2]	2643 (0.452)	1491 (0.248)	CC, UHH, HC (anthropogenic disturbance, fire suppression)
Swan-Pelican[3]	1515 (0.280)	152 (0.030)	CC, UHH, HC (increased access)
Riding Mtn.[3, 4]	3105 (1.009)	3,054 (0.995)	CC, HC (fire suppression)
The Pas[3]	340 (0.196)	234 (0.130)	CC, UHH, HC (fire suppression)
Tom Lamb[3]	585 (0.206)	178 (0.057)	CC, UHH, HC (fire suppression)
Red Deer Bog[3]	490 (0.107)	195 (0.041)	CC, UHH

1 = Saskatchewan, 2 = inter-provincial population, 3 = Manitoba, 4 = largely not hunted (HC = Habitat Change, CC = Climate Change, UHH = Unsustainable Hunter Harvest).

Predation and harvest mortality (e.g., sex-selective harvest) can have significant effects on adult sex ratios and calf survival which influence demographic parameters including production, recruitment, abundance, λ, and overall population performance (Haufler et al. 2002, Skalski et al. 2005). Because hunting (licensed and rights-based) is likely additive to natural mortality, its effect on population state and structure is potentially exacerbated by a harvest strategy not linked to population performance measures which should inform biologically sustainable, license allocation strategies. This management shortcoming has likely contributed to the long-term declines observed in the study populations (Fig. 2–4). Various forms of sex and age selective harvest strategy were implemented in each of the management units during recent decades despite the unknown stochastic effects of rights-based harvesting, predation rate, disease/parasite outbreaks, or large-scale disturbance events. These strategies generally allocated more licenses to harvest adult bulls, particularly since the mid-2000s with the removal of calves from non-draw hunting seasons, and presumably created a skewed adult sex ratio in favor of females. Licensed calf harvest was restricted to draw-only seasons of limited allocation since the mid-2000s, and for cows in the entire study period.

We found a significant density-dependent relationship between the adult sex ratio and population trend (Fig. 5B). Most of the populations with density above the regression line were increasing ($\lambda > 1.0$) and those below decreasing ($\lambda < 1.0$), suggesting that population growth was impaired when the adult sex ratio fell below a density-dependent threshold. Eberhardt (2002) also observed a sequence of changes in vital rates and demographic measures in relation to population abundance and trend. The relative rate of increase in a moose population is greater when the population is skewed towards females, and when most adults are in the "prime" age classes, whereby fecundity and survival are maximized (Van Ballenberghe 1983). In a moose population with a given sex ratio, harvest allocations to maintain density above the regression line (Fig. 5B) while maintaining a stable bull:cow ratio are likely to result in stable or increasing populations.

Population density varies across moose range (0.1 to 1.1 moose/km^2) but is generally <0.5 moose/km^2 in the boreal forest of North America (Crête 1987, Messier 1994, Timmermann and Buss 1998, Arsenault 2000, Maier et al. 2005). Populations that are widely distributed at low winter density require a higher bull:cow ratio to ensure adequate reproduction (Schwartz 1998). Timmermann (1992) recommended an adult bull:cow ratio > 0.5 at a density of 0.30 moose/km^2, and Messier (1996) a bull:cow ratio of 0.4 to 0.5 to maximize sustainable harvest of 0.025 moose/km^2 (under a selective harvest regime) at 0.28 to 0.35 moose/km^2; our assessment of the Boreal Plain Ecozone populations support these recommendations. For example, Fig. 5B illustrates adult sex ratios across a range of population density relative to λ that could be used to set population objectives and evaluate performance within a Management-by-Objective framework based on management units.

Unbalanced adult sex ratios can result in several negative consequences depending on the degree of the imbalance and density of the moose population. A protracted breeding season resulting from a skewed sex ratio favoring females can shift neonate sex ratios in favor of males which can reduce population growth rate (Ballard et al. 1991, Boer 1992). Low bull:cow ratios can impair breeding effectiveness (Crête et al. 1981, Schwartz 1998, Laurian et al. 2000) because of the inability of bulls to locate and breed estrous cows in low-density populations (Page 1983, Sæther et al. 2003) and protract contraception over 2–3 estrous cycles that cause reduced twinning (Aiken and Childs 1993) and late-born calves more susceptible to winter mortality (Bubenik and Timmermann 1982, Sæther et al. 2003). Lower body mass of males can be associated with a low proportion of adult males in the population (Solberg and Sæther 1994), and can influence reproductive success in polygamous Cervids (Sæther et al. 2003).

Collectively, the relationships depicted in Fig. 5 suggest a negative feedback system; specifically, that stable to growing populations at higher winter densities are characterized by a lower adult sex ratio and proportionately lower calf recruitment rate than depressed populations at lower density with declining λ. From a population performance perspective, this suggests that abundant populations approaching their upper limit in size and density (i.e., carrying capacity) have proportionately lower calf production and winter calf recruitment rates than populations below their mean abundance state. It is important to note that we assessed calf recruitment with mid-winter calf:cow ratios which likely overestimate true recruitment because predation of ungulate calves occurs continuously in natural systems (Musante et al. 2010, Environment Canada 2012, Hurley 2016, Jones et al. 2017). Recruitment is the most variable of demographic metrics for ungulate populations, but it reflects fecundity and survival of offspring and strongly influences inter-annual variation in population growth (Gaillard et al. 2000, Monteith et al. 2015).

To effectively manage a species, its population dynamics must be thoroughly understood. Therefore, consistent methods to survey moose population demographics and long-term data sets are essential to understand population performance. Management-by-Objective provides a foundation of actionable science that drives management decisions and informs ongoing survey needs from which management prescriptions are evaluated and adjusted based on population performance through an adaptive management process (Artelle et al. 2018).

It is essential to link population objectives and performance within an appropriate scale of management and to implement population monitoring programs that provide information with direct relevance and use to evaluate population status and management prescriptions. Monitoring populations with consistent methods over the long-term will provide insights about population performance metrics used to develop population objectives and guide management under a Management-by-Objective framework (Arsenault 2000, Lyons et al. 2008). In the absence of reliable harvest data at the management unit scale, this framework requires relevant data about population demography and performance over time to monitor the consequences of management actions imposed on a population and/or its habitat, and to monitor outcomes relative to the desired objective (Arsenault 2000, Lyons et al. 2008, Sauer et al. 2013).

Assessing population performance relative to numerical objectives is a crucial step towards establishing population performance metrics for informed and structured decision-making within the Management-by-Objective framework (Strickland 1985, Lyons et al. 2008, Sauer and Knutson 2008). High male harvest under a selective harvest strategy that results in considerable over-kill of males is neither optimal nor viable over the long-term for effective breeding of receptive females (Messier 1996, Sylvén 2003). Saskatchewan came to this conclusion and subsequently altered its harvest strategy to include population performance measures within a Management-by-Objective framework (Arsenault 2000), but failed to fully implement the framework by linking sustainable harvest to long-term demographic objectives for each management unit. Manitoba has not established moose population objectives or management planning at any scale, potentially subjecting the population to chronic and unsustainable hunting mortality, and contributing to population decline and implementation of hunting moratoriums in some GHAs to induce population recovery. In addition, there is no coordinated moose management between Manitoba and Saskatchewan for shared populations or biologically sustainable population or harvest objectives. Our study suggests moose populations in both provinces would benefit from the development of these objectives and full implementation of a Management-by-Objective framework.

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