TECHNICAL REPORT

Re-evaluation of Trends in Moose Populations in the Cariboo Region 1985-2012

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EXECUTIVE SUMMARY

In 1998, a British Columbia (BC) provincial-level review of moose harvest statistics indicated declining moose numbers in the Cariboo Region from 1985 to 1997; and bull:cow ratios were below provincial standards. In 2012 and 2013, population surveys in three specific locations in the region all indicated declines in local populations of moose. In response to this and other related information, Regional biologists have concluded the possibility of a region-wide decline in numbers of moose and called for a third-party independent review of the situation. Our objectives were to use a combination of scientifically credible quantitative analyses and expert opinion to:

1. Review status of moose populations in four of the five Game Management Zones (GMZs) in the region;
2. Determine if there has been sufficient evidence to either confirm or reject the biologists' notion that moose populations have declined;
3. Identify and assess all potential factors which may be influencing moose population trends and assign relative rankings to the importance of each factor; and
4. Make recommendations for actions that will help achieve regional moose management objectives.

The data reviewed included Stratified Random Block surveys, composition-level surveys, and annually conducted hunter harvest questionnaires. Metrics used to assess status of moose populations included estimated population density (#moose/km^2), calves:100 cows, bulls:100 cows, hunter success, catch-per-unit-effort (CPUE), and number of reported moose harvested. The first notable conclusion about these data was the paucity of information, particularly in recent years. The paucity of data meant that our inspection of population trend would necessarily be guided most strongly by apparent trends at the level of a few Wildlife Management Units that had repeat sampling. A second notable conclusion about the data was an apparent maturation in application of SRB methods over time, in particular the derivation and use of sightability correction factors (SCF) but we also noted a trend in decreasing sampling variation. The potentially confounding factor of a change in application of SCFs had to be taken into account by contrasting both corrected and naïve estimates of population density.

The proportion of observed mean densities higher than the regional management objective of 0.4 moose/km^2 was higher (66%) in the 1995-2002 period than in the subsequent 2003-2012 period (33%). This suggests that the likelihood of observing densities higher than the management objective in SRB surveys, while they did occur, is apparently becoming less likely. At the GMZ level we noted population density to have shown a tendency to decline:

- GMZ 5A – moose densities generally below the management objective and no indication of an overall trend in density.
- GMZ 5B – moose densities highest in the region and the population appears to be relatively stable to increasing remaining near the management objective.
- GMZ 5C – moose densities tended to remain near to or below the management objective.
- GMZ 5D – similar to GMZ 5C, estimated historical moose densities were at or below the management objective.

At the WMU level (and prior to 2013), there were 5 locations that had more than one SRB survey allowing for comparisons between periods prior to, and after, 2005: Horsefly

River, Kluskus, Rose Lake, Anahim East, and Big Creek. The results indicated that in four cases, moose densities had declined between survey periods, and this decline was statistically significant for Horsefly River, Anahim East, and Big Creek, but not significant for Rose Lake or Kluskus. This comparison of SRB survey data between time periods at the level of individual WMUs demonstrates strong evidence of population decline and this seems most evident in the units west of the Fraser River.

Survey results indicate that regional bulls:100 cow ratios have tended to increase, and since 2000 have generally been above the management target of 30 bulls:100 cows; this is more the case in GMZ 5B and GMZ 5C. Trends in calves:100 cows shows a general decrease in estimates of this ratio since approximately 2002 compared with the period 1994-2001; estimates appear to be below the management target of 40 calves:100 cows since approximately 2004-2005 although recent SRB results show potential improvement particularly in GMZ 5B and GMZ 5C. However, if calf mortality has not changed significantly over the recent time, the slightly improved ratio in the latter two GMZs could also be indicative of recently heightened vulnerability of cows (i.e., consistent with the increased bulls:100 cows observed in the same GMZs).

Since 2000, the period of primary interest, all hunter reported metrics (except CPUE) appear to have been relatively stable with no obvious or statistically significant trend. CPUE, by comparison rose sharply between 2000 and 2003 followed by abrupt declines through to 2005. However, the number of moose harvested remained stable indicating a relative increase in efficiency of hunting.

To meet objective 3, we undertook three types of analyses: (1) demographic modelling of moose population dynamics to identify patterns of mortality that would be necessary to improve consistentcy with the observed survey and hunting data from 2000-2012, (2) exploration of plausible changes in factors affecting vulnerability of moose to predation and non-regulated mortality over that time period; and (3) investigation of potential changes in landscape and habitat characteristics that may be related to decreasing habitat quality for moose.

From the demographic modelling we found that assumptions of non-hunting mortality rates on bulls as estimated from the management models used by the Ministry in their allocations were broadly consistent with observed patterns, except in GMZ 5D where mortality rates on bulls may be > 50% higher than current assumptions. By comparison, mortality rates on cows generally needed to be 30-50% higher than current management assumptions in order to plausibly match observed data. Required average annual mortality rates on calves appear to be in the 50-65% range across GMZs to generate plausible patterns, which is within published estimates of annual losses to calves in the presence of predators.

The results of the vulnerability modeling indicated that the estimated non-regulating mortality (both extent and effort) were negatively related to all three types of survey data (density, bull:cow ratios, calf:cow ratios), while number of years of deep snow and relative abundance of wolves also were negatively related to both density and bull:cow ratios. Relative changes in hunter access were related to densities but not strongly to the other response measures. We found that loss of moose habitat was negatively correlated with densities, while annual harvesting rates was negatively related to bull:cow ratios. Proportions of moose habitat in the most suitable class were positively associated with calf:cow ratios. When vulnerability and habitat factors were combined, moose population densities were lower in areas where non-regulated mortalities were assumed to have increased and where forest harvesting rates 5 years previous were higher (a lag effect), relative to other areas. As above, bull:cow ratios were negatively associated with forest harvesting rates but positively associated with MPB effects, especially where areas of non-regulated moose harvests were assumed to be extensive. Calf:cow ratios were associated with areas where moose habitat was in the most suitable class; other effects of vulnerability factors were not clear for this response variable. We caution that the amount of residual (unexplained variation) remaining after these model fits was large, indicating that the explanatory power of these models remains very modest.

Details on key conclusions are provided. In general, we concur that evidence for a regional-level decline in moose is strong enough to warrant broad changes in management of moose in the Cariboo Region. That said, the paucity of information from inventory (i.e., population surveys) and potential sources of mortality (i.e., regulated and unregulated hunting, predation and other natural causes) will restrict the ability for managers to respond effectively unless effort is made to construct a designed and strategic approach to obtaining such information. Based on evidence from a variety of sources (e.g., dynamics of hunter success; timing of the MPB epidemic and forest industry response; an apparent bias in the population decline to cows and calves; and lack of consistent population response to apparent changes in moose habitat, wolf populations, or winter weather), we consider the most plausible deductive explanation for the moose population decline was an increase in vulnerability of moose to human-caused, and other, sources of mortality coincidental with the MPB epidemic. While the effects from hunters was partially controlled by regulation, it seems plausible that unregulated hunters and/or predators continued to benefit from the enhanced vulnerability of moose which, if accurate, has continued unchecked. While this is our best judgement based on deductive reasoning, it must be emphasized that we had no source of independent data to test the conclusion, and deepen the search for explanations.

There are many places where deeper and different analytical methods might be used to further assess our conclusions at this point. Those suggestions are provided as recommendations for further research. Our key management recommendation is to emphasize the need for effectiveness monitoring including the collection of basic inventory as well as designed research to improve understanding moose mortality rates – much of which remain as assumptions unless progressive steps are taken to change that.

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INTRODUCTION

In North America, moose (*Alces alces*) are reported to be in decline throughout most of their southern range (Murray et al. 2006, Lenarz et al. 2010); although some southern populations appear to be increasing (Murray et al. 2012). Provincially, recent survey results suggest that marked declines in moose populations have occurred during the last decade within the Cariboo Region (≈17 – 60% decline), central portions of the Omineca Region (≈50% decline), Bulkley Valley Lakes District (≈20% decline), and Nass Wildlife Management Area (≈70% decline; MFLNRO 2012). Populations are also suspected of being in decline in the North Thompson, the Bonaparte, and the Nehalliston Plateau based on anecdotal information and harvest information. In other areas of British Columbia (BC) where survey information exists, moose populations are considered to be stable (Peace Region), or stable to increasing (Okanagan and west Kootenay Region).

Moose population densities have been shown to be dependent on a number of factors, including the nutrition-mediated carrying capacity of their habitats and on the densities of their principal predators, wolves (*Canis lupus*) and bears (*Ursus americanus*) (Gasaway et al 1992). Bergerud (1992) indicated that the carrying capacity for moose in food-limited systems is 1,500 moose/1,000 km^2 (or 1.5 moose/km^2), or greater. In a review of moose population dynamics in moose-predator systems, Boutin (1992) found moose densities to range between 0.2-0.7 moose/km^2 and Bergerud (1992) estimated moose carrying capacities in systems where moose are the principal prey of wolves to be about 300 moose/1,000 km^2 or 0.3 moose/km^2. Gasaway et al. (1992) found that moose densities in lightly harvested populations regulated by healthy wolf populations in the northern boreal mountains ranged between 0.05-0.42 moose/km^2 (Gasaway et al. (1992) and that moose could attain densities between 0.17-1.45 moose/km^2 after predators are held below carrying capacity.

Ecological mechanisms accounting for declines in moose populations are likely a complex function of habitat, nutrition, and predator-prey factors. Potential contributing factors in declining populations include increased numbers of predators, increased hunting, lack of summer thermal cover, declines in browse species, parasites (e.g., winter ticks, carotid artery worms), other diseases, micro-nutrient deficits, habitat fragmentation, and competition with other ungulates for forage (Murray et al. 2006). Climate change-mediated effects (direct or indirect) on survival and reproduction have also been suggested in recent studies (Murray et al. 2012, van Beest 2012). Factors may also act synergistically over time. For example, declines in forage supply or increases in predator abundance may initiate a decline, and other sources of mortality or the effects of parasites and diseases may act to continue to suppress populations.

Wildlife populations are characterized by estimates of population size (i.e., density or abundance) and distribution, the demographic composition and vital rates of the population (i.e., its age-class structure, sex ratio, survival, and fecundity), and the dynamics of both of these features (i.e., annual variation and long-term trends). Some of these attributes can be obtained from population surveys, while for managed species, others can be inferred from other data (e.g., hunting statistics). However, some attributes such as estimates of survival rates and causes of mortality require more focused studies. In general, if changes in one or more ecological conditions (e.g., changes in climate, habitat condition, predator-prey dynamics, prevalence of disease) affecting moose are occurring, these may in turn cause detectable changes in the population dynamics. For example, where changes in habitat conditions occur, trends in population and/or demographic composition may be related to habitat factors ultimately responsible for mortality to breeding adults or to juveniles that would otherwise be recruited into the breeding population.

Beginning in 1993, moose harvests in the Cariboo Region were regulated under a combination of a general open season (GOS) and Limited Entry Hunting (LEH) systems, with quotas for the commercial (guided) sector[1], with full implementation of LEH after 1999. Under the LEH and quota system, harvestable moose are allocated between the resident and commercial (guided) sectors every three to five years. The allocation depends on periodic assessments of moose populations and population condition in different management zones in the Region, combined with resulting harvest statistics, and stakeholder consultations[1]. In the Cariboo Region, concerns have been growing that populations in some management zones may be declining. In 1998, a review of harvest statistics indicated declining moose numbers from 1985 to 1997, and bull:cow ratios that were below provincial standards (Hatter 1998). Concerns about possible declines in the densities of moose in the Cariboo have re-emerged based on results from recent surveys which indicate substantial declines in moose populations and their demographic condition in some Wildlife Management Units (WMUs) since previous surveys (EDI 2012, Davis 2012, Davis 2013).

Our objectives were to use a combination of scientifically credible quantitative analyses and expert opinion to:

1. Determine if there is sufficient evidence to either confirm or reject biologists' conclusions that most moose populations in the Cariboo region are declining;
2. Identify and assess all potential limiting factors which may be influencing moose population trends in the region;
3. Assign relative rankings to the importance of each limiting factor; and
4. Make management recommendations to achieve moose population objectives in the region.

STUDY SCOPE

Study Region

This analysis was conducted in the BC Ministry of Environment's Management Region 5 (Cariboo Region). This 116,538 km^2 region is primarily located in the central interior ecoprovince (Demarchi 1991) and its climatic patterns are dominated by the rainshadow effect of the coastal mountains, with cold winters, and warm dry summers. The Cariboo Region is divided into five Game Management Zones (GMZs), with two of the Zones (5A-B) located east of the Fraser River, and the remaining Zones (5C-E) west of the Fraser River (Figure 1). GMZ's are amalgamations of WMU's which share similar ecological characteristics and hunting patterns[1], and thus provide a suitable geographical framework for implementing harvest management strategies. A description of the moose habitat in these areas is available from Eastman and Ritcey (1987).

[1] see details in British Columbia Ministry of Forests, Lands and Natural Resource Operations. 2011. Evaluation of Alternative Moose Harvest Strategies in the Game Management Zone 5B; East Cariboo. Unpublished report.

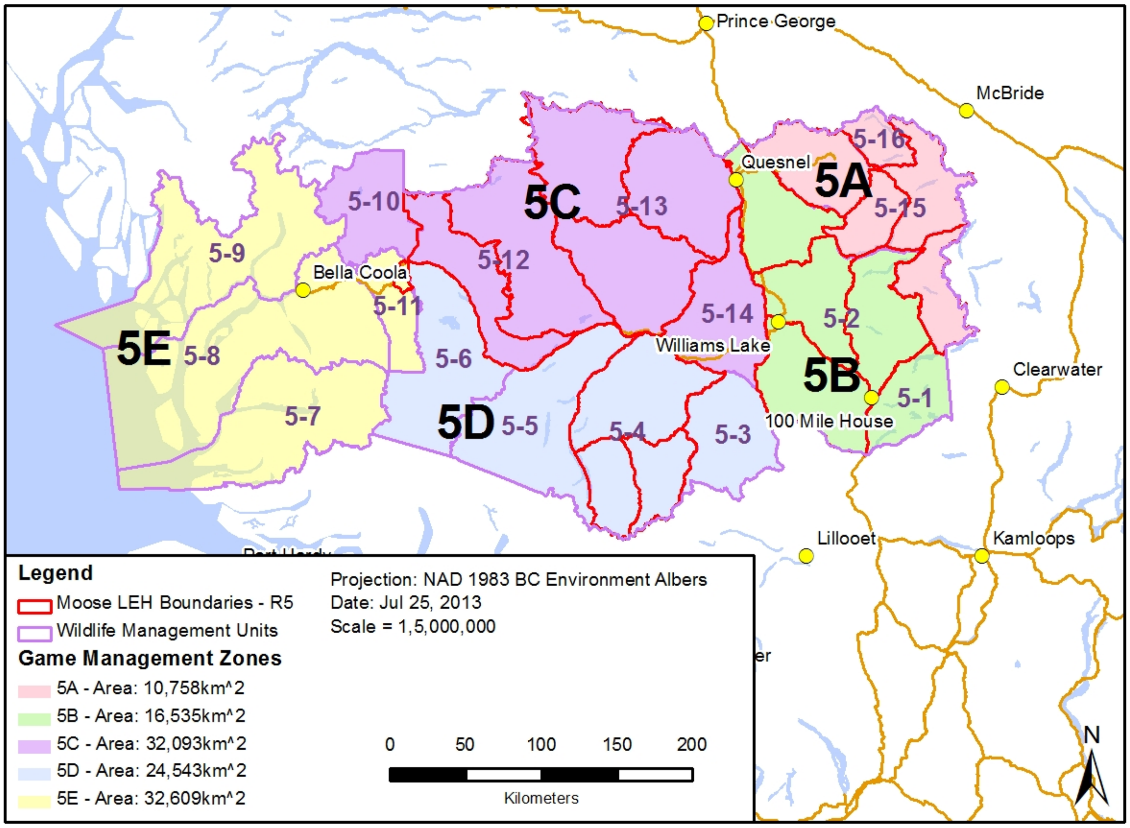

Figure 1. Ministry of Environment Management Region 5 showing locations of the game management zones (GMZ) and individual wildlife management units (WMUs).

More recently, Dawson and Hoffos[2] have characterized winter moose habitat quality in portions of GMZ's 5C and 5D using a combination of habitat capability mapping and application of a moose winter habitat model. Unless otherwise noted in subsequent sections, GMZ 5E is excluded from our analysis because of the paucity of survey information there.

Management of Moose

As stated in the Introduction, management of moose populations in the Cariboo Region is regulated under the Limited Entry Hunting system including quotas set for the guided (commercial) sector[3]. Allocations are set every five years, and the procedures to determine the allocation follow the Big Game Harvest Management and Moose Harvest Management Procedures (4-7-01.07.1 and 4-7-01.07.03 respectively)[1] which can briefly be summarized under each harvest option:

1. Assess status of the moose populations within each of the 4 GMZs that are normally assessed (e.g., GMZs 5A-5D) to determine an estimate of Annual

[2] Dawson, R. and R. Hoffos. 2012. A Cumulative Impact Assessment Approach for First Nations Consultation: Pilot Project for the West Chilcotin. Draft report prepared for the B.C. Ministry of Forests, Lands and Natural Resource Oeprations, Williams Lake, B.C.
[3] LEH and quota systems are used where intensive management regimes are required (see footnote 1)

Allowable Mortality (AAM). In general, GMZ-level population estimates of moose in the Cariboo follow the Level 2 BC Resource Inventory Standards for population counts, age, and sex determinations (BC RIC 2002). Abundance estimates are based on periodic abundance surveys using the stratified random block (SRB) methods adapted from Gasaway et al. (1986) and Oswald (1982). Compositional (i.e., population age/sex composition) surveys are also undertaken in addition to SRB surveys. Harvest data for moose from LEH hunter returns and hunter questionnaires[4] are compiled and analyzed to assess the trends in mortality due to hunting and to compare to trends observed in the demographic indicators that are calculated from survey data. Survey results are extrapolated on the basis of the estimated total suitable moose habitat within each GMZ to estimate total numbers of moose in the GMZ.

2. From the overall AAM estimate, the following deductions are made in the order below:
   i. The supply of moose for First Nations (FN) traditional use, although unknown, is assumed as a constant harvest per allocation period (see methods for details).
   ii. The remainder of the AAM (i.e., the Annual Allowable Harvest [AAH]) to be allocated is estimated using a population modelling approach (e.g., White and Lubow 2002). Estimates of population sizes, recruitment, and survival rates by age class can be generated from multiple sources of data using model-fitting methods implemented in a spreadsheet format. Hunter removals are implemented as a series of hypothetical harvest options, and removals by both regulated hunters and FNs are incorporated into the population model. Model results are interpreted as an estimate of the relative probabilities that population objectives will not be met under the suite of harvest options being considered. After consultations with stakeholders, the Regional Manager selects an AAH considering the priorities of conservation, FN sustenance harvest, resident harvest, non-resident harvest, and other stakeholder concerns.
   iii. The AAH is allocated between residents and commercial sectors considering the Harvest Allocation Procedures (4-7-01.03.1). For guides, individual quotas are calculated based on the estimate of harvestable moose within each guide territory following the Quota Procedures (4-7-01.05.1).

The overall management objectives for key demographic attributes of moose populations in the Cariboo Region are given in Table 1.

Data Description

The datasets used for analysis of moose populations were provided by FLNRO staff in the Cariboo Region. We supplemented the data by accessing the original reports where available. Where possible, we used the most recent summaries of the assembled data and if differences occurred between that and original datasets, we contacted FLNRO staff to confirm the reason for the differences.

[4] Moose and elk are managed under the Limited Entry Hunting Program, and harvest figures for these species are taken from Hunter Sample and Guide Declarations (source: Big Game Harvest Statistics 1976-2010.xls)

Table 1. Post-hunt management objectives for moose populations in the Cariboo Region, British Columbia (Lirette 2012).

Attribute	Management Objective	Comment
Demography		
overall density	>40 moose/100 km^2	Overall target for the Cariboo Region. this target applies to both high and low density MUs[b]
bull:cow[a] ratio	>30 bulls to 100 cows	Sex ratios above this target indicate sufficient bulls to maximize reproductive success.
calf:cow ratio	>40 calves to 100 cows	Ratios observed in early winter below this level indicate low recruitment of young moose into the breeding population.
spike-fork males: bulls	>50 sf males: 100 bulls	Ratios above this level ensure adequate pool of young males available to recruit into the breeding male population.
Harvesting		
FN harvest	Ensure FN harvest needs are met	
resident hunter CPUE[c]	Resident hunter success rate is < 25 days/ harvested moose (equivalently > 0.004 moose/hunter-day)	
Other		
trend	Stable or increasing population	
recovery planning	Manage moose numbers in conjunctions with caribou recovery efforts	Caribou recovery in MUs 6, 10, 11, 12, 15 may require habitat management and predator management actions that influence moose populations.

[a]in surveys, cows include yearling and adult (2+) females as these are difficult to distinguish in the field.
[b] Note that targets can vary between high density and low density MUs, where low density is defined as ≤ 200 moose per 1000 km^2 of fall range (see citation in footnote 1).
[c]We use the common acronym CPUE (catch per unit effort) in reference to success rate of hunters (e.g., total harvested moose as a proportion of the number of hunter days).

Data of six main types were used:

1. Intensive aerial population surveys based on SRBs conducted at the WMU (or lower) level, yielding estimates of total moose (bulls, cows, and calves) and population composition (bulls:100 cows and calves:100 cows). Moose densities were usually estimated from these data using the programs Moosepop and Aerial Survey[5],

[5] Moosepop extends sample results to the entire survey area, and Aerial Survey applies the Sightability correction Factor (SCF) as well as checking the Moosepop results. Moosepop also estimates bull:cow and calf:cow ratios (in addition to the observed ratios). Estimated densities and ratios are given together with their associated levels of precision.

2. Aerial population composition surveys of WMUs, yielding moose population composition data only.
3. Data from returned Hunter Questionnaires and compulsory reporting from Guide Outfitters, yielding estimates of hunting effort (number of hunters, kills per hunter day, and kills). In addition, we also examined projections from the moose management models used by government to allocate hunting opportunities.
4. Model projections from implementation of a stage-based demographic model for moose were used to assess the relative effects of varying mortality sources upon observed population statistics for moose at the GMZ-level.
5. Spatial (GIS) landscape data including moose habitat capability mapping, Vegetation Resources Inventory, harvested areas, roads, streams, wetlands. Time series of forest harvest areas and forest losses due to mountain pine beetle (MPB) were used where available. Grids of the SRB survey areas were also examined. See Appendix B for a description of how these data sources were processed.
6. Questionnaire responses from biologists were used to help augment places where empirical data were either not available at all (e.g., moose harvest levels by FN or moose mortality rates due to predators), where collection of data did not necessarily meet sampling requirements for the analysis (e.g., weather), or where resources needed to extract data would have exceeded project budget (e.g., access changes due to the development of forest roads). Here we used expert judgement to summarize the relative importance of different climatic, predator, and access factors in the different GMZs that may be related to altered vulnerability of moose to mortality.

Estimated population densities from SRB surveys constituted the principal empirical data used to assess population size and trend. Other available demographic indicators derived from SRB and population composition surveys (i.e., observed and estimated bull:cow and calf:cow ratios) were also used to assess concordance of the biological mechanisms underlying population trends. Indicators of regulated harvests of moose, including catch (or kill) per unit effort (CPUE) and numbers harvested were used both to help assess the likelihood of population decline and moose harvest itself was also considered as potential factor contributing to population decline. Model projections from separate demographic models were used to assess the veracity of assumptions made in the harvest allocation regarding current and predicted levels of mortality within moose populations. Spatial data were used to examine factors that may be contributing to observed trends for moose populations. Details of the methods used to obtain each type of data used in this analysis are described in Appendix A.

METHODS

Assessment of Population Trends

We made *a priori* predictions regarding how densities of moose populations should vary if hypothesized declines are actually occurring (Table *2*). These predictions can be considered at three levels of spatial extent: the Region level, the GMZ level, and the survey area level. In general, if a decline is occurring, we expected the proportion of all surveys with lower estimated densities to have increased over time (spatially), and also we expected the proportion of resurveys of areas with lower densities to have increased with time. In addition, we expected that if populations are declining, survey intensity must have increased in order to maintain precision on the estimates, otherwise sampling variance can be expected to have increased. Provided the annual sample design at the survey level was robust, we also expected a significant[6] linear (or curvilinear) decline in GMZ- and Regional-level population density estimates over time. Finally, in a declining population of moose, we would expect a trend towards fewer moose being harvested over time in combination with increased amount of effort (i.e., either more hunters or more hunter days per kill). However, this expectation may be confounded as fewer LEH permits are typically issued as the estimated population numbers decline.

Table 2. Predictions of effects of moose population declines on estimated density attributes as estimated from moose population surveys and hunter harvest data at three scales of analysis: Region level, GMZ level, and survey area level.

Predictions related to Declining Abundance	
1.	Higher proportion of subsequent surveys with significantly lower density estimates relative to previous estimates.
2.	Increasing variance in individual survey estimates as moose become patchy in distribution and/or occupy less area of suitable habitat.
3.	Significant linear or curvilinear decline in population density estimates (GMZ and Region) over time.
4.	Either increases in areas surveyed or increases in sampling variance with smaller densities. Survey intensity must increase in order to maintain precision on the estimates, otherwise sampling variance can be expected to increase
4.	A reduction in the number of moose harvested over time in combination with increased hunter effort.

Assessment of Mechanisms Underlying Population Trends

If population declines in moose are in fact occurring, we expected predictable changes in one or more measureable demographic attributes (i.e., the underlying mechanisms for population change) (Table *3*). For example, extremely low bull:cow ratios may indicate insufficient mature bulls to maximize reproductive production.[7] In addition, low early winter calf:cow ratios may indicate poor survival of calves and, in combination with poor adult survival, may lead to population decline due to insufficient recruitment into the breeding population. Unless the mortality agent leading to population decline is indiscriminate of age and sex, we also expect that areas with low population composition ratios in early winter surveys (i.e., bull:cow and calf:cow) will be those areas with low density estimates in the same survey or reduced densities in subsequent surveys. Finally, provided the annual sample design at the survey level was robust and unless the mortality agent leading to population decline is indiscriminate of age and sex, we'd also expect a significant linear (or curvilinear) decline in GMZ- and Regional-level estimates of population composition ratios (bull:cow and calf:cow) over time.

If mortality estimates (including natural mortality, regulated and non-regulated hunting mortalities) for moose are accurate, we also expected that a demographic model for

[6] Unless stated otherwise, statistical significance is assumed to occur at P<0.10.
[7] Use of this indicator is notably tenuous since the relationship has not been demonstrated; at least in some studies(Laurian et al. 2000).

moose would be able to reconstruct the approximate pattern of observed population measures (density, bull:cow ratios, calf:cow ratios) observed in surveys. Where patterns in these measures cannot be predicted by the model, we expected to be able to adjust parameters in the model to improve the predicted patterns relative to those observed. The specific mortality parameters we used are described in the Results section.

Table 3. Predictions of effects of moose population declines on estimated demographic attributes as estimated from moose population surveys and hunter harvest data.

As in Table 2 these predictions can be evaluated at three scales of analysis: Region level, GMZ level and survey area level.

Predictions related to Declining Abundance	
1.	Higher proportion of subsequent surveys with calf: cow ratios significantly below previous estimates
2.	Higher proportion of subsequent surveys with bull:cow and calf:cow ratios significantly below previous surveys.
3.	Significant linear or curvilinear decline in estimates of population composition ratios (GMZ and Region) over time.
Predictions related to Spatial-Temporal Concordance among Demographic Attributes	
4.	Higher concordance between density in $survey_t$ and bull:cow, and calf: cow and $survey_{t-1,t}$
5.	Higher concordance among estimates of demographic attributes in nearby areas than geographically remote areas

Assessment of Factors Contributing to Population Trends

Observed population trends are expected to be related to a complex of habitat conditions, sources of mortality, and/or reduced productivity (see Introduction). We considered two types of factors: (1) those related to changing habitat conditions; and (2) those related to changes in the vulnerability of moose that could cause higher mortality rates. Based on the limited data available to assess the potential factors, we developed a set of *a priori* predictions relating habitat and vulnerability factors to population trends (Table *4*).

Changes in forest cover due to MPB-induced mortality, or altered forest harvesting levels, or both could reduce habitat quality in the short-term (i.e., 1 to 5 years) by reducing snow interception, security cover, and forage availability for moose. However, forage values for moose are also expected increase due to logging (and perhaps MPB) in the mid-term (i.e., 6 to 40 years). Therefore, the quality and abundance of habitat is expected to be strongly related to changes in forest cover in a dynamic way through time. We assumed, in our model of moose habitat suitability, that forest cover between 5 and 40 years of age dominated the characterization of suitable habitat (see Appendix C). Thus, when losses of forest cover occurred, the effects on moose habitat quality was assumed to lag by approximately five years before moose habitat recovery was detectable, and it could be 1-2 years longer to detect effects on moose density. Similarly, forests logged > 40 years ago were expected to decline in habitat quality for moose. Here, lag effects, while possible, are less likely to be detectable because of the uncertain nature of the fine-scale structure of forests at or subsequent to that age.

Table 4. Predictions of effects of habitat changes, predation, and access factors on moose population trends.

We evaluated these predictions only at the GMZ level of analysis, as the data available to address these predictions was most easily obtained and summarized at this level.

Predictions related to factors that may contribute to population trends	
Factors related to decreased habitat quality:	
1.	Higher timber harvest rates may lead to decreased habitat quality in the short-term (i.e., 1-5 years) by removing snow interception cover, reducing forage availability, and/or reducing visual cover for moose; all potentially contributing to lowered population densities.
2.	Tree mortalities due to MPB effects may reduce habitat quality at least in the short-term by removing snow interception cover, reducing forage availability, and/or reducing visual cover for moose; all potentially contributing to lowered population densities.
3.	
Factors related to increased vulnerability to sources of mortality:	
4.	Higher abundances of predators (e.g., wolves) may lead to lower population densities.
5.	Increasing area and/or number of years for which snow depths exceed 1 m lead to reduced security cover and lower population densities.
6.	Increased non-regulated hunting leads to lower population densities.
7.	Increased access leads to increased mortality from predators or from regulated and non-regulated hunting and therefore to lower population densities.

We considered that increased abundances of wolves to be positively related to increased vulnerability of moose to mortality. While bears are also known predators particularly of moose calves we considered bears to be a secondary predator. Wolf abundances are a function of many factors for which we have little to no data and hence is beyond the scope of this study to determine. However, we do know that wolf control efforts have historically been undertaken in the Region either to reduce potential losses of livestock or to meet objectives of Mountain Caribou recovery.

Moose may become significantly more vulnerable to mortality under several types of conditions. If snow depths exceed 1 m, their energetic expenditure for locomotion will increase. We examined both the numbers of years that snow depths in GMZs exceeded 1 m, as well as the proportion of the areas of each GMZ used by moose with > 1 m snow depths. If the density of roads and linear features increases then mortalities from predators and from regulated and non-regulated hunting may also increase as a result of this increased access. As well, if non-regulated hunting effort increases either through increased numbers of hunters or increased areas hunted, this could increase moose vulnerability.

The potential relationship of each vulnerability factor on moose density was examined through a categorical questionnaire given to the regional biologists (Table 5). The questionnaire was used to provide information about factors where empirical data were either not available at all (e.g., FN hunting effort), not available at a relevant spatial scale (e.g., snow depths), or not easily gathered (e.g., extent and location of new road infrastructure) and although the questionnaire could have been used broadly across a spectrum of experts and/or frequently within a class of expert (both to increase sample sizes and variance of answers), we only had resources and time to send one questionnaire to gather judgement from regional biologists.

Table 5. Indicators and scores used to elicit expert opinion on factors related to vulnerability of moose in the Cariboo Region.

For each indicator, two types of scores were used: C=categorical; Q=quantitative., where categorical scores (range: 0-4) are relative ranks between the GMZs. Scores were obtained for 3 time periods (pre-2000, 2000-2005, 2006-2012 for each GMZ

Indicators	Score Type	Possible Values				
		lowest				highest
Comparative abundance of wolves	C	0	1	2	3	4
Relative effort to reduce wolves	C	0	1	2	3	4
Years where snow in habitat >1.0m[a]	Q	0-1	2	3	4	5
% of habitat where snow > 1.0m[a]	Q	0	25	50	75	100
FN hunting numbers in zone[b]	C	0	1	2	3	4
FN hunting extent in the zone[b]	Q	0	25	50	75	100
Comparative change in access	C	0	1	2	3	4

[a] Combined together (via multiplication) to create a single index called "deep snow effect".
[b] Combined together (via multiplication) to create a single index of "non-regulated hunting effect".

Data Analysis

Unless specifically stated otherwise, significance levels for all statistical tests used in the analyses of collected data was taken to be P = 0.10.

Density and Population Composition Data

Data were gathered from the available surveys; including total numbers of moose by sex, age-class, and habitat type. These data were used by the original surveyors to estimate overall moose densities, observed and estimated bull:cow and calf:cow ratios using the program MoosePop. Sightability correction factors (SCFs) were estimated using the program Aerial Survey (Unsworth et al. 1998). Each type of estimate was available in an unadjusted (Moosepop) and an adjusted (SCF corrected) form where the adjusted estimate (± 90%) was calculated by the analysis program taking into account the survey design and variation in detectability of moose due to different vegetation characteristics. We use adjusted density estimates, unadjusted ratios from SRBs, and observed ratios from SRBs and composition surveys in the analyses. Abundances estimated by the original surveyors for harvest allocation analyses were derived from estimates made by Moosepop, although for three SRB surveys in 2008 (MU-15), Heardpop was also apparently used (likely because Aerial Survey assumes equal-sized sampling units (grid cells).

Density Estimates

We compared the estimates of moose density from the compiled survey summary with the estimates from the original survey reports. Before proceeding with analyses, we found that these two sources of density estimates frequently differed[8], particularly in

[8] 21 of 40 estimates had SCF different than the original report. In all but 2 cases, SCF was changed to 1.4 from the original 1.25

SRB surveys conducted pre-2000, where SCFs were estimated using different methods from those of Quayle et al. (2001), which form the current standard. Because management decisions would likely have been made using the original estimates before subsequent correction, we considered both types of density estimates (original SCF, modified SCF) in our analyses. We do not use extrapolated abundance estimates to assess population trends as abundances are estimated from density and therefore do not provide more information about potential population trends that density does, and they include an additional source of potential error (i.e., estimated suitable habitat) in addition to the sampling error included in the calculation of density.

Because the geographic areas surveyed are not necessarily identical between samples, we first interpreted results using graphical analyses and non-parametric methods (e.g., local area-weighted smoothing). Smoothing used a weighted local polynomial fitting procedure where the survey area was applied as the weight on each observation. This weighting makes the assumption that larger areas surveyed should have greater accuracy in determining the evidence for a population trend. Because SRB surveys are designed to be representative samples, we do apply parametric statistics to examine trends where required.

Population Composition

As described above, we used composition survey data where available for estimates of observed bull:cows and calf:cow ratios. These estimates may be symptomatic of potential reasons for declines, and are used as ancillary data supporting interpretations of causes of a decline and the weight of evidence for a decline. Generally, composition survey locations and sampling decisions were less well documented compared to SRB surveys. In particular, precision estimates and areas samples were not reported for composition surveys. Therefore, the results based on composition surveys are less rigorous than those for SRBs. Consequently, we merged observed ratios from SRBs and composition surveys together for analysis, but distinguished between the two due to the different sampling intensities.

Big Game Harvest Information

We assessed the available big game harvest data for: (1) trend information that could support the notion of moose population decline and (2) as a potential source of evidence about the causes of a decline if it occurred. In particular, we examined big game harvest data for moose to determine if metrics of hunter success and harvest totals were consistent with expectations for a declining population (e.g., declining hunter success). In addition, we examined additional game species harvest records to determine if there was evidence of increased hunter success that supported an overall change in hunter efficiency (increases in hunter success for all game species) or suggested that large predators may be becoming more abundant (increases in hunter success for predators only). Harvest data may also indicate potential factors in population decline (e.g., stable to increasing) due to such factors as changes in hunter efficiency. Such changes in efficiency might be expected under rapid access development or due to loss of canopy cover (e.g., mountain pine beetle) that may have increased sightability of moose to hunters.

We examined hunter harvest information for all big game species listed in the source databases[9] for Region 5. We calculated annual harvest statistics for the period of 1987 to 2010 by GMZ, and summed over GMZs, where possible for all species. Data for ungulates included moose, white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), and elk (*Cervus canadensis*). Data for large carnivores included grizzly bear (*Ursus arctos*), black bear, wolves, and cougars (*Puma concolor*). Moose and mule deer have harvest records in the LEH database. Data on grizzly bear and cougar harvest is obtained through compulsory inspections.

For each species we summed the management unit harvest records by year and GMZ, and by year summed over all 4 GMZs. We did not include records coded as 500 as these accounted for a small proportion of kills (e.g., 121 moose between 1976 and 2010) and appeared to be records that were difficult to reliably assign to a management unit. We estimated harvest statistics (number of hunters, number of hunter days, and number of kills) by summing records for resident harvest only. We estimated CPUE as the ratio of kills per hunter day, and hunter success as the ratio of kills per hunter. We did not include non-resident hunter results as selection by trophy hunters influenced hunter success (Lirette 2011).

For moose, we merged data records from the Big Game database and LEH database up to, and including, 1998 after which we used data records only from the LEH database. All regulated hunting of moose subsequent to 1999 was conducted under the LEH regulations. For all other species, we relied solely on the Big Game database as these species were managed under General Open Seasons (GOS), or in the case of mule deer, under both GOS and LEH seasons.

We also estimated total kills and kills by animal class (bulls and cow/calf) for moose between 1987 and 2010 by incorporating non-resident results. For records from the Big Game database we combined kills of females and juveniles as representative of the cow/calf category. For records from the LEH database, we combined ‘Antlerless’ and ‘Cow or Calf’ into the cow/calf category. We incorporated estimates of FN harvest based on data provided in provincial documents[10]. FN harvest was assumed to occur post-regulated hunting and to be unselective among animal classes (i.e., in proportion to abundance of each class), based on assumptions in AAH models used since 2000[11] (see also Hatter 2004). We also assumed a wounding loss multiplier of 1.15 to 1.20 as per AAH models and applied the multiplier to all regulated hunting kills.

Demographic Model Projections

To assess the role of mortality factors on the observed population trends in each GMZ, we implemented and used a moose demography model described in Appendix B. We partitioned mortality into 3 components: known regulated hunting mortality (kills by class obtained from harvest questionnaire results), assumed non-regulated hunting mortality based on estimates of FN hunting allocations as stated in the AAH models, and

[9] Source material included LEH Survey Estimates 1984 to 2010- reformatted v2.xlsx and BIG GAME HARVEST STATISTICS 1976 – 2010.xlsx.
[10] FN Allocation Numbers 2004 – 2008.doc and 2011 First Nation Needs Estimates.xls.
[11] Estimates of FN harvests for the period 1993-2000 (GMZMOOSE.xls) assumed that 20% of FN harvest was on bulls and 80% on antlerless.

estimates of natural (predators + other) mortality, also as stated in the AAH models. As this was intended as an exploratory analysis only, we did not attempt to determine best-fitting parameter values to each GMZ. Rather, model performance was assessed visually by comparing graphical outputs of response variables. Only age/sex class mortality estimates were varied in our explorations. Tests of other demographic hypotheses, such as reduced productivity, were not explored with the model, nor did we test sensitivity to non-mortality-related parameter values in this study. More detailed investigations with this model could easily be undertaken (see Management Recommendations).

Simulations of population trends for the Region as a whole, and for each GMZ, were initiated with the population data available for each spatial unit at the year 2000, and run until 2012. We provided the model with the estimates of annual stage-specific harvest mortalities for each GMZ (see Appendix B for details). We set up alternative scenarios of natural (predator and other) mortalities on each stage, which are applied in addition to known mortalities from regulated hunting and assumed mortality from FN hunting. For this exploratory analysis, we varied levels of natural mortality for calves, females, and males (Table 6) by successive 33% increases over the base scenario; the latter being based on management models currently used by Government. For each projected year and RMZ, we calculated density, bulls:100 cows, and calves:100 cows from the results for comparison with the empirical results observed during population surveys.

Table 6. Range of the age/sex class-specific levels of unknown (natural predator + other) mortalities used to initiate scenarios to explore demographic outcomes with the population model.

As described in the text, these mortality rates are added to the total known regulated hunting mortality and estimates of non-regulated hunting mortality to arrive at a total mortality estimate for each class. Note that mortality rates in the top row are increased by approximately 33% on each additional row.

Spatial Unit	Calves		Cows		Bulls	
	Mortality Rate[1]	CV[2]	Mortality Rate	CV	Mortality Rate	CV
Region	0.16 - 0.53	0.11	0.07 – 0.15	0.06	0.04 -0.26	0.11
GMZ 5A	0.16 – 0.24	0.11	0.10 – 0.13	0.06	0.04 -0.05	0.11
GMZ 5B	0.21 – 0.58	0.11	0.13 – 0.15	0.06	0.07 – 0.15	0.11
GMZ 5C	0.17 – 0.44	0.11	0.07 – 0.12	0.06	0.07 – 0.15	0.11
GMZ 5D	0.18 – 0.53	0.11	0.08 – 0.13	0.06	0.17 – 0.26	0.11

[1] See Table 10 and its post-table notes for a description of how these values were derived.
[2] Coefficients of variation estimated from SD estimates for survival rates in Hatter (2004) and references cited therein.

Factors Related to Population Trends

As described above, the factors analysis was designed to examine changes in both habitat conditions and vulnerability of moose in relation to population trends. The spatial datasets we used for habitat conditions were obtained from the provincial Land and Resource Data Warehouse and included the following:

a. VRI (2002-2012), DEM and locations of freshwater (see Appendix C).
b. Road data (1999-2012)

c. Annual mortalities from MPB (2000-2012).

These spatial datasets were processed for each GMZ as follows:

1. For three time periods (pre-2000, 2000-2005, 2006-2012)[12], we developed summary tables describing the amount of forest area harvested by year, the amount of productive forest in age classes appropriate for the moose habitat model, and the annual area of forest killed by MPB. Because the data on roads did not contain sufficiently interpretable information (i.e., activation status, year built), we were unable to include this variable further in our analyses. The VRI data was processed according to the procedures described in Appendix C.
2. Once the spatial data was processed, we classed the annual forested area harvested and cumulative total forested area that was either severely, or very severely, impacted by MPB[13] as percentages of the productive forest landbase, and expressed these as averages for each of the three time periods. In addition, we calculated the average percent forest area harvested and the cumulative total of forest area severely/very severely impacted by MPB in the previous five years. This variable was used to explore the potential for time-lag effects of changing habitat conditions on moose responses.
3. The moose habitat model results were also summarized for the three time periods as classes of no habitat (nil), moderate suitability, and high suitability.

Once the data processing was completed, we had six habitat condition variables available: (1) the average % of the winter moose habitat that was high suitability; (2) the average % of the winter moose habitat that was unsuitable; (3) the average % of the productive forest that had been harvested; (4) the average % of the productive forest that had been harvested in the previous time block; (5) the average cumulative % of the productive forest that had been severely/very severely impacted by MPB, and (6) the average cumulative % of the productive forest that had been severely/very severely impacted by MPB in the previous five years.

Using these six variables, we then examined their relationship to the three demographic response variables (density, bull:100 cow ratios, calf:100cow ratios) observed in the population surveys in each GMZ in each time period, using recursive partitioning and regression analysis (rpart analysis). This analysis (which is closely related to classification and regression tree analysis Brieman et al. 1984), is an alternative to logistic regression and a useful way to explore the structure of a set of data, while also developing decision rules for predicting clusters of observations on the basis of their similarity in variance. To demonstrate the apparent structure of relationships between factors and the response variables, we used tree diagrams showing where values for each factor tended to cluster into similar groupings. Recursive partitioning analysis also gives an estimate of the importance of each factor (calculated as the number of times that factor is used in making splits in the tree structure), as well as an estimate of the overall variance explained by the model. Because rpart methods can generate overfitted models (Brieman et al. 1984), we set two constraints before splits be attempted: (1) there be a minimum of two observations in a node and (2) that the overall R-squared be

[12] We were forced to generalize the analytical approach into time periods because there were insufficient survey data to allow for finer resolution analyses.
[13] These stands were assumed to be comprised of a majority of killed trees.

reduced by 0.001. Finally, the resulting tree model was pruned to a size that minimized the number of classification errors during model cross-validation.

Similarly to the habitat condition variables, we explored the relationships of the vulnerability factors with the observed moose population parameters using the rpart analysis. Because of the close relationships between (1) number of years with snow in habitat > 1.0m and % of habitat in zone where snow > 1.0 m, and between (2) FN hunting numbers in zone and FN hunting extent in zone, we combined each of these pairs into an index of "effect" by factoring each pair together (see footnotes to Table *5*). All analyses and graphical summaries for the assessment of trends in habitat and vulnerability were conducted using R (R Core Team 2012**)**. We have provided a detailed example of rpart results in Appendix E to assist the reader in interpreting the figures and tables forming the results of that analysis.

RESULTS

Assessment of Moose Population Trends

A total of 71 moose population surveys were undertaken in the Cariboo Region since 1985 (Table 7). The majority of these (n =40) were SRB surveys. Survey effort varied from GMZ to GMZ, with variable duration between SRBs in a given GMZ (Table 8). GMZ 5B received most effort with 5A and 5C next in the number of surveys, and RMZs west of the Fraser River receiving comparatively fewer surveys. SRBs were the most common survey method except in RMZ 5A. In general, the areas surveyed were not held constant between surveys, although in many cases previous survey areas were resurveyed in subsequent surveys, while additional areas were added (see Figure 2). SRBs were used more commonly in the eight years prior to 2002 (i.e., usually three surveys per year on average) compared to the 11-year period afterwards when only one survey per year on average has been conducted (Table 8).

Table 7. Overall summary of the total number moose surveys undertaken in the Cariboo Region from 1985 to 2012.

GMZ	GMZ Area (km2)	Composition Surveys	Stratified Random Block Surveys	Total # Surveys
East of Fraser River				
5A	10,758	12	4	16
5A/B	-	5	-	5
5B	16,535	8	15	23
West of Fraser River				
5C	32,093	1	14	15
5C/D	-	3	-	3
5D	24,543	1	7	8
5E	32,609	1	-	1
Total	116,538	31	40	71

Table 8. Number of surveys by type undertaken in GMZs East and West of the Fraser during each AAH time period.

Time Period	East of Fraser River		West of Fraser River	
	Composition	SRB	Composition	SRB
Pre-1994	4	-	3	-
1994-1997	3	7	-	11
1998-2001	7	6	1	4
2002-2004	4	1	-	2
2005-2008	7	4	2	2
2009-2012	-	1	-	2
Totals	25	19	6	21

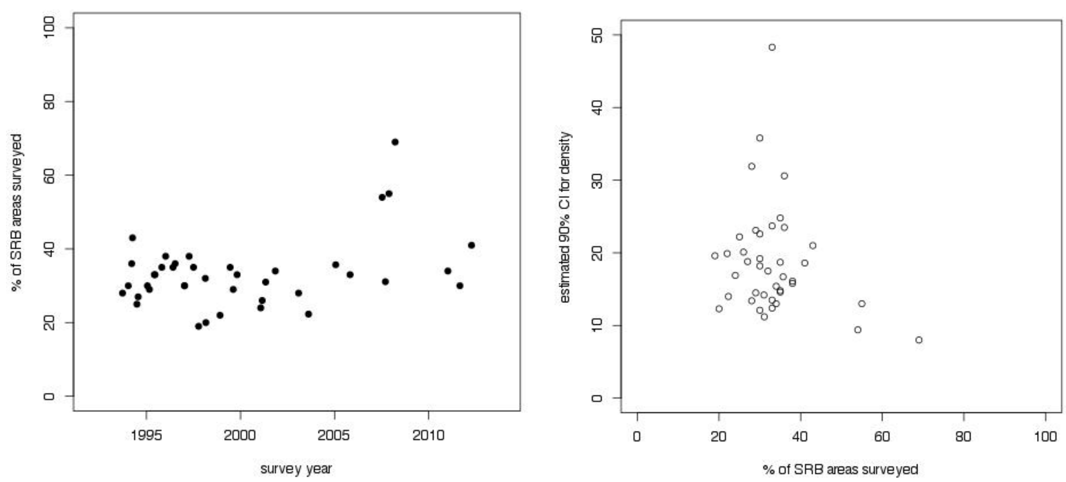

Figure 2. Scatterplots of the sampling intensity (left graph) and estimated level of precision (right graph_ for SRB surveys (N=40) occurring in the Cariboo Region over the years 1994-2012.

Regional Level

For the Region as a whole, graphical examination of density estimates from individual SRB surveys suggest that a weakly declining Region-wide trend in moose densities may have occurred over the period 1995-2012, especially in the post-2000 period, regardless whether original densities or modified densities are considered (Figure *3*). There is wide scatter among density estimates between surveys and among adjacent years. The proportion of observed mean densities that are higher than the Regional management objective of 0.4 moose/km^2 is higher (66%) in the 1995-2002 period than in the subsequent 2003-2012 period (33%), although confidence limits are not considered in this comparison. This suggests, that the likelihood of observing densities higher than the management objective, while they did occur, is apparently becoming less likely in the mid- to late-2000's compared with the mid-1990's to early 2000's.

The slopes of weighted linear regression models fitted to the original and modified densities from the SRB surveys across the region were insignificantly less than zero for original densities but significantly less than zero for modified densities for the period 1995-2012 ($\beta_{original}$ = -0.0094, p = 0.124; $\beta_{modified}$ = -0.013, p = -0.013; df = 39 for both

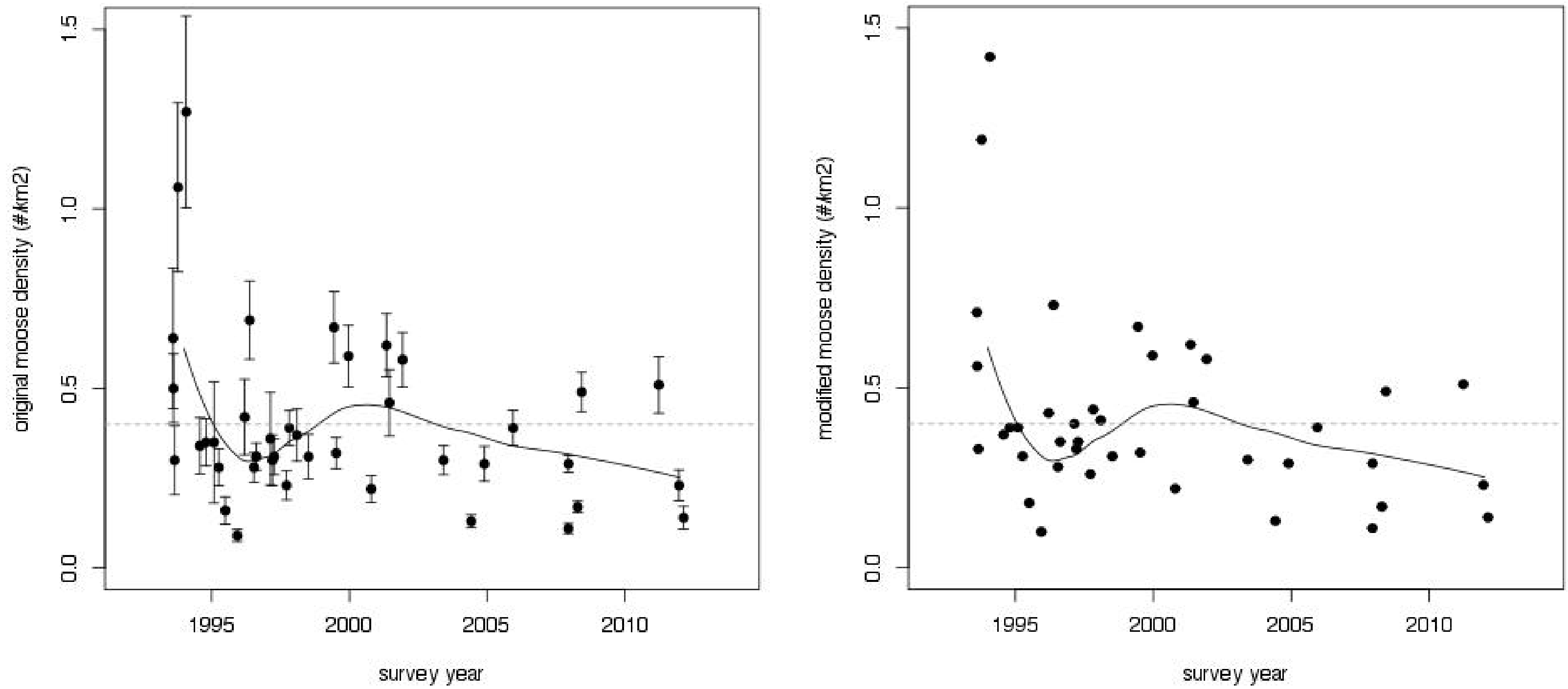

Figure 3. Scatterplots and smoothed trend lines of adjusted moose density estimates from SRB surveys (N=40) in the Cariboo Region over the years 1994-2012.

Shown are the original adjusted densities as reported in source reports together with the 90% CI as estimated from Aerial Survey (left figure), and the modified adjusted moose density estimates using SCFs currently used by FLNRO (right figure). No CI estimates are shown for these latter estimates. Individual points had their X-axis value (survey year) offset by a small and random amount to reduce overlaps between points. The smoothed lines on each curve represent a GMZ area-weighted LOESS (locally weighted polynomial regression) line fitted to these points, where 67% of the points influence the smooth at each value. The dashed gray line indicates the overall management target for moose density in the Cariboo Region.

regressions)[14]. These slopes suggest a range of estimates of the annual rate of decline based on density for the region as a whole; -0.98%/year (estimated from original densities) and -4.56%/yr (estimated from modified densities). However, the results are not robust and appear dependent on the influence of the first year (1994; *n*=5 surveys) and last year (2012; *n*=2 surveys) of data. If data for these 2 years are excluded, the regression slopes for both observed and modified densities for the years 1996-2011) are not significantly different from 0 ($\beta_{original}$ = 0.0049, *p* = 0.41; $\beta_{modified}$ = 0.0019, *p* = 0.76, df= 31 for both regressions). Correspondingly, the annual rates of population change based on original and modified density estimates for the period 1995-2011 range from increases of 1.5% (estimated from original densities) to 0.55% (estimated from modified densities).

The sampling variance for density estimates as measured by % of the mean density (analogous to a coefficient of variation) appears to have declined through time (Spearman $r = -0.62$; $p < 0.05$; N=40). This trend may be due to apparent changes in survey methods through time, where surveys occurring since 2005 appear to intensify the sampling of SRB blocks until a desired level of precision is reached (Figure *2*), whereas it is less clear that earlier surveys used this protocol. We did not analyse the basic data collected in each SRB survey and so could not address the hypothesis regarding how the spatial distribution of moose may (or may not) effect sampling variance.

The temporal density of SRB surveys across the Region has tended to diminish since the mid 1990's (*Table 8*), so that the strength of evidence these surveys provide for documenting the rate of change in population density is gradually becoming poorer through time. This issue is especially important when interpreting trends at finer spatial scales, such as at the GMZ-level (see below).

GMZ Level

Using the adjusted moose density results from Figure *4*, we describe the observed patterns in estimated moose densities for each GMZ below:

GMZ 5A (east of Fraser River)

Moose densities have historically been considered to be low in this GMZ (Hatter 1998), and only 4 surveys (one in 2004 and 3 in 2008) have been undertaken over the period we examined. In general, moose densities observed since 2004 (0.11 to 0.29 moose/km^2) were well below the management objective of 0.4 moose/km^2. There is no indication of a significant overall trend in density[15] (linear regression: $\beta_{density}$ = -0.015, p = 0.63, df = 2), although statistical power is low. There are indications that densities may have increased in the last survey year (2008) (*Figure 4*).

[14] Note that the original densities for surveys prior to 1999 assumed a lower sightability correction factor (SCF) that for surveys since 1998. The densities were re-estimated by government biologists using a higher SCF, and hence densities increased over the original estimate.
[15] For this GMZ, original and modified densities are identical.

GMZ 5B (east of Fraser River)

Estimated moose densities have historically been the highest in this GMZ of all the GMZs in the region. Overall, there has been a tendency for densities to decline between 1994 and 2012, although slopes of the regressions are not significant (original densities: $\beta_{original}$ = -0.020, p = 0.29; $\beta_{modified}$ = -0.026, p = 0.22; df = 13 for both regressions). Densities appear to have declined considerably throughout the period 1994-1998 and may have remained relatively stable since then at the management objective. However, with only two SRB surveys conducted since 2001, evidence to support the observation of population stability in recent times is weak.

GMZ 5C (west of Fraser River)

Estimated moose densities in this GMZ have tended to remain near to, or below, the management objective over much of the 1994-2012 period with an approximately stable to slightly increasing trend (original densities: $\beta_{original}$ = 0.003, p = 0.60; $\beta_{modified}$ = -0.0002, p = 0.99; df = 12 for both regressions), except for the most recent SRB survey (2012: MU 5-12) where the mean density is lower than any other mean observed over this period; note though that confidence limits overlap with density estimates from the mid 1990's. It is possible therefore that current densities in the GMZ are declining, although the strength of this conclusion is limited.

GMZ 5D (west of Fraser River)

Similar to GMZ 5C, estimated historical moose densities in GMZ 5D were at or below the management objective of 0.4 moose/km^2 during the mid-1990's. In general, moose densities appear to have shown a tendency to decline between 1995 and 2012, although slopes are not statistically significant (original densities: $\beta_{original}$ = -0.014, p = 0.20; $\beta_{modified}$ = -0.017, p = 0.16; df = 5 for both regressions). Unlike GMZ 5C, the two SRB surveys conducted in 2005 and 2012 indicate a declining trend at the WMU level (see below), although not necessarily below density levels that were observed in the GMZ in the mid-1990's. The recent studies have been undertaken in the same WMU (5-4) and may or may not be indicative of a GMZ-wide trend.

Summary

These results for estimated densities indicate variation in trends among GMZs and suggest a geographical difference in apparent trends in densities east vs west of the Fraser River. In no case is the evidence for GMZ-specific trends unequivocal (whether increasing or decreasing) on the basis of current evidence, largely due to the paucity of SRB surveys in all GMZs during the last decade. However, given the larger combined area of GMZs 5C and 5D (56,636 km^2) compared to 5A and 5B (27,293 km^2) and the slightly stronger evidence of a decline in the former, it is more likely than not that combined moose densities are tending to decline over the Region; especially since 2005. More data would be required to reach stronger conclusions on population trend at the GMZ-level based on estimated densities.

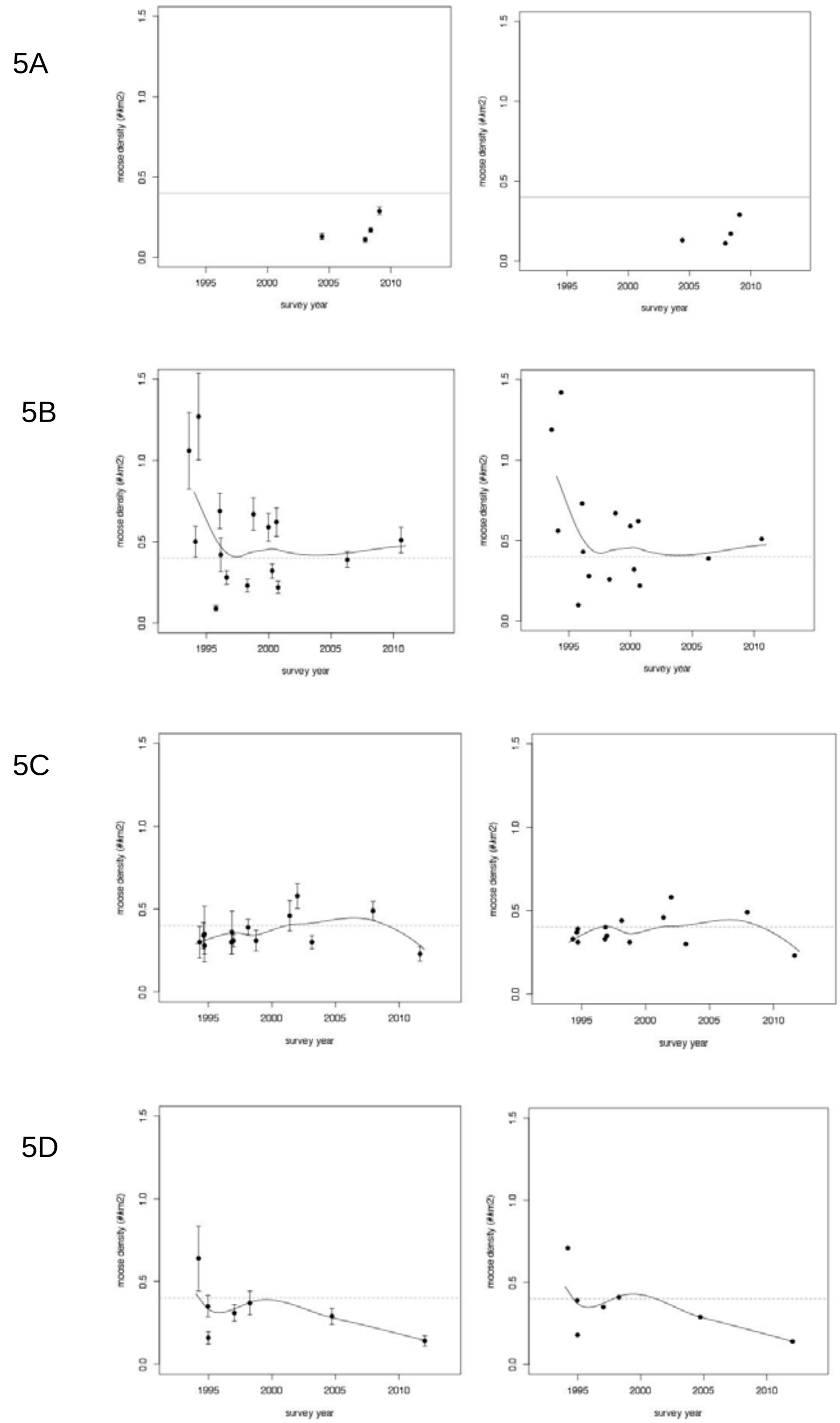

Figure 4. Scatterplots and smoothed trend lines for adjusted moose density estimates for GMZs 5A-5D from SRB surveys in the Cariboo Region over the period 1994-2012.

See *Figure 3* caption for description of the graph elements. Smoothed trend lines were only calculated where there are sufficient data points in both the x and y dimensions to fit a smoothed line.

WMU Level

Sequential SRB Surveys

Only two WMU's have SRB surveys that spanned the time period from the mid 1990's to the post-2005 period (Figure 5). Results from other WMUs are either examined below (Previous Statistical Tests of Trends), or are for periods pre-2001 only and less important for the purposes of this report. Of the two WMUs shown in Figure 5, Horsefly River (WMU 5-02B; GMZ 5B) shows a continuing and significant decline in moose density from 1994-2006. In particular, there was an approximately 50% drop in density between 1994 and 1996 in Horsefly River, and a further significant decline of 46% between 2000 and 2006. Kluskus (WMU 5013C; GMZ 5C) shows no evidence of a decline. In fact, densities for Kluskus increased 22% between 1997 and 2008, although not significantly, a result also broadly consistent with the results at the GMZ-level for 5C.

Statistical Tests of Recent Trends in SRB Surveys 2001-2012

As part of three recent SRB survey studies (Davis 2011; Davis 2012; EDI 2012) the authors conducted statistical comparisons of the adjusted mean moose densities (± 90% CI) between 2 time periods for three survey areas using the methods developed by Gasaway et al (1986). The three surveys were Rose Lake (GMZ 5B-WMU 5-02C) surveyed in 2001 and 2011; Anahim East (GMZ 5C-WMU 5-12) surveyed in 2002 and 2012, and Big Creek (GMZ 5D-WMU 5-04) surveyed in 2005 and 2012. These comparisons were possible because the study areas and survey designs were considered comparable between these surveys. The results (see Figure 6) indicated that in all three studies, moose densities had declined between survey periods, and this decline was statistically significant for Anahim East and Big Creek, but not significant for Rose Lake (see relationship of CIs for each survey area in Figure 6).

Summary

Taken together, the results at the WMU level show less ambiguity in trends than do results combined at the GMZ and Regional levels. Although only 50% of the WMUs have more than 1 SRB survey, these tend to demonstrate a statistically significant decline in moose populations (4 of 5 surveys described above).

Assessment of Mechanisms Underlying Population Trends

In this section, we investigate a series of indictors (population composition, big game harvest statistics, and projections from a demographic model) primarily as an attempt to build a weight-of-evidence consistent with the notion of wide-spread decline in the Cariboo Region moose population. Although weight-of-evidence can been provided in rigorous analytical approach, we took a simpler qualitative approach based on the an attempt to simply ascertain whether the evidence or information supporting one side of a cause or argument (i.e., no population decline) is greater than that supporting the other side (i.e., there has been a population decline)[16],[17].

[16] http://support.sas.com/resources/papers/proceedings13/095-2013.pdf (accessed July 21, 2013)
[17] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2709979/ (accessed July 21, 2013).

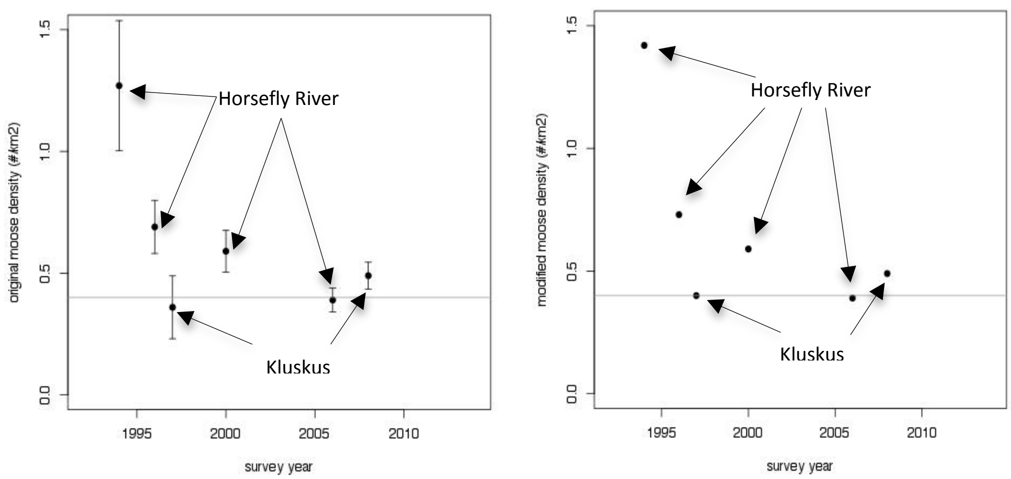

Figure 5. Comparison of adjusted moose densities (± 90% CI) for 2 SRB survey areas (2 WMUs) where surveys spanned the mid- 1990's to post-2005 time period.

Shown are the original adjusted densities as reported in source reports together with the 90% CI as estimated from Aerial Survey (left figure), and the modified adjusted moose density estimates using SCFs currently used by MoE (right figure). No CI estimates are shown for these latter estimates.

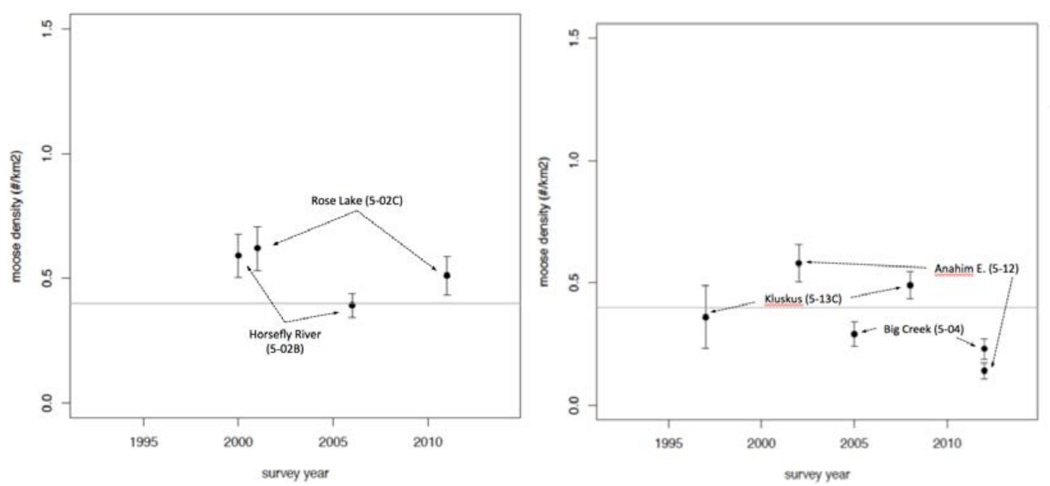

Figure 6. Comparison of adjusted moose densities (± 90% CI) for 5 WMUs with sufficient data to statistically compare them for significance of declines (see text for explanation).

Note: recent data (2013) for Mackin Ck. is not included in this figure.

Population Composition Indicators

Regional Level

Ratios of Bulls:100 Cows

In general, patterns in observed and unadjusted bulls:100 cows ratios for the composition and SRB surveys show a tendency for this ratio to be increasing throughout the period we examined (1994-2012), and no survey since 2008 had a mean bull:100cow ratio below the management objective (i.e, 30 bulls:100 cows), although for that year the 90% CI for one survey intersects the management objective (Figure 7). The number of times that the bulls:100 cows were lower than the Regional management objective was much higher (observed ratios: 54%; estimated ratios 55%) in the 1994-2002 period than in the 2002-present period (observed ratios: 9%; estimated ratios: 9%). The estimated bulls:100 cows taken from SRB surveys tended to have lower variance than those of the composition surveys, although they both indicated similar trends. Note that composition surveys have not been undertaken in the region since 2007, so interpretation of an apparent reduction in the bulls:100 cows is difficult. The composition results for 2007 show considerable uncertainty, and this combined with the lack of subsequent surveys may account for the apparent decrease in the bulls:100 cows for this survey type in the latter part of the 2004-2007 period. Taken together, these results suggest that regional bull:100 cows tended to increase, and since 2000 have generally been above the management target.

Ratio of Calves:100 Cows

Trends in observed and unadjusted calves:100 cows over the Region from SRB surveys revealed a general decrease in estimates of this ratio since approximately 2002 compared with the period 1994-2001 (Figure 8). The number of times that calves:100 cows were higher than the Regional management objective was much higher (observed ratios: 68%; unadjusted estimates of ratios: 61%) in the 1994-2002 period than in the 2002-present period (observed ratios: 10%; unadjusted estimates of ratios: 18%). Although recent improvement in this ratio is apparent for both observed and unadjusted estimates, it is unclear whether this ratio is recovering back to the management objective on the basis of the few recent SRB surveys.

Observed calves:100 cows obtained from composition surveys appears to show somewhat lower (and slightly more variable) results than those observed on SRB surveys. Challengingly, the trend suggested is of a general decline in this ratio to levels well below the management objective over most of the period, with a weak indication of some improvement in the last year of composition surveys (2007).

Taken together, these results suggest that regionally, the calf ratio is quite variable from survey to survey and from year to year. The results suggest that over the long-term, this ratio was more likely to have been at or below its management objective, rather than above it, and has trended downward since at least 2000. There are recent indications of improvement in this ratio, but it is not yet possible to determine if this improvement is geographically widespread, or will be sustained. This conclusion contributes to the weight-of-evidence that there could have been a population decline prompted by insufficient juvenile recruitment; particularly if adult mortality was high during the same period.

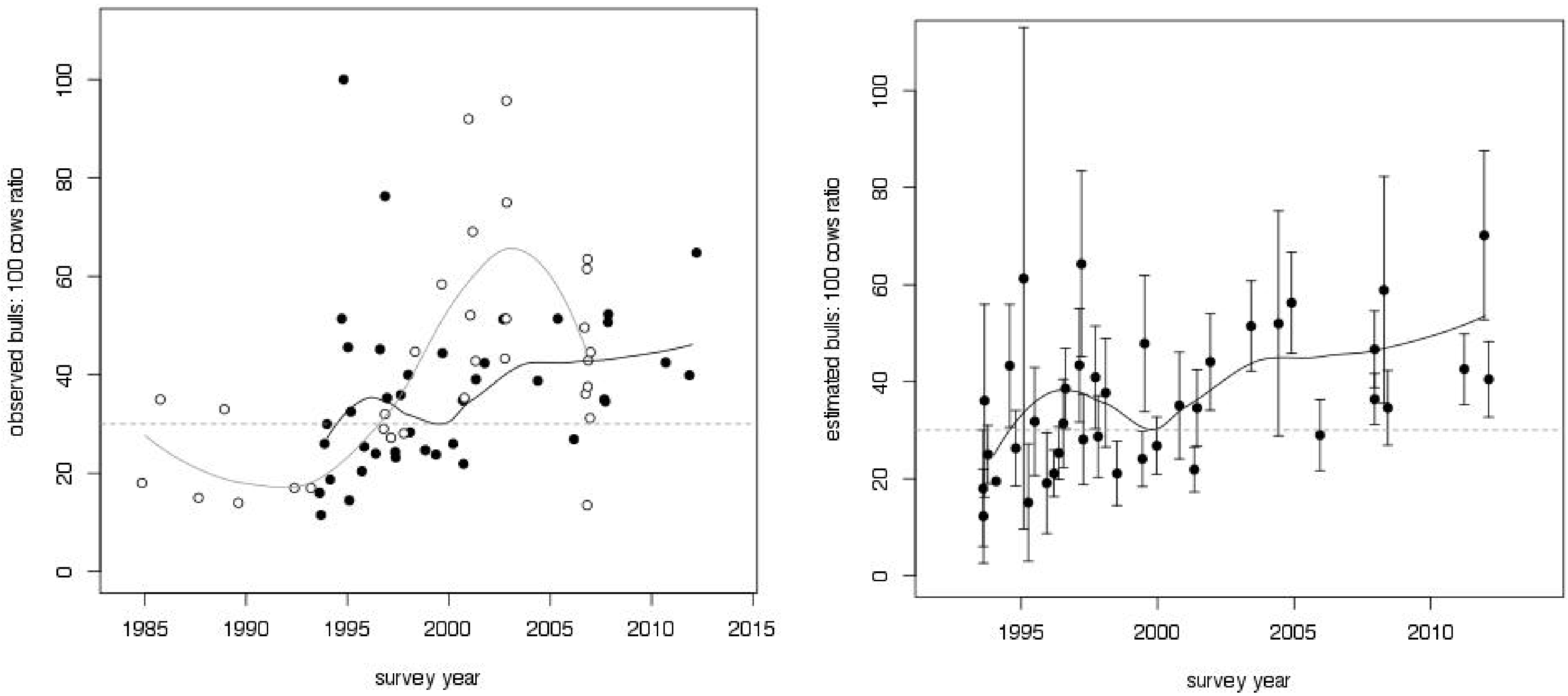

Figure 7. Scatterplots and smoothed trend lines of ratios of bulls:100 cows obtained from composition (N=31) and SRB surveys (N=40) for the Cariboo Region over the period 1985-2012.

Shown are the observed ratios of bulls:100 cows obtained from source reports from composition surveys (open circles) with a LOESS trend line (gray line) and SRB surveys (solid circles) with a LOESS trend line (black line) (left-most graph), and the estimates of ratios of bulls:100 cows from SRB surveys only (solid circles) with a LOESS trend line (black line) calculated by the program Moosepop (right-most graph) together with the calculated 90% CI estimates and LOESS trend line. LOESS trend lines are calculated using the same assumptions as described in the caption for *Figure 3*. The dashed line indicates the overall management target for bulls:100 cows ratios in the Cariboo Region.

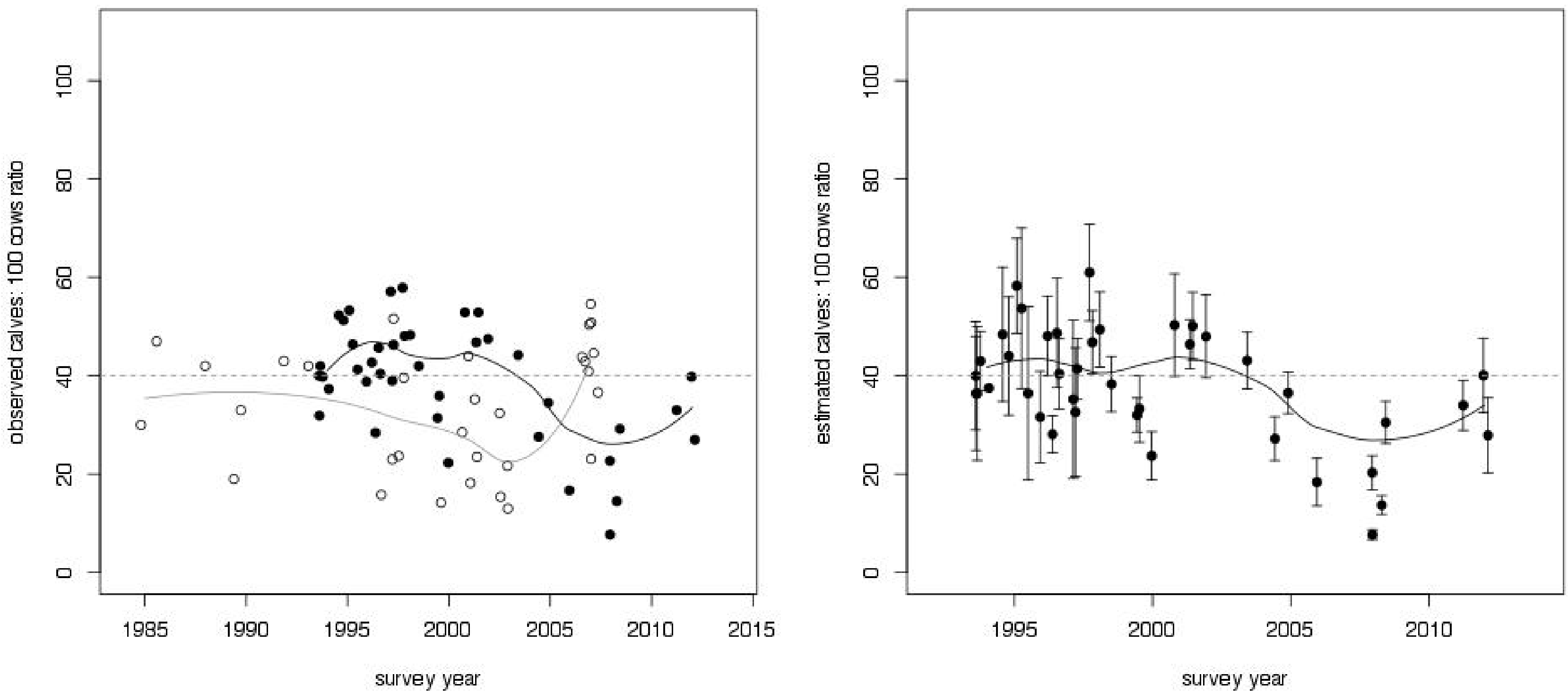

Figure 8. Scatterplots and smoothed trend lines of ratios of calves: 100 cows obtained from composition (N=31) and SRB surveys (N=40) for the Cariboo Region over the period 1985-2012.

Shown are the observed ratios of calves:100 cows obtained from source reports from composition surveys (open circles) with a LOESS trend line (gray line) and SRB surveys (solid circles) with a LOESS trend line (black line) (left-most graph), and the estimates of ratios of calves:100 cows from SRB surveys only (solid circles) with a LOESS trend line (black line) calculated by the program Moosepop (right-most graph) together with the calculated 90% CI estimates and LOESS trend line. LOESS trend lines are calculated using the same assumptions as described in the caption for *Figure 3*. The dashed line indicates the overall management target for calves:100 cows ratios in the Cariboo Region

GMZ Level

Ratios of Bulls:100Cows

Using the observed and estimated bulls:100 cows ratios obtained from SRB and composition surveys shown in Figure 9, we describe the observed patterns in this ratio for each GMZ below. Note that some composition surveys spanned GMZs 5A and 5B and were not included in the graphs below.

GMZ 5A (east of Fraser River)

In general, ratios of bulls:100 cows for this GMZ were available only post-2000, and generally indicate the bull ratios were above the management objective. The estimates tend to show both wide scatter in means and also wide 90% confidence limits, indicating high sampling variation and little indication of any particular trend over time in this GMZ.

GMZ 5B (east of Fraser River)

Pre-1998, observed and unadjusted estimates for bulls:100 cows in this GMZ tended to be below the management objective, irrespective of the survey method, and they show a weakly increasing trend through the period 1994-2012. Since 2006, most observations indicate that this ratio was at, or above, the management objective, but the number of samples since 2007 have been limited. Thus as for GMZ 5A, it is unclear how supportable is the indication of an increasing frequency for this indicator to be above the management objective.

GMZ 5C (west of Fraser River)

Although observed and estimated values for the ratio of bulls:100 cows for this GMZ showed wide sampling variation and wide scatter in mean values prior to 1999, the ratio appeared to be above, but declining toward the management objective. Since 1999 the ratio appears to be increasing, and may now be back to the higher levels that were observed in the mid-1990’s, and above the management objective since at least 2008. This increasing trend for the ratio to be above the management objective, while inferred from limited data observations, appears to be moderately supported by the data.

GMZ 5D (west of Fraser River)

Bulls:100 cow ratios for this GMZ are estimated from relatively few observations over the 1994-2012 period. Although ratios bracketed the management objective pre-1998, very limited observations (n = 2) in the 2000’s suggest that they have increased above the management objective, although the most recent observation suggests that this may not be indicative of a long-term increasing frequency above the management objective.

Summary

In summary, patterns in ratios of bulls:100 cows show somewhat similar trends in the different GMZs, towards remaining above the management objective during the 2000’s (from historically lower values in the 1990’s) although whether the apparent gradual increases in this above-objective frequency are still occurring is difficult to determine.

Ratio of Calves:100 Cows

Similar to the assessment of bull ratios, we describe the observed patterns in calves:100 cows for each of the GMZs below based on observed and estimated ratios obtained from SRB and composition surveys shown in Figure 10. Again, some composition surveys spanned GMZs 5A and 5B and were not included in the graphs below.

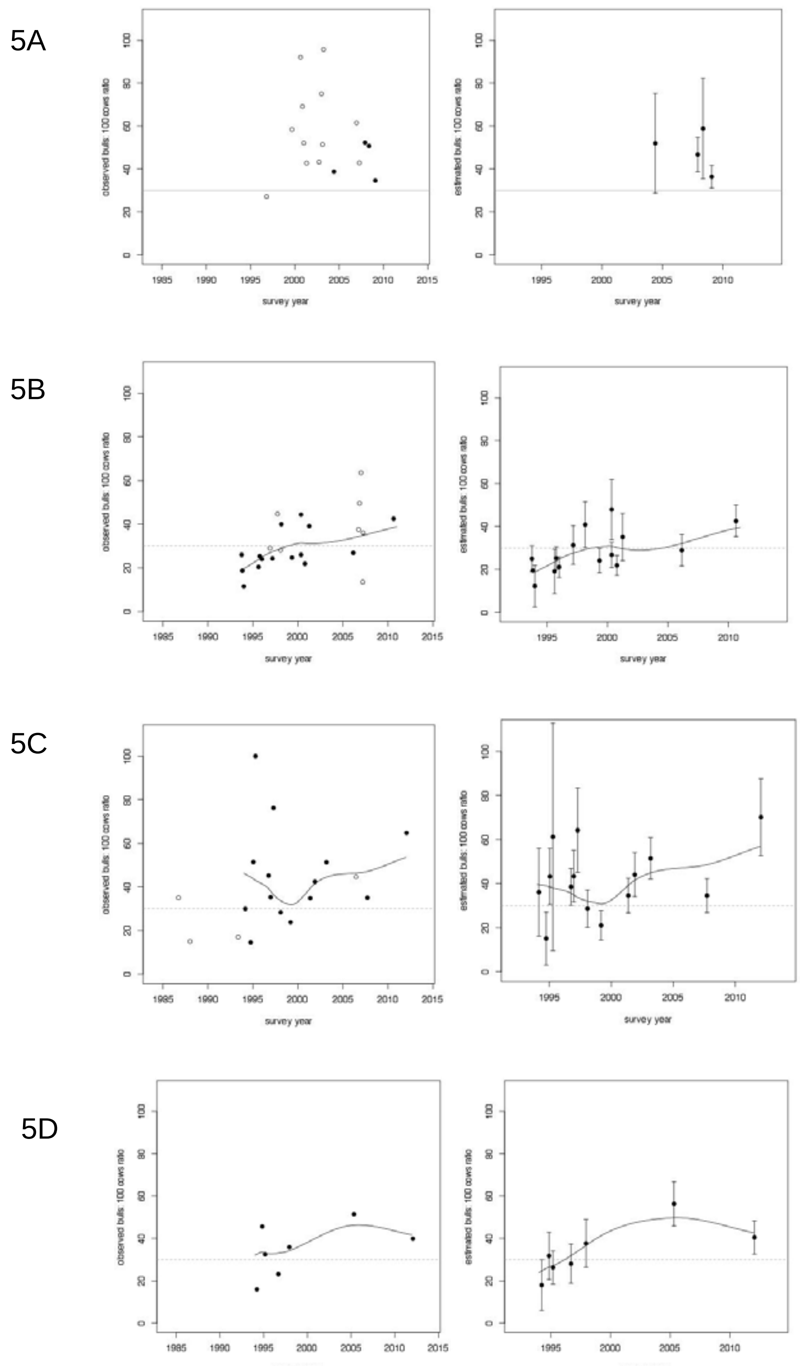

Figure 9. Scatterplots and smoothed trend lines for ratios of bulls:100 cows for GMZs 5A-5D obtained from composition and SRB surveys undertaken in the Cariboo Region over the period 1985-2012.

See *Figure 7* caption for description of the graph elements. Smoothed trend lines were only calculated where there were sufficient data points in both the x and y dimensions to fit a smoothed line.

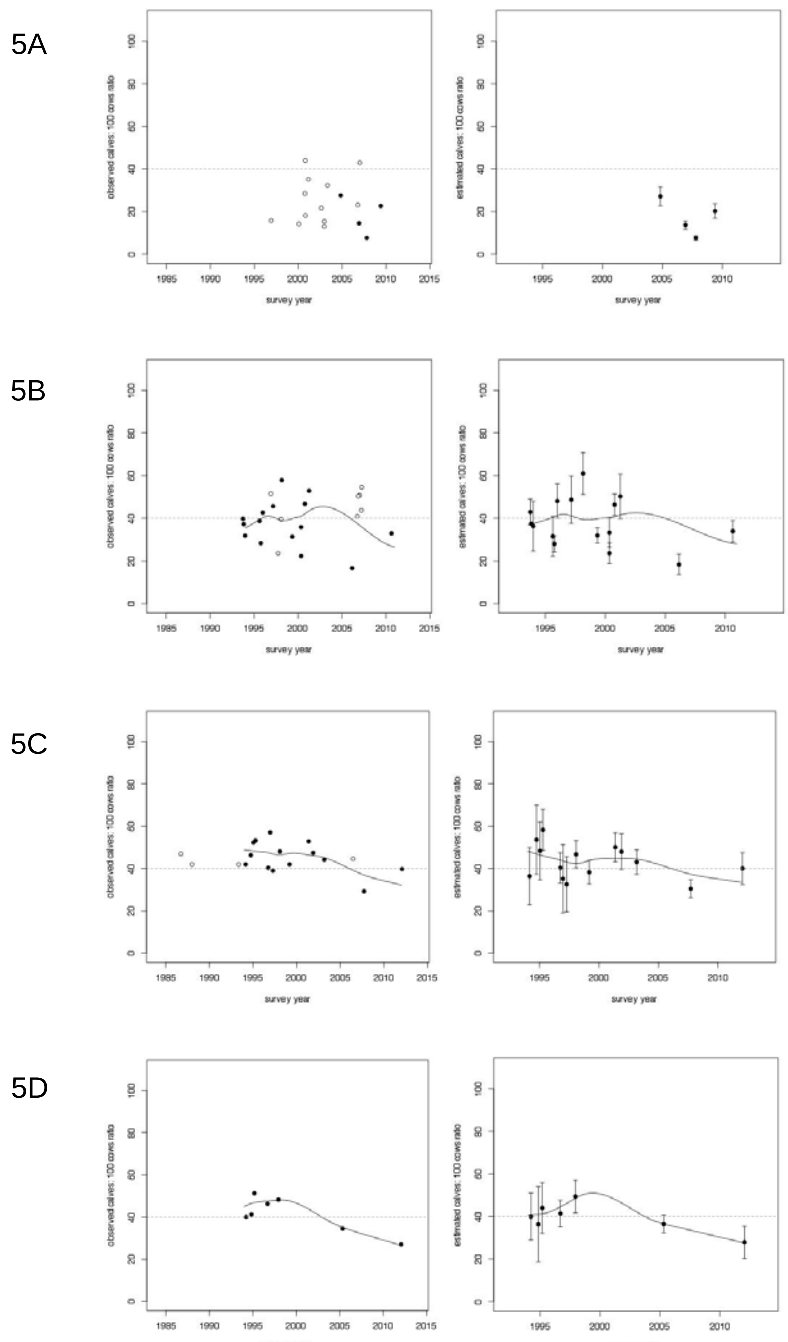

Figure 10. Scatterplots and smoothed trend lines for ratios of calves: 100 cows for GMZs 5A-5D as obtained from composition and SRB surveys for the period 1985-2012.

See *Figure 7* for description of the graph elements. Smoothed trend lines were only calculated where there were sufficient data points in both the x and y dimensions to fit a smoothed line.

GMZ 5A (east of Fraser River)

Ratios of calves:100 cows have generally been well below (approximately 50% below) the management objective during the period for which we have data (1997-2010) and there is no clearly apparent trend in the observations. These estimates suggest sustained poor recruitment of calves into the breeding population throughout the period.

GMZ 5B (east of Fraser River)

Observed and unadjusted ratios of calves:100 cows in this GMZ tended to approximate the management objective prior to 2005, with a gradual decline since then. The ratios from composition surveys do not support a declining trend. While the trend may be stable or slightly declining, the closeness of the ratios to the management objective suggests that moose populations in the GMZ may be vulnerable.

GMZ 5C (west of Fraser River)

This GMZ shows ratios of calves:100 cows that have shown a long-term gradual decline from the mid 1990's, although most estimated mean values are within the 90% CI of the management objective. It is unclear from the present pattern whether calf:cow ratios in this GMZ may be contributing to the current concern over potential population declines in this GMZ, although the recent ratios are just at or below the management objective.

GMZ 5D (west of Fraser River)

Ratios of calves:100 cows for this GMZ indicate that this ratio was near to the management objective in the mid 1990's, and appear to increase above it by 1998-1999. The samples taken since indicate that the ratio may be declining, and may now be below the management objective (based on 1 SRB survey in 2012).

Summary

Overall, calves:100 cow ratios do appear to be declining in most GMZs, and all indicate that since 2006 the average ratios may more often than not be below the management objective (especially in GMZ 5A). This supports the region-wide trend described above, and suggests that patterns are general across the GMZs.

WMU Level

Ratios of Bulls:100 Cows and Calves:100 Cows

Examination of the composition data for the particular WMU-level surveys showed that:

1. Bull ratios are currently significantly above the management objective for all three study areas. This ratio had increased for 2 of the 3 survey areas (Rose Lake and Anahim East), statistically significant for Rose Lake but not for Anahim Lake. The ratio for Big Creek had declined between survey periods, but is still significantly above the management objective.
2. Calf ratios have declined for all three study areas, and for 2 of 3 (Rose Lake and Big Creek) are significantly below the management objective. These declines are statistically significant for Rose Lake but not for Anahim East and Big Creek.

Big Game Harvest Indicators

Availability of Big Game harvest data was variable by species and GMZ (Table 9). For some species, missing data differing year ranges prevented estimates (5A for cougars and 5C for grizzly bears, elk, 5A for white-tailed deer, and 5B for grizzly bears) or required different year ranges (white-tailed deer in 5B, C and D; grizzly bears in 5D).

Regional Level

Regionally, harvest data for moose revealed a strong increasing trend in CPUE and hunter success (Figure 11) between 2000-2003 followed by abrupt declines through to 2005. Between 1993 and 1999, the Cariboo Region was implementing LEH regulations that markedly reduced both numbers of hunters and hunter days (Figure 12). In spite of continued low numbers of hunters (and hunter days), CPUE and hunter success have remained marginally declining (CPUE) or stable (hunter success) since 2005 although both these metrics remained at levels higher than they were between 1987 and 1999.

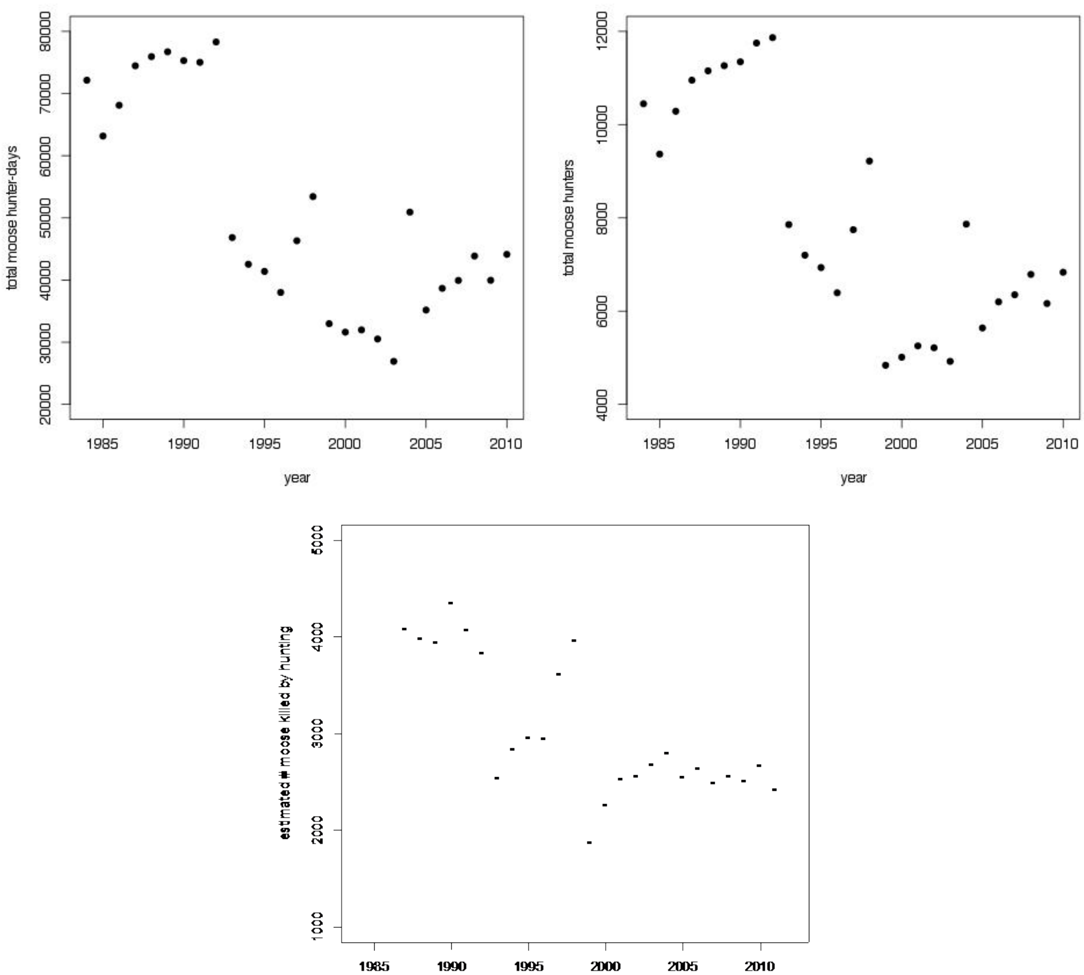

Figure 11. Overall Region 5 estimates of resident and LEH hunting effort for the time period 1987-2010 as estimated from resident and LEH hunter survey returns.

Shown are the number of hunter-days expended on moose (top-left graph), and the total number of hunters (top-right graph). The total number of moose killed by resident and LEH hunters is shown in the bottom-left graph. Resident data for 2011 were not complete and so are not shown here.

Table 9. Years with available harvest data for big game species in the Cariboo Region, British Columbia.

GMZ	Moose	White-tailed Deer	Mule Deer	Elk	Grizzly Bear	Black Bear	Wolf	Cougar
A	1976 - 2011	1988 2010	1987 - 2010	1976 - 1984	1976 - 2010	1976 - 2010	1976 - 2010	1976 - 2008
B	1976 - 2011	1987 - 1988,2000 - 2010	1987 - 2010	1976 - 1984	1976 - 1987	1976 - 2010	1976 - 2010	1976 - 2010
C	1976 - 2011	1987 - 1988,2000 - 2010	1987 - 2010	1976 - 1984	1976 - 2000	1976 - 2010	1976 - 2010	1976 - 2010
D	1976 - 2011	1987 - 1988,2003 - 2010	1984 - 2010	1976 - 1983	1976 - 2000	1976 - 2010	1977 - 2010	1976 - 2010

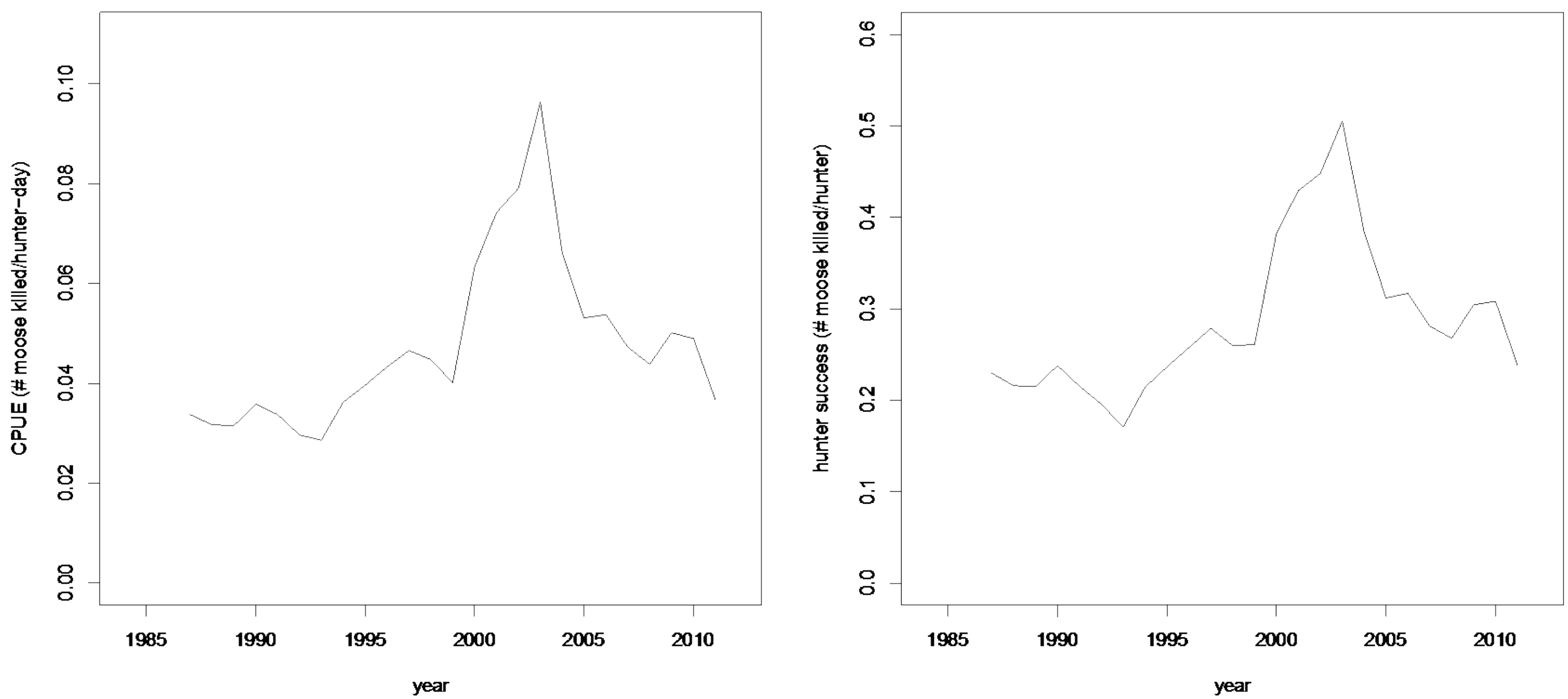

Figure 12. Region-wide moose hunting catch per unit effort (left-graph) and hunter success rate (right-graph) for Region 5 for the period 1987-2011 as measured from resident and LEH hunter returns.

Catch per unit effort (CPUE) is measured as the number of moose killed/hunter-day, while per hunter success rate is measured as the number of moose killed/hunter.

At the regional level, there was no marked increase in CPUE and hunter success for most other big game species. However, similar to the statistics for moose, CPUE (Figure 13) and hunter success (not shown) increased dramatically for mule deer between 1999 and 2004 even though the number of hunters and hunter days declined. The peak in CPUE for mule deer lagged that of moose by one year but the subsequent decline was more gradual approximating that of moose by 2009. Hunters of, and days spent hunting, white-tailed deer increased markedly between 2000 and 2010 with CPUE and hunter success variable but weakly increasing over this period. The number of hunters and days spent hunting black bears declined marginally with CPUE and hunter success variable but somewhat low since 2005. Hunters and hunter days increased for cougars while CPUE and hunter success on that species was variable but generally declining. Grizzly bears were hunted only in GMZ 5A since 2000. Grizzly bear hunters and hunter days were weakly increasing and CPUE and hunter success peaked

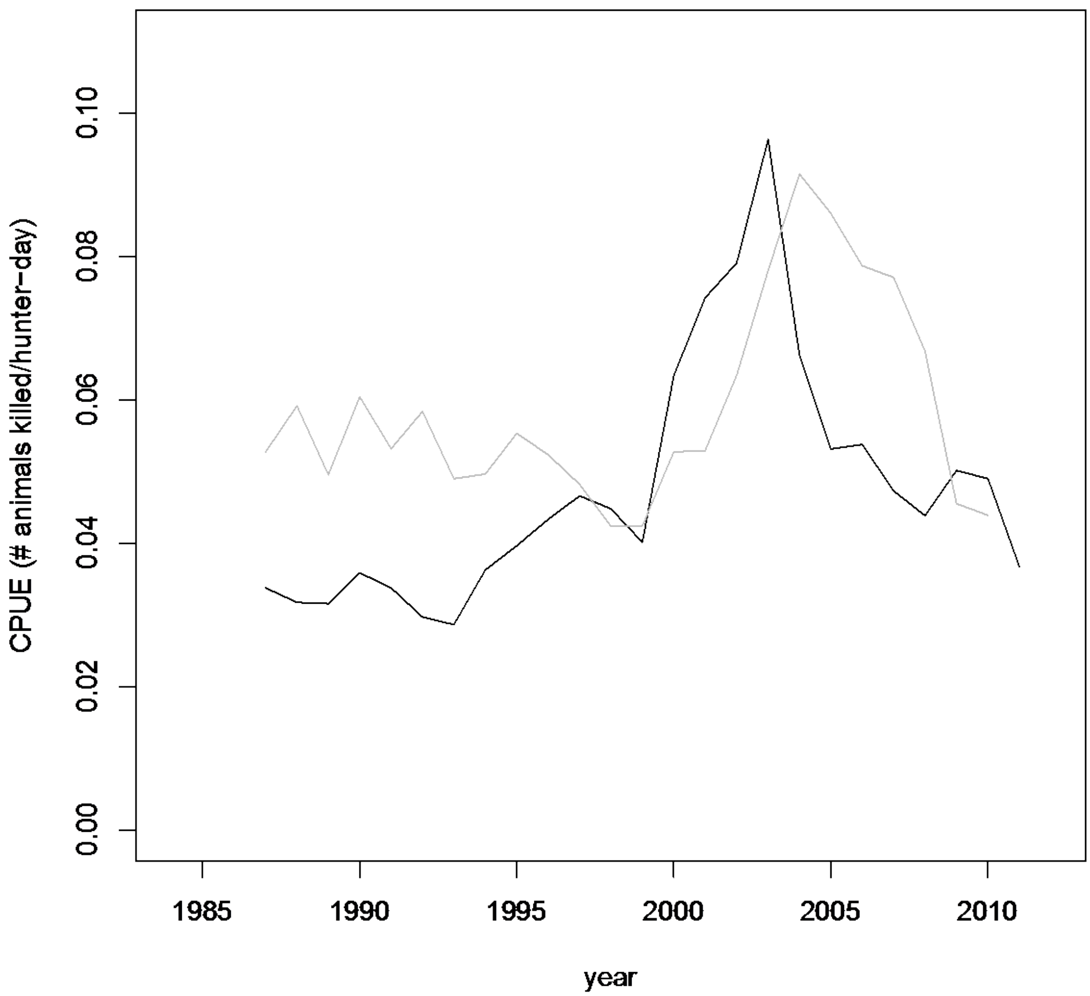

Figure 13. Overall Region 5 comparison of moose and mule deer CPUE for the time period 1987-2010 as estimated from resident and LEH hunter survey returns.

Shown is the moose CPUE (black line); see also Figure *11*) and mule deer CPUE (grey line). Data for mule deer was not available for 2011.

between 2002 and 2004 but both have since declined. All metrics for wolves were highly variable demonstrating no general trends over time.

Total moose kills (Figure 14) ranged from a high of 4,349 moose in 1990 to a low of 1,879 moose in 1999. Between 1987 and 2010, the slope of a linear regression ($p < 0.001$) was -73.3 indicating that the long-term trend was for 73 less moose harvested annually. However, for our focal period of interest (2000-2012), kills have remained fairly stable at ~2,400 moose per year with a slope insignificantly different from zero.

Kills by animal class (Figure 15) indicated that the initial decline in moose harvest has been weighed heavily towards bulls with the known cow/calf harvest remaining relatively stable from 1993 to 2010. An increase in the cow/calf harvest in 2004 coincides with the assumed increase in FN allocation from 751 to 964 animals.

GMZ Level

Trends in CPUE and hunter success by GMZ (Figure 16) mimicked region-wide trends and indicated that the region-wide results were not driven by the results of one or two GMZs.

Demographic Projections

The estimates of kills from regulated hunting, assumed kills from FN hunts, and mortality from unknown natural sources are presented in Table 10. In general the average total annual mortality rates for calves and bulls was similar (0.345 calves, 0.375 bulls) but most mortality for calves was assumed to be from natural causes while hunting was the leading mortality factor for bulls; especially in GMZ5B where the hunting rate on bulls was almost twice the regional average. Hunting rates on bulls was half the regional average in GMZ5D but it was assumed that natural mortality rates in this GMZ exceeded the regional average for all sex/age classes.

Results of the demographic projections suggested that currently assumed patterns of mortality could not account for the observed patterns in all demographic indicators in any GMZ (Figure 17). Generally, tracking of calf ratios was best with variable results for bull ratios, and density was consistently overestimated in all GMZs. The projected results were closest to observed results in GMZ 5C, except for the pattern of observed densities, which continue to increase in the projections while the observed densities are declining in this GMZ. We found that increases in cow and calf mortality by 33 to 66% above the natural levels of mortality as estimated in the AAH model tended to improve the fit of the models (Figure 18).

Assessment of Factors Contributing to Population Trends

Habitat Condition

We found that forest harvesting patterns expressed as a function of the total % of productive forest logged varied annually among the different GMZs (Figure 19), as did the levels of MPB-caused tree mortality (at least since 2000) (Figure 20). It is likely that

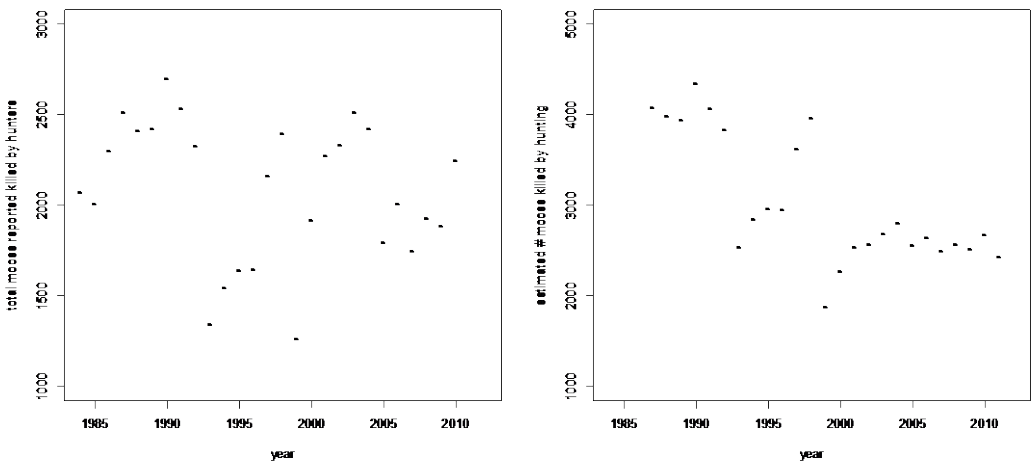

Figure 14. Overall Region 5 estimates of the number of moose killed by non-trophy hunters and the total moose killed by all sources of hunting mortality for the time period 1987-2011 as estimated from resident and LEH hunter survey returns, FN hunts, and wounding losses.

Shown are the total number of moose killed by resident and LEH hunters (left graph), and the total estimated hunting mortalities of moose from all non-trophy sources (right graph).

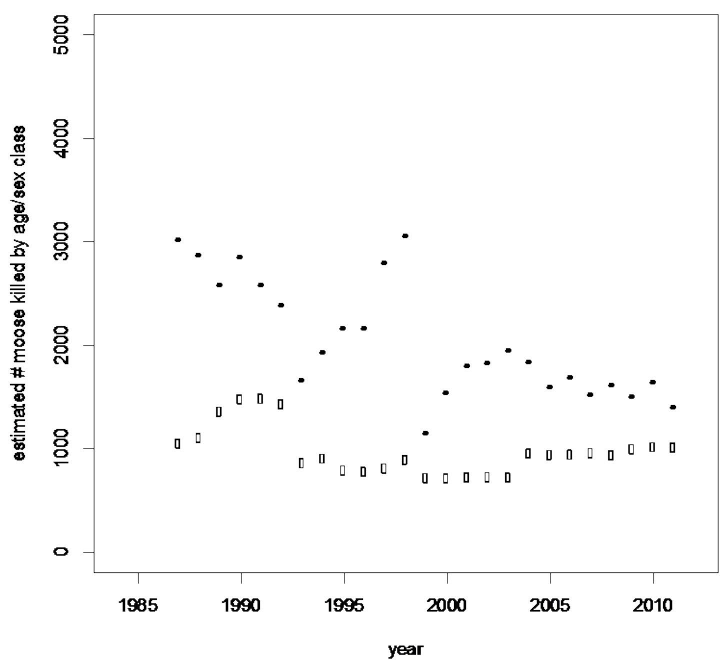

Figure 15. Overall Region 5 estimates of the number of bulls (black circles) and cows/calves killed (grey circles) by all sources of hunting mortality for the time period 1987-2011 as estimated from resident and LEH hunter survey returns, FN hunts, and wounding losses.

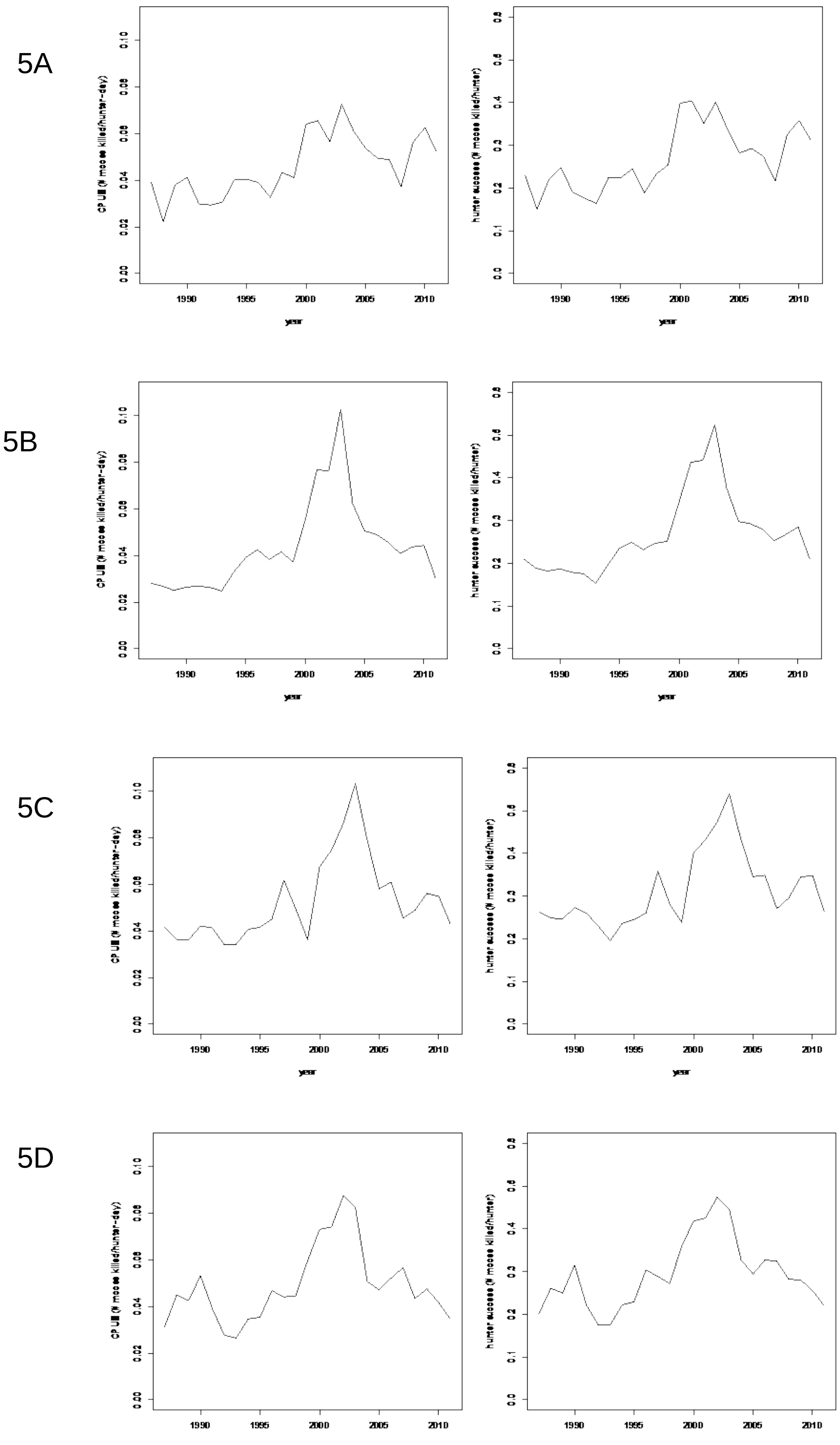

Figure 16. GMZ-level moose hunting catch per unit effort (left-graph) and success rate (right-graph) for GMZs 5A-5D for the period 1987-2011 as measured from resident and LEH hunter returns.

Table 10. Estimates of components of average annual mortality used in demographic simulations.

The estimated annual mortality rate per class is the sum of columns 2 and 3 plus one of columns 4 through 6 depending on the scenario.

Spatial Unit	Class	Known Hunting Rate[1]	Assumed Non-Regulated Hunting Rate[2]	Natural Mortality[3]		
				Current[4]	Moderate Increase (+ 33%)	High Increase (+ 66%)
Region	Calves	< 0.01	0.041	0.294	0.392	0.489
	Cows	< 0.01	0.024	0.116	0.155	0.193
	Bulls	0.232	0.022	0.119	0.158	0.197
GMZ 5A	Calves	< 0.01	0.005	0.190	0.253	0.316
	Cows	< 0.01	0.005	0.107	0.142	0.178
	Bulls	0.269	0.006	0.048	0.063	0.079
GMZ 5B	Calves	< 0.01	0.032	0.245	0.326	0.407
	Cows	< 0.01	0.024	0.144	0.192	0.239
	Bulls	0.419	0.015	0.053	0.070	0.087
GMZ 5C	Calves	< 0.01	0.072	0.283	0.377	0.471
	Cows	< 0.01	0.039	0.108	0.143	0.179
	Bulls	0.204	0.040	0.123	0.163	0.204
GMZ 5D	Calves	< 0.01	0.030	0.319	0.424	0.530
	Cows	< 0.01	0.022	0.133	0.151	0.188
	Bulls	0.144	0.016	0.214	0.285	0.356

[1] Averaged over known hunter returns as a proportion of estimated population size for the period 2000-2012.
[2] Averaged over assumed numbers of non-regulated hunting mortality by class as a proportion of estimated population size for the period 2000-2012. Non-regulated kills are assumed to be unselective.
[3]. This mortality includes unknown non-regulated hunting, predation and other sources of mortality.
[4] Current values for average annual natural mortality for each class (see Table 6) were estimated from the government AAH models where they are estimated by averaging results for each study excluding wolf removal studies, and taking into account the known hunting mortalities.

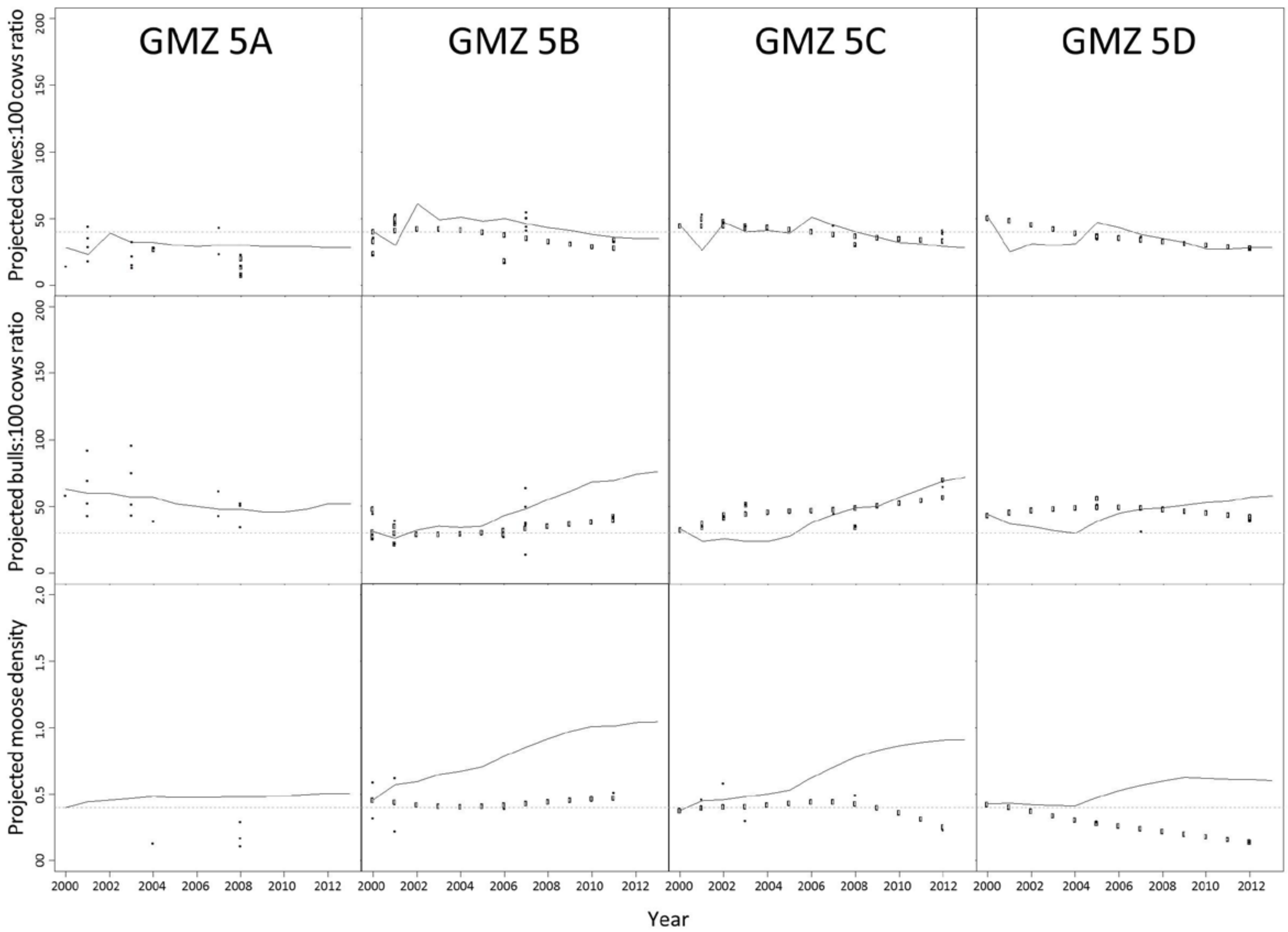

Figure 17. Projected demographic patterns for moose in GMZs 5A-5D from 2000-2012 based on current mortality estimates from government data and models (Table 10).

Shown for each demographic indicator are the projected values (black line) plotted with observed (black circles) or estimated (open circles), and LOESS smoothed average values (gray circles) as per previous graphs.

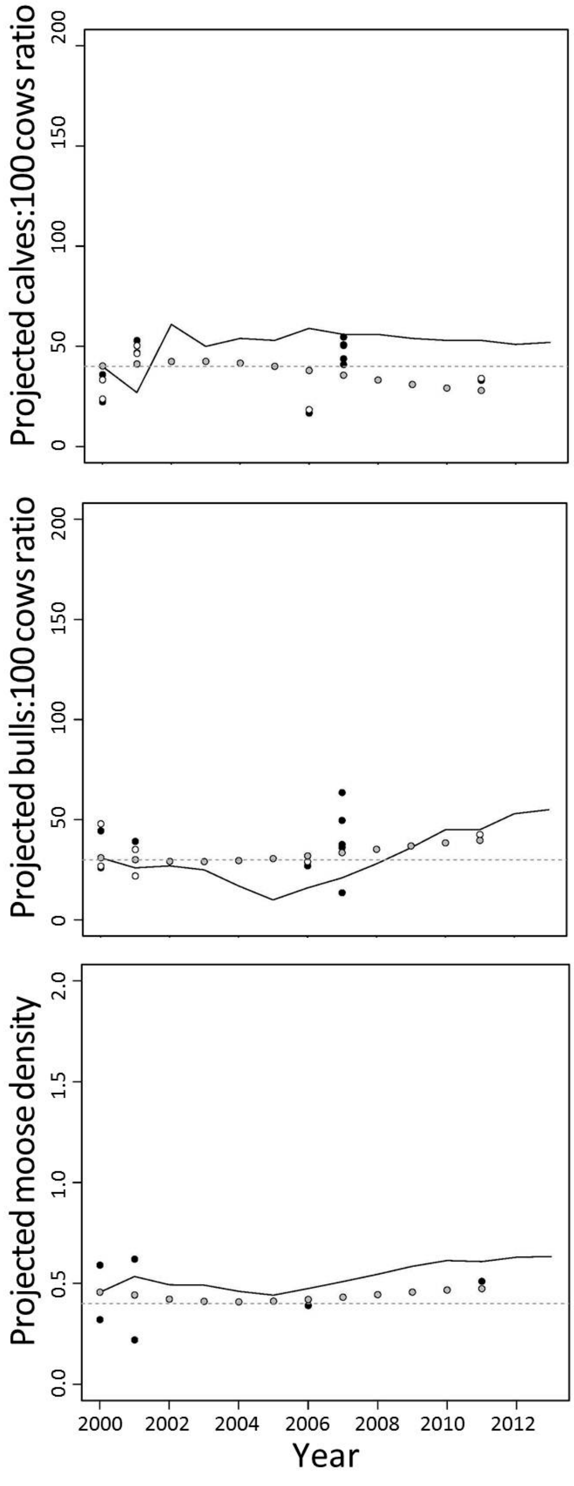

Figure 18. Projected demographic patterns for moose in Game Management Zone 5B from 2000-2012 based on a 50% increase in cow mortality over current mortality estimates.

Shown for each demographic indicator are the projected values (black line) plotted with observed (black circles) or estimated (open circles), and LOESS smoothed average values (gray circles) as per previous graphs (see Figure 3 caption for a description of how the smoothing was done).

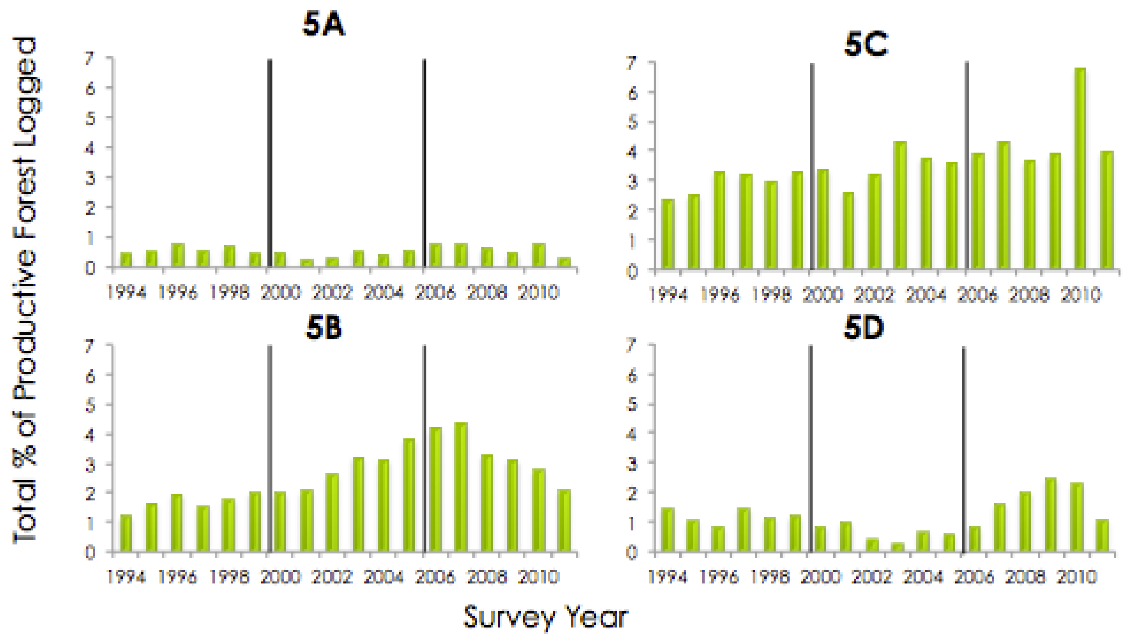

Figure 19. Percentage of productive forest lands harvested annually between 1994 and 2011 in each Game Management Zone (5A – 5D) in the Cariboo Region, British Columbia.

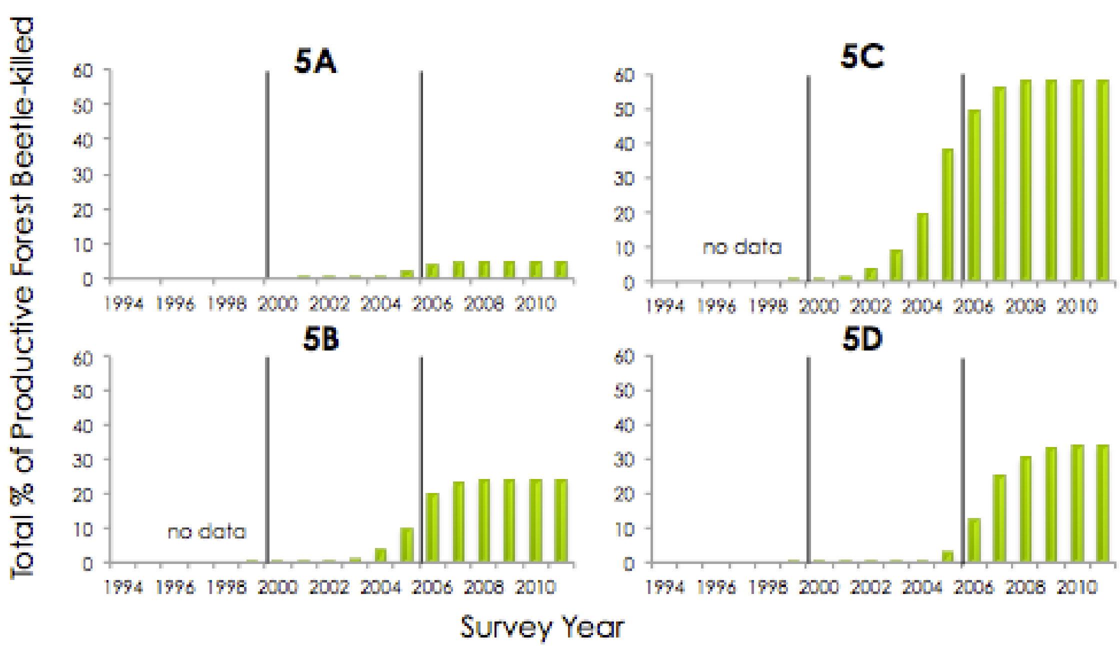

Figure 20. Percentage of productive forest lands with severe or very severe MPB-caused tree mortality occurring between 1994 and 2011in each Game Management Zone (5A – 5D) in the Cariboo Region, British Columbia.

the levels of forest harvest (e.g., via salvage harvesting) were at least partially related to the levels of MPB mortality, especially in GMZ5B and GMZ5D, but this relationship is complex and was likely mediated by the availability of roads required to access MPB-killed stands. Forest harvest was generally low in GMZ5A and GMZ5D compared to the other RMZs and increased significantly in GMZ5B in the mid-2000s before dropping off again while forest harvest in GMZ5C was relatively high and has remained so. The amount of MPB-killed forest was highest in GMZ5C and least in GMZ5A and has generally leveled off in all zones after 2006.

The percent of RMZs characterized as of little to no value to moose is greatest in RMZ5A and RMZ5D at close to 60% although habitat in RMZ5D was apparently improved during the middle time period while habitat in RMZ5A was marginally degraded during the last time period (Figure 21). RMZ5B has the lowest amount of low-valued habitat but during the middle time period, the amount increased to approximately that of the other RMZs. The percent of RMZs characterized as high-valued moose habitat is greatest in RMZ5B and RMZ5C at close to 20% or slightly under (respectively) remaining so across the three time periods (Figure 22).

The resulting model of habitat factors in relation to moose population densities observed across the region was relatively simple (Figure 23), highlighting the role of amount of moose habitat and its quality, although with low explanatory power (R^2 = 0.25)[18]. Note that the actual partitioning factor (% moose habitat classed as high suitability) is closely related to, but is not the same as, the most important factor (% moose habitat classed as nil suitability) (Table 11)[19]. Both results do, however, indicate that observed moose densities were correlated with habitat suitability. Other factors, those associated with habitat change (i.e., forest harvest or MPB attack), did not end up in the final model explaining the variance observed in moose population densities although both factors did have a relatively high importance value. The models relating habitat to regional bull ratios appeared to be best represented by the factors of habitat change (Figure 24: left panel; R^2 = 0.26) and Table 12 (left panel), although amount of suitable habitat remained important as well. The habitat quality factors that most closely related to regional calf ratios were % of moose habitat classed as high quality (Figure 24: right panel; R^2 = 0.34) with % productive forest harvested (no lag) also having high importance (Table 12: right panel). The lagged variables for forest harvest and MPB-killed timber did not enter any of the final models and were never ranked with an importance value.

Vulnerability

Analysis of the results obtained from the questionnaire (Table 13)[20] indicated that several factors apparently are related to the changes in moose population density at the regional level, including relative change in access, relative effort to control wolves, the effect on non-regulated hunting, and relative wolf abundance. On the basis of the resulting model (Figure 25; Table 14), it appears that lower moose population densities

[18] See Appendix E for a detailed description of the figures and tables that form the basis of results from the rpart analyses.
[19] Factors can remain important in partitioning subsets of the data without explicitly appearing in the most parsimonious and final models. See Appendix E for more discussion on this topic.
[20] As an example of interpreting the scores in this table, the values for comparative abundance of wolves in GMZ A (relative to all other GMZs) is interpreted as moderate pre-2000, dropping to low in 2001-2005 and to very low in 2006-2012.

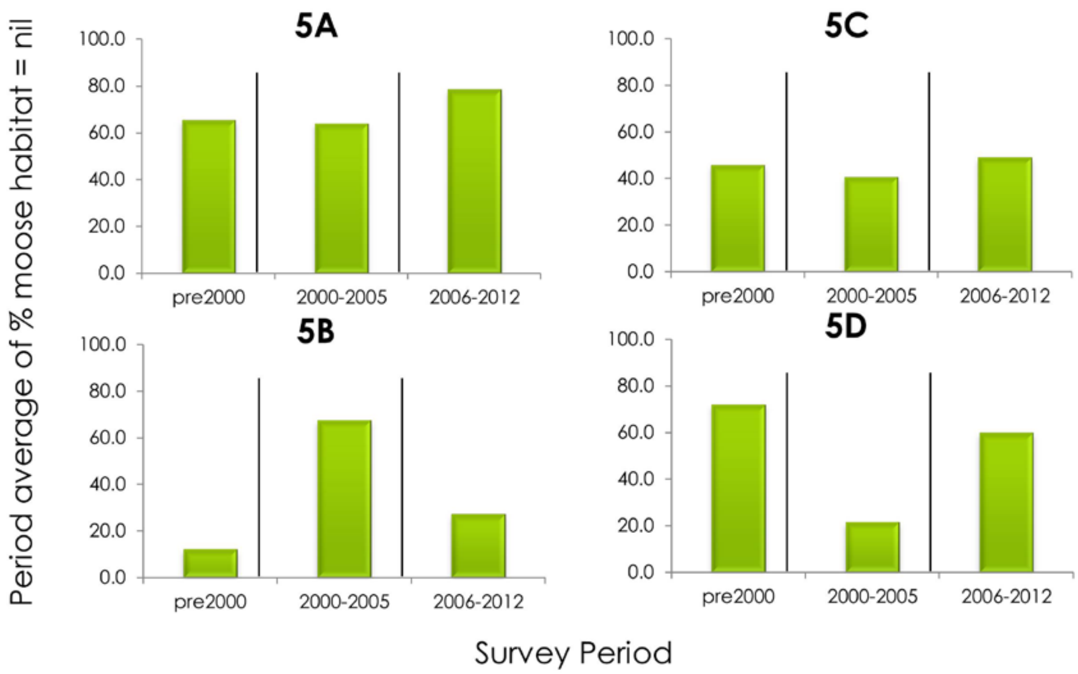

Figure 21. Period average of percent moose habitat with nil value between 1994 and 2011 in each Game Management Zone (5A – 5D) in the Cariboo Region, British Columbia.

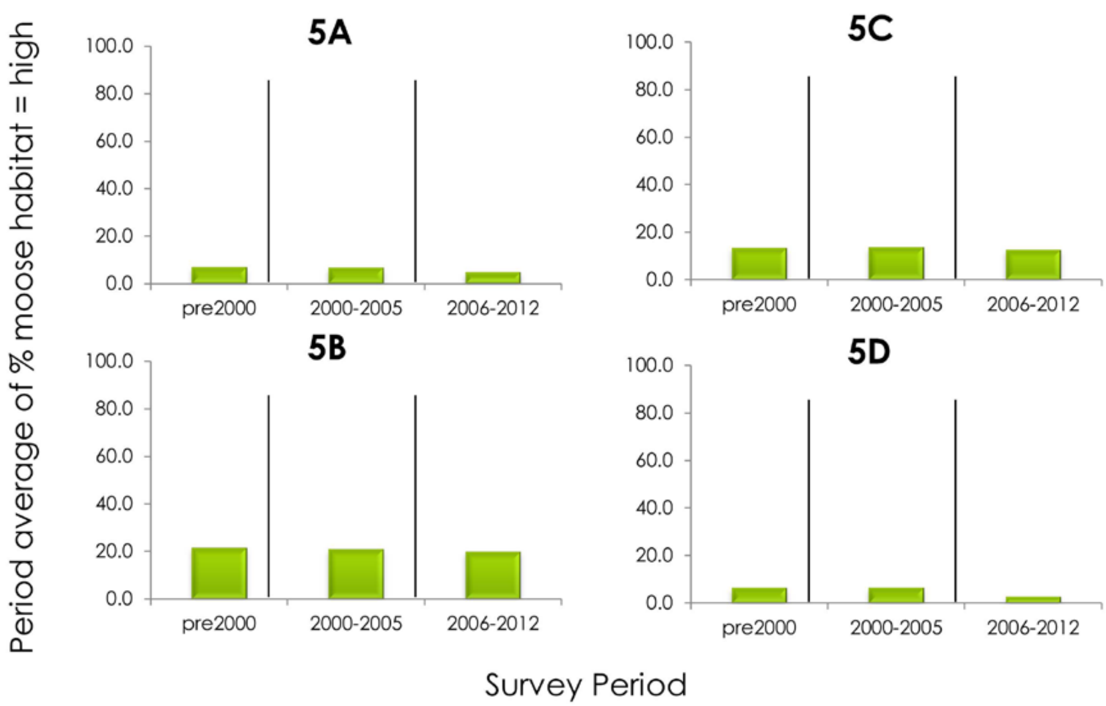

Figure 22. Period average of percent moose habitat with high value between 1994 and 2011 in each Game Management Zone (5A – 5D) in the Cariboo Region, British Columbia.

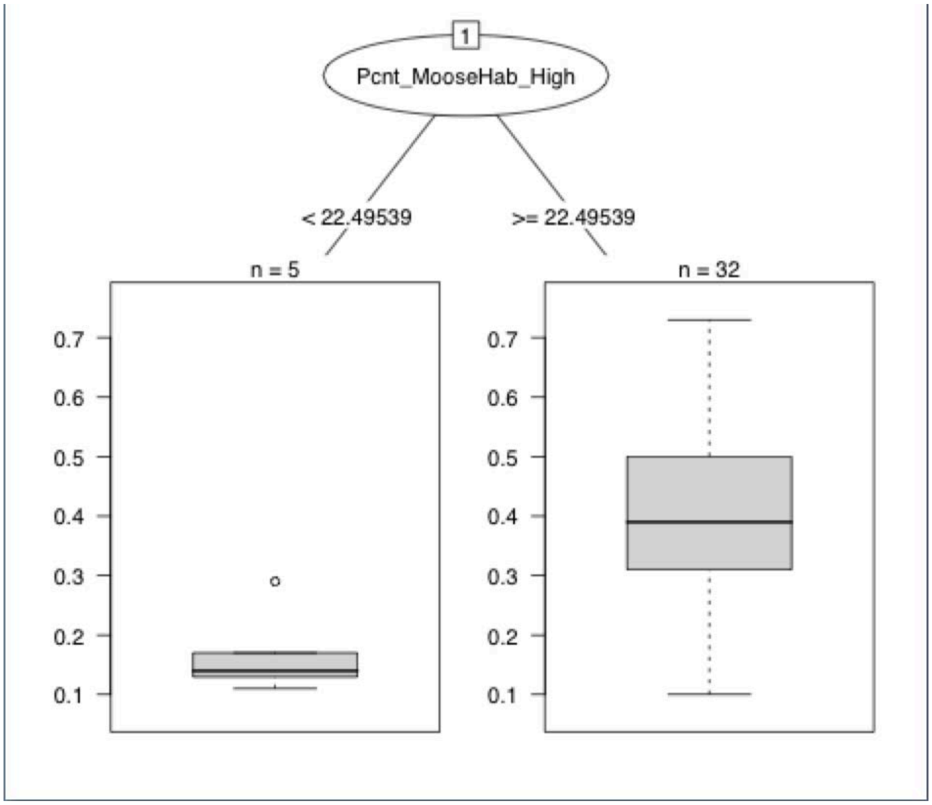

Figure 23. Partitioned tree diagram relating factors associated with habitat condition for moose with population densities (N=39) observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Cariboo Region, British Columbia.

Table 11. Importance of habitat condition factors in explaining the variance of moose population densities observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Caribou Region, British Columbia.

Factor variable	**Importance in model-fitting**
% Moose habitat = Nil	40
% Productive forest harvested (no lag)	20
% Forest killed by MPB (no lag)	15
% Moose habitat = high	12
% Productive forest harvested (5 year lag)	1

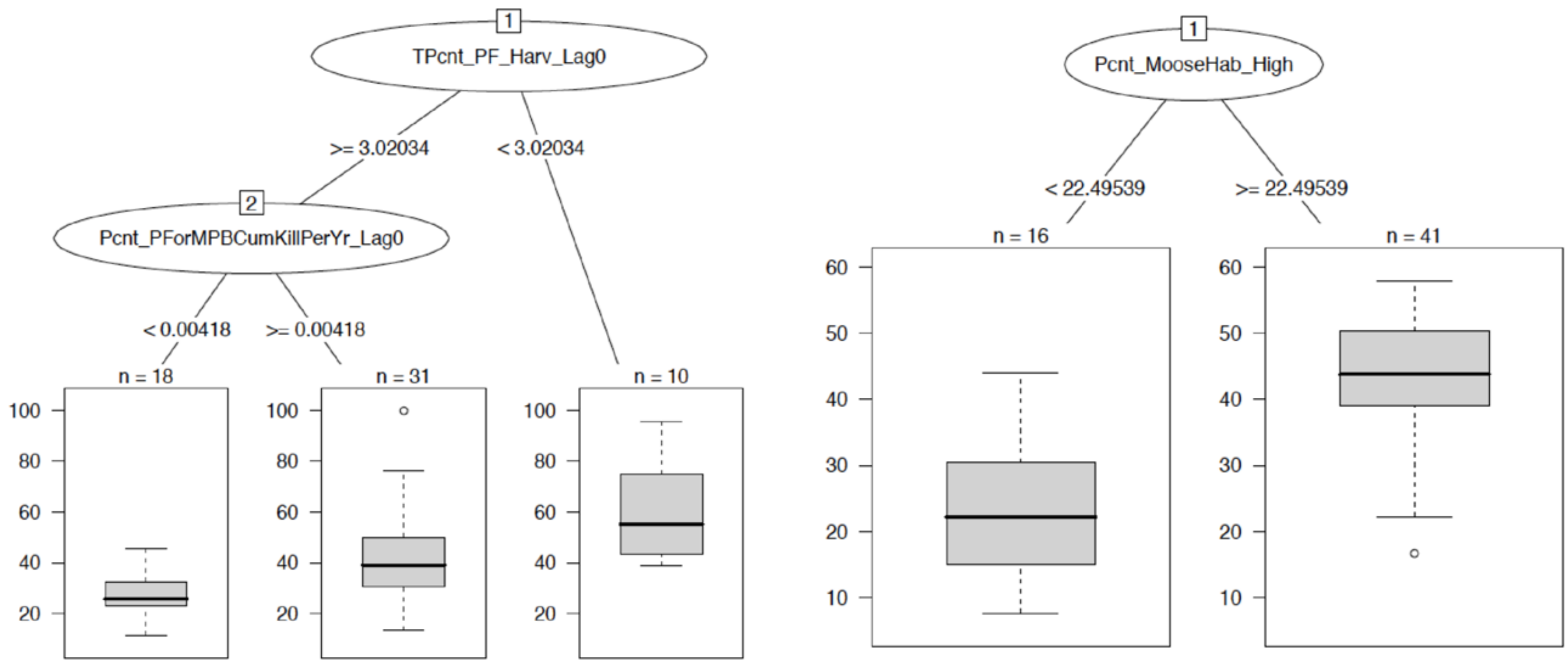

Figure 24. Partitioned tree diagram relating factors associated with habitat condition for moose with bull (left panel) and calf (right panel) ratios (N=59) observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Cariboo Region, British Columbia.

Table 12. Importance of habitat condition factors in explaining the variance of bull and calf moose ratios observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Caribou Region, British Columbia.

Bulls: 100 Cows Ratio		**Calves: 100 Cows Ratio**	
Factor variable	**Importance in model-fitting**	**Factor variable**	**Importance in model-fitting**
% Forest killed by MPB (no lag)	46	% moose habitat = high	49
% Moose habitat = nil	28	% Productive forest harvested (no lag)	43
% Productive forest harvested (no lag)	24	% Moose habitat = nil	8
% moose habitat = high	12		

Table 13. Questionnaire results containing expert judgement on factors related to vulnerability of moose during three time periods (pre-2000, 2001-2005, 2006-2012) in four Game Management Zones (GMZ) in the Cariboo Region, British Columbia.

Indicators	GMZ	Time periods		
		pre-2000	2001-2005	2006-2012
comparative abundance of wolves	A	3	2	1
comparative abundance of wolves	B	1	2	3
comparative abundance of wolves	C	1	3	4
comparative abundance of wolves	D	1	3	4
Relative effort to reduce wolves	A	1	3	3
Relative effort to reduce wolves	B	4	1	2
Relative effort to reduce wolves	C	4	1	2
Relative effort to reduce wolves	D	3	1	1
Number of years where snow in habitat >1.0m	A	5	5	5
Number of years where snow in habitat >1.0m	B	2	0	3
Number of years where snow in habitat >1.0m	C	2	0	2
Number of years where snow in habitat >1.0m	D	2	0	2
% of habitat in zone where snow > 1.0m	A	100	100	100
% of habitat in zone where snow > 1.0m	B	30	20	30
% of habitat in zone where snow > 1.0m	C	20	10	20
% of habitat in zone where snow > 1.0m	D	20	10	20
FN hunting numbers in zone	A	1	1	1
FN hunting numbers in zone	B	2	4	4
FN hunting numbers in zone	C	2	4	4
FN hunting numbers in zone	D	2	4	4
FN hunting extent in the zone	A	25	50	50
FN hunting extent in the zone	B	80	90	90
FN hunting extent in the zone	C	50	60	70
FN hunting extent in the zone	D	50	70	80
comparative change in access in zone	A	4	1	1
comparative change in access in zone	B	4	1	1
comparative change in access in zone	C	2	3	4
comparative change in access in zone	D	4	3	2

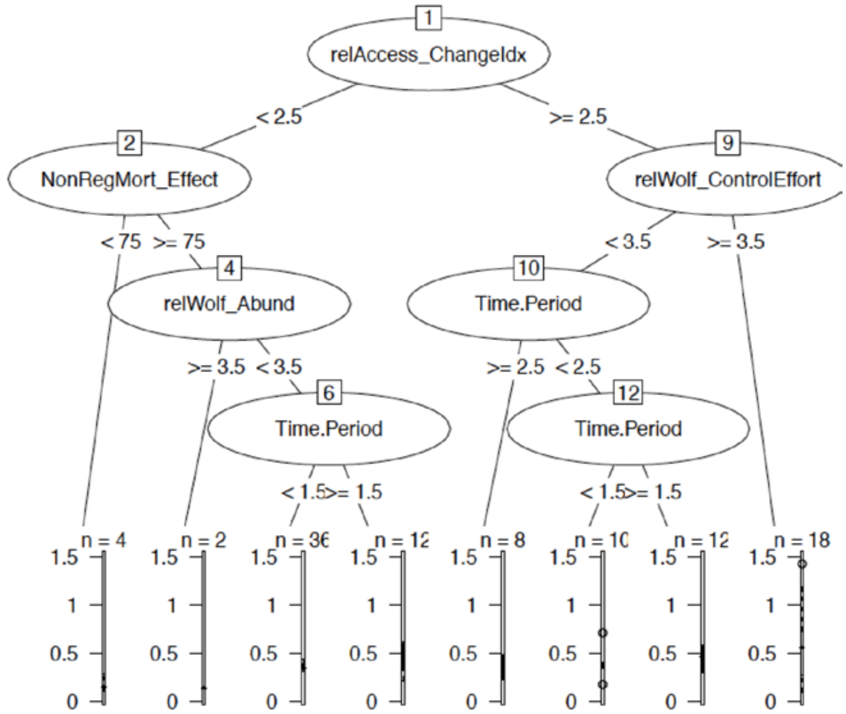

Figure 25. Partitioned tree diagram relating factors associated with vulnerability of moose with population densities (N=39) observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Cariboo Region, British Columbia.

Table 14. Importance of vulnerability factors in explaining the variance of moose population densities observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Caribou Region, British Columbia..

Factor variable	Importance in model-fitting
Deep snow effect	22
Relative wolf control effort	19
Non-regulated mortality effect	18
Relative wolf abundance	16
Relative change in access	15
Time period	9

tended to be associated with higher non-regulated hunting effort and higher wolf abundance if the relative change in access was low, and with higher wolf control effort if the relative change in access was higher. However, there were exceptions to that pattern (i.e., the lowest observed densities occurred where non-regulated hunting effort tended to also be low), and because the overall variance in regional density explained by these factors was low (R^2 = 0.25), these results need to be interpreted with caution. Analysis of the importance factors revealed that there was a hidden interaction among these factors with the deep snow effect and that the relative importance among the other factors was similar, except for time period which was ranked somewhat lower.

Examination of the relationships between vulnerability factors and bulls:100 cows suggested that higher ratios were also related to higher wolf abundances if the deep snow effect was higher, and lower ratios were related to higher non-regulated hunting if the relative change in access was lower (Figure 26: left panel). In this model, the most important factors are the deep snow effect, non-regulated mortality effect and the relative wolf abundance (Table 15: left panel). For calf-cow ratios, the non-regulated mortality effect was the dominant variable appearing in the fitted model (Figure 26: right panel), although the deep snow effect was approximately equal to it in importance (Table 15: right panel). Again the amount of variation explained by the model fits was relatively low (bulls: 100 cows ratio: R^2 = 0.25; calves: 100 cows ratio: R^2 = 0.33) suggesting that the structures revealed by the models are not robust to the influence of other factors. We note also that effects of the Quesnel Highlands predator management study may be influencing moose densities in this GMZ prior to 2005.

Vulnerability and Habitat Condition Factors

Given the large amount of unexplained variation in the model fits with separate treatments of the vulnerability and habitat quality factors, we combined the two sets of factors to see whether additional relationships could be identified with the three demographic response variables. We found that both vulnerability factors and habitat quality factors were important relative to regional moose population densities (Table 16), but that the simplest tree model related higher percentages of moose habitat classed as high suitability to higher densities (Figure 27; R^2=0.25) as it was in the analysis with habitat quality alone. The combination of factors changed the relative order of importance of the individual factors, but most of those identified in the separate analyses were retained as important in the combined analysis. Note that the amount of variation explained did not increase.

For bulls:100 cow ratios, the habitat quality factors associated with changes in habitat (i.e., higher% productive forest harvested was associated with higher bulls: 100 cow ratios, while amount of forest killed by MPB was also associated, but negatively (Figure 28; left panel). By importance, the majority of factors linked to bull:cow ratios were habitat quality, although deep snow effect, and both relative wolf control effort and non-regulated mortality effect had influence on this ratio (Table 17; left panel). As for the separate models, the quality of moose habitat was the dominant factor related to calf: 100 cow ratios, with high quality moose habitat linked to higher calf:cow ratios (Figure 28; right panel). Both habitat quality and vulnerability factors interacted and were important (Table 17; right panel) with sources of mortality becoming important under some habitat conditions.

DISCUSSION

Evidence for Declines in Moose Populations

In general, there was evidence of a population decline in the Caribou Region in the mid-1990s (Hatter 1998). From our analysis of SRB survey data, it seemed that the population stabilized around 2000 and may actually have been recovering up to about 2003 after which, the population again went into region-wide decline between 1994 and

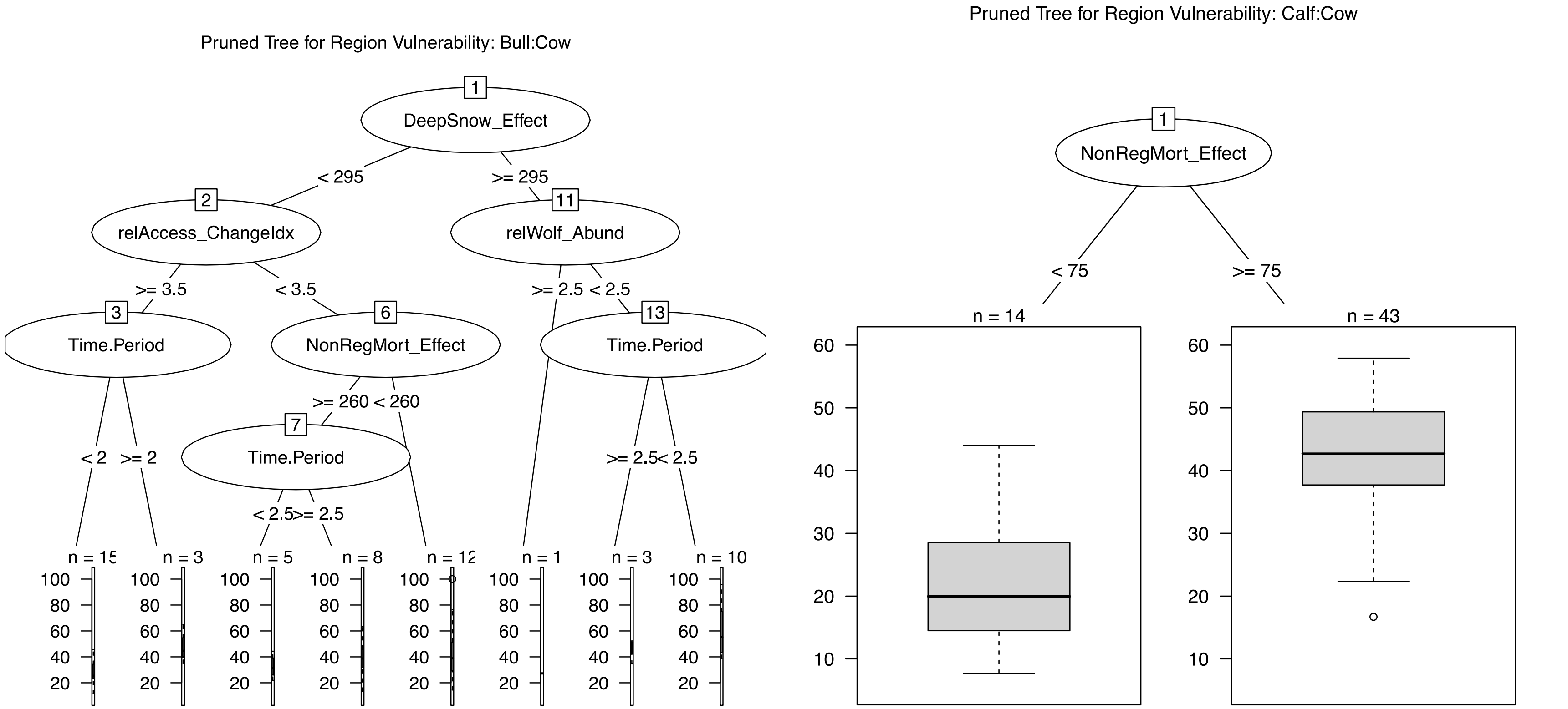

Figure 26. Partitioned tree diagram relating factors associated with vulnerability of moose with bull (left panel) and calf (right panel) ratios (N=59) observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Caribou Region, British Columbia .

Table 15. Importance of vulnerability factors in explaining the variance of bull and calf moose ratios observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Caribou Region, British Columbia.

Bulls: 100 Cows Ratio		**Calves: 100 Cows Ratio**	
Factor variable	**Importance in model-fitting**	**Factor variable**	**Importance in model-fitting**
Deep snow effect	27	Non-regulated mortality effect	50
Non-regulated mortality effect	26	Deep snow effect	50
Relative wolf abundance	15		
Time period	12		
Relative wolf control effort	10		
Relative access change	10		

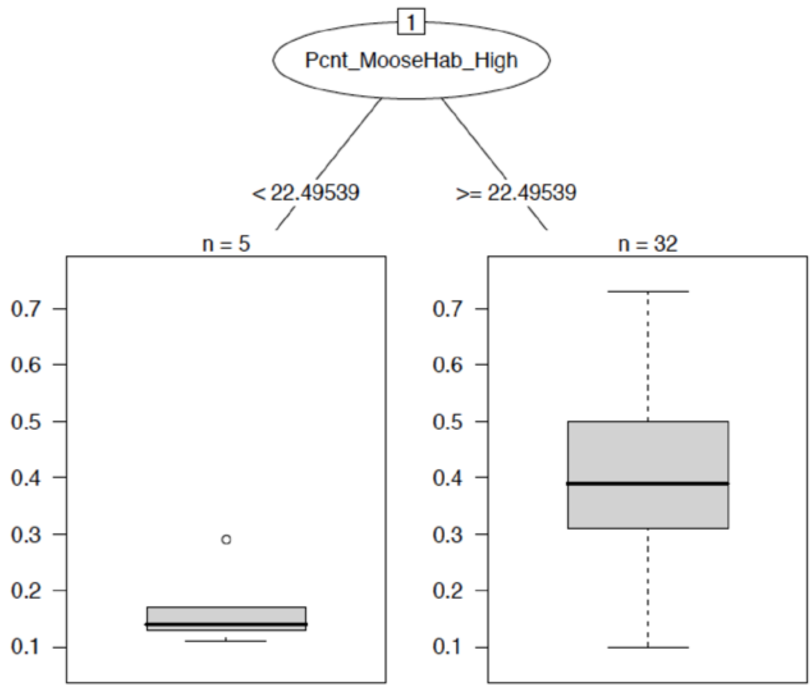

Figure 27. Partitioned tree diagram relating factors associated with habitat condition and vulnerability of moose with moose population densities (N=39) observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Cariboo Region, British Columbia.

Table 16. Importance of the habitat condition and vulnerability factors in explaining the variance of moose population densities observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Cariboo Region, British Columbia.

Factor variable	Importance in model-fitting
% Moose habitat = nil	21
Deep snow effect	17
% Productive forest harvested (no time lag)	13
Forest killed by MPB (no time lag)	12
% Productive forest harvested (lag=5 years)	9
% Moose habitat = high	8
Relative wolf control effort	7
Non-regulated mortality effect	7

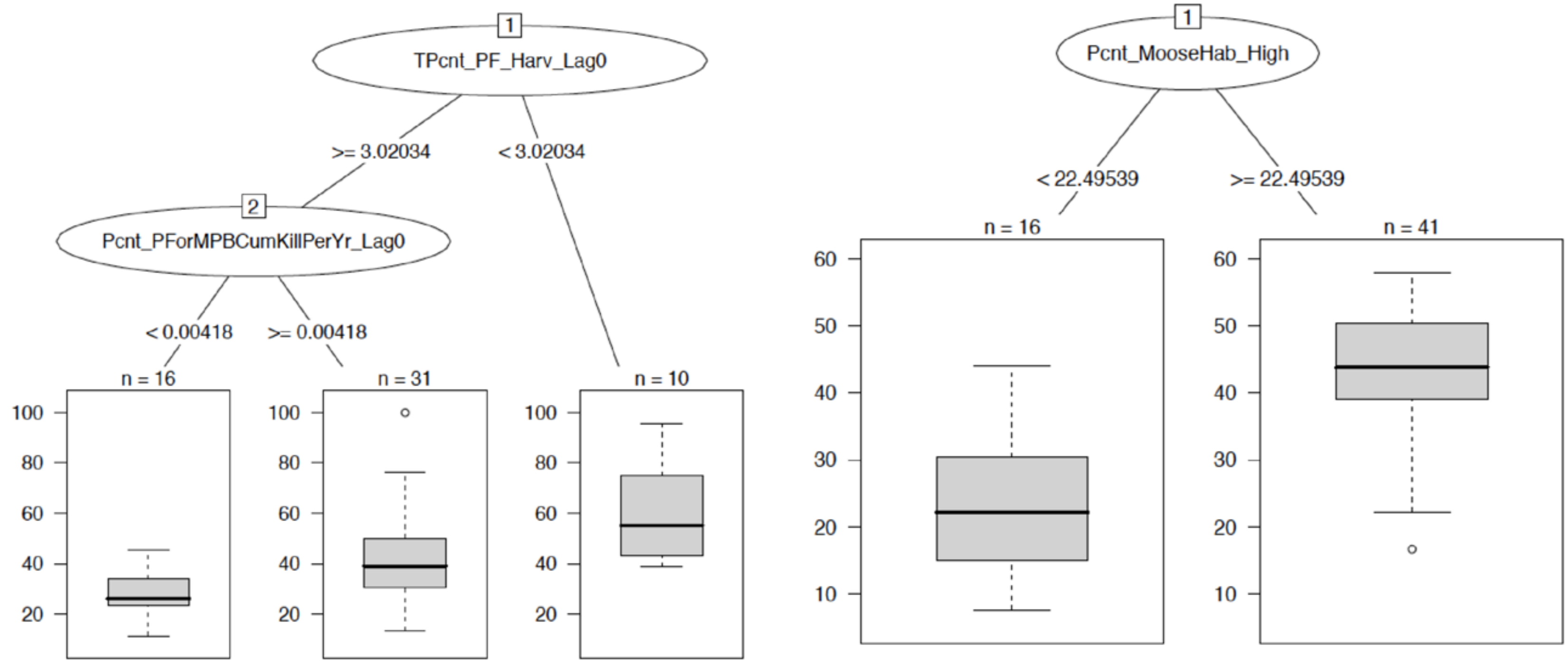

Figure 28. Partitioned tree diagram relating factors associated with habitat condition and vulnerability of moose with bull (left panel) and calf (right panel) ratios (N=59) observed during three time periods (pre-2000, 2001-2005, 2006-2012) in the Cariboo Region, British Columbia.

Table 17. Importance of the combined habitat quality and vulnerability factor variables used in fitting partitioned trees to regional bulls: 100 cows and calves: 100 cows ratios for the three time periods.

Bulls: 100 Cows Ratio		**Calves: 100 Cows Ratio**	
Factor variable	**Importance in model-fitting**	**Factor variable**	**Importance in model-fitting**
% Productive Forest harvested (no time lag)	21	% moose habitat = high	26
% Forest killed by MPB (no time lag)	20	Non-regulated mortality effect	20
% Moose habitat = nil	16	% Productive forest harvested (no lag)	19
Relative access change	15	Deep snow effect	17
% moose habitat = high	11	% Moose habitat = nil	8
Non-regulated mortality effect	9	Relative wolf abundance	3
Deep snow effect	8	Relative wolf control effort	3

2012. LEH hunting regulations were being implemented during 1995-1998, and were fully in place by 1999. While there is a suggestion of a recovery of densities in the pooled data by 2000 there are relatively few surveys post 2001 and the majority of those surveys have resulted in estimated densities below target. The incomplete sampling design at the Regional level (i.e., poor replication of individual SRBs within and among RMZs) unfortunately leads to an apparent lack of distinct statistical trends at that level. Support for this notion is that the strongest evidence for population decline appears to be at the finer scale of WMUs. There is statistically significant evidence of declines occurring in 5 of 12 WMUs, while 1 WMU is apparently stable, and trends in remaining 6 WMUs are essentially unknown. The significantly declining WMUs occur in GMZs 5B (Rose Lake, Horsefly River), 5C (Anahim East) and 5D (Big Creek). Since 2004, estimated densities of moose have generally remained at, or below, the management targets. Given this WMU-level evidence distributed across at least three GMZs on both sides of the Fraser River, we suggest that there is sufficient evidence to infer that a large-scale decline in moose populations is generally occurring throughout the Cariboo Region.

We found that the underlying SRB survey data, as collected historically, were relatively weak for use in assessing moose population trends. For example, the relatively fewer samples collected in the 2000-2012 period necessarily led to vacant cells in the overall monitoring design (i.e., less than 50% of the total number of WMUs had repeated surveys conducted within this period). We also note at least two other changes in sampling techniques: (1) a reliance on a single SCF factor since 2000, and (2) some evidence to indicate that later surveys have paid more attention to sampling strata until a desired precision is obtained. These apparent shifts in sampling technique somewhat confounds analysis of earlier vs later time periods, although improved precision per survey overall does offer benefits.

Mechanisms and Factors Associated with Trends in Moose Populations

Population Composition

In general, we found that the number of bulls:100 cows have increased above the management target across the region as a whole (i.e. within each GMZ) and appear to be continuing to increase. Notwithstanding the fact that evidence is lacking on potential demographic effects of low bull ratios (Laurian et al. 2000), it's certainly unlikely with the increase in the bull ratio that insemination of cows could be posing a constraint on regional population growth. The increase in the bull ratio could be due to fewer bulls being harvested by hunters (but this is not supported by recorded statistics on the regulated hunt), fewer bulls dying to other causes in recent times (seems unlikely during an apparent population decline) or by increased mortality of cows (plausible, if the mortality agent is sex selective). In addition, we found that calf: 100 cow ratios have declined below the management target of 40 in all GMZs since the mid-2000s, and may be continuing to decrease. While it is likely that the bull:100 cow ratio could increase substantially and not likely result in lowered reproductive success (Laurian et al. 2000), concomitant changes in insemination dates (and hence parturition dates) could be of some demographic importance. Later-born calves may have lower survival either due to less growing time before winter or due to a reduced predator swamping effect by spreading out births over time. Low calf:cow ratios are more directly tied to population declines as they indicate the status of year-on-year recruitment into the breeding age classes. Presently, there is little indication that the ratios are recovering towards target levels. Given that the patterns in this indicator are similar in every GMZ (although trend is difficult to quantify in GMZ5a because of lack of data), identifying reasons for the low ratios is a critical step in modifying management actions for improving overall moose densities.

Harvest Patterns

In general, the moose population in the Cariboo Region was apparently declining in the mid- to late-1990s when 9,000-10,000 hunters were spending 60,000 days annually to harvest a little over 2,000 moose each year (28 days per moose). This situation was at least partially responsible for a policy change to switch regulations to focus solely on LEH and in 1999 ~3,000 bull only permits were allocated over the region. This change dropped the number of hunters in the period 1999-2003 to only 2,500 hunters spending 15,000 days annually with a harvest about 1,000 moose; albeit at a better success rate of 15 days per moose. However, in 2003 there was an all-time low of 12,600 hunters after which another policy change was used to introduce 40 cow/calf tags to the LEH hunt and in the years following, hunter numbers increased to just over 3,000 and about 20,000 days annually but harvest has remained the same at about 1,000 moose per year reducing the success to 20 days per moose.

The strong increase in hunter success in all GMZs following full implementation of LEH would indicate an increase in vulnerability of moose perhaps due to a significant reduction in number of hunters (i.e., less disturbance to push moose into security cover). However, the policy change and increase in hunter success was also coincidental with the onset of, and response to, the MPB epidemic and vulnerability of moose could have increased due either to the change in habitat (i.e., dead trees) or to increased salvage logging (i.e., removal of cover) or to the change in access associated with salvage logging (i.e., more roads). This change in vulnerability is essentially a supposition at this point as it would take focused research to provide the necessary information for such a conclusion. Nevertheless, if a reduced number of hunters, increased access, or loss of visual cover effectively increased vulnerability of moose to hunters, then it is possible that similar trends would have occurred for other big game species, and in fact the same increase in success did occur for mule deer.

The subsequent decline in hunter success (2004-2005) for moose is significant. If vulnerability of moose increased due to less hunting pressure, increased hunter accessibility, and/or decreased visual cover; none of those factors have been reversed and so vulnerability of moose as a function of those factors is presumably still high. The decrease in CPUE in the period 2004-2005 can only be a reflection of fewer moose which would be consistent with the conclusions drawn from analysis of the population surveys. A similar reduction in CPUE for mule deer has not been as sharp as that for moose indicating that moose and deer populations may have declined somewhat differently. Important to note is that the regulated hunting portion of the mortality causing the decline has remained stable since the focus on LEH at about 1/3 of the available permits and at levels that are ½ of the pre-LEH harvest. It appears unlikely that regulated hunting has directly instigated the decline of moose populations in the region and so the apparently unsustainable portion of mortality must come from either unregulated hunting or natural sources. The hunter harvest metrics however, did not offer support for a conclusion that there was an increase in large predator population levels during our period of study. Although grizzly bears did exhibit a peak in CPUE between 2002 and 2004 as did moose and mule deer, harvest data for grizzly bears were sparse.

Demographic Model Projections

Our trials using the demographic model that we implemented for this study showed that current estimates of moose mortality from AAH models (resident hunter, non-resident guided hunts, non-regulated hunting, estimated wounding losses and other natural mortality) do not track observations from SRB surveys. Our explorations to date indicate that increases in the rates of assumed mortality, and in particular cow and calf mortality, substantially improves the fit of projected demographic outcomes relative to the observations. Mortality rates on cows generally needed to be 30-50% higher than current management assumptions in order to plausibly match observed data. Required average annual mortality rates on calves appear to be in the 50-65% range across GMZs to generate plausible patterns, which is within the range published estimates of annual losses to calves in the presence of predators (e.g., Boutin 1992). By comparison, we found that assumptions of non-hunting mortality rates of bulls per GMZ as estimated from the AAH models were broadly consistent with observed patterns, except in GMZ 5D where mortality rates on bulls may be > 50% higher than current assumptions. It is possible that because cows and calves appear to be declining faster than bulls, at least some portion of the extra mortality is predominantly occurring on ranges during periods of sex-segregation (.e.g., early winter), although we have no independent data to examine that possibility.

Assessing sources and levels of mortality is a difficult task without independent data derived from radio-collaring studies that follow the fates of individuals from birth to death. Mortality on moose can be apportioned in at least six different places (Figure 29). In this study, we assumed that reported hunting statistics were accurate (i.e., reported with negligible error). For the Cariboo region, there is no recent empirical information to estimate the other mortality values (constants and/or variances). For example, wounding loss estimates, originally obtained from empirical data, were treated as a constant over the period of this analysis. Natural mortality estimates used in AAH calculations were adjusted to match population estimates, but these estimates do not consider the underlying uncertainty in the population estimates (Hatter, *pers comm*.). Estimates of the non-regulated hunting component were based on estimates of the needs of First Nations, but not on actual hunting data. Finally, each source of mortality could interact differently with hypothesized causal factors linked to declines (habitat-related or mortality-related). Note that in this study, we did not vary productivity (fecundity) of moose as a function of habitat condition. This could lead to over-estimates of moose numbers, and thus an over-estimate of the mortality parameters required to emulate observed demographic patterns using the model.

Based on the assumptions used in the periodic annual allowable harvest (AAH) determinations, the allocation of FN sustenance needs assumed that FN were able to harvest at the allocation level in our analysis of moose kills. This may be unlikely if moose populations have declined substantially and the apportioning of FN kill between bulls and cow/calf animal classes may also change to reflect higher proportions of bulls in the FN kill. Ministry AAH models for more recent harvest allocation periods assume a

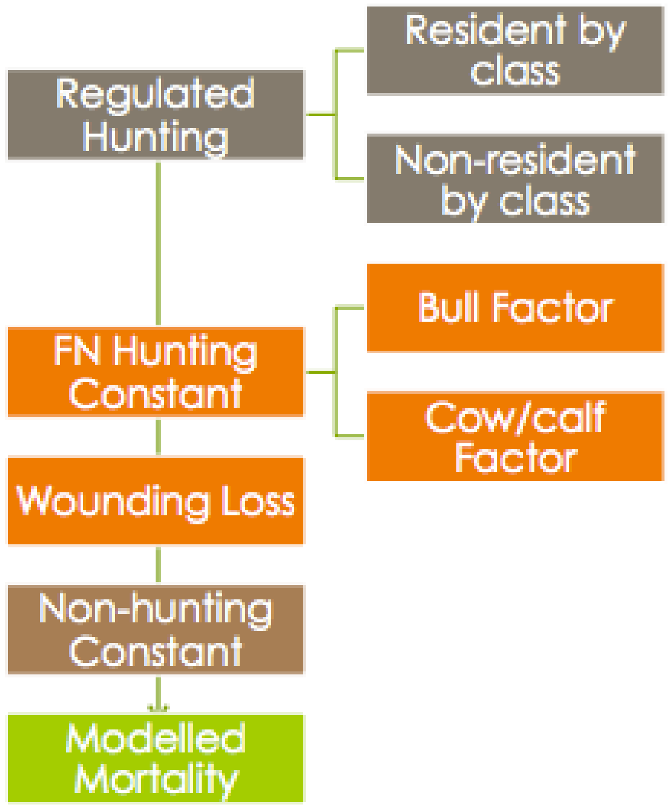

Figure 29. Conceptual relationships between sources of mortality as represented in the assumptions used in the modelling portions of this study.

Different colours represent groupings of assumptions about mortality as inferred from the presently available data: dark grey: reported hunting statistics; orange: assumptions derived from government AAH models; brown: unknown mortality; green: predicted total mortality.

non-selective harvest by FN (bulls and cows harvested according to population sex ratio) and somewhat lower wounding loss (1.15) than what previous allocation periods assumed (and our modelling assumed).

Spatial Data Analysis

We were not able to identify a single habitat factor that clearly related strongly with the density or composition data from the SRB and/or composition surveys. Unfortunately, it is often difficult to interpret the significance of any particular level of linear population decline in terms of habitat changes when there is no detectable, dramatic change in the population (Ludwig 1993). As a result, although many studies demonstrate linear decline of populations with loss of habitat, it is difficult to pin-point any ecologically significant habitat level threshold before the population become much smaller and more vulnerable.

Our two main factors related to habitat condition affecting moose were harvesting of productive forests and the loss of productive forests due to mortality by MPB. We found that forest harvesting patterns varied among the different GMZs, and also were important variables linked with moose density and bull:cow ratios. Yet, the quality of available habitat was also important (especially for calf:cow ratios), as were factors affecting vulnerability of moose (e.g, snow depth and extent, predator and non-regulated hunting effects). However, taken together, the effects of all factors (habitat condition and vulnerability) was only able to explain 20-40% of the variance in the demographic indicators, suggesting that the interactions between observed moose response variables and the factors we considered are either weak, or the potential mechanisms are confounded and difficult to disentangle. We note that the coarseness of some of the data sources combined with the relative sparseness of the SRB survey data likely limited the statistical power of the tests to reveal causal linkages.

We found that the initiation of the MPB-induced losses of productive forest appeared to co-occur with the rapid increase in CPUE, although we have not yet fully explored possible reasons for that co-incidence. It is possible that the mortality caused to forests as a result of the MPB outbreak led in some way to the increased vulnerability of at least some moose because: (1) moose may have had to alter habitat use patterns in response to the tree mortality or (2) there may have been increased access from MPB salvage roads leading to increased harvesting of moose by predators and non-regulated hunting. We infer from the patterns in the regulated hunting data that if human hunters did take advantage of any increased access as a consequence of MPB effects, the regulated hunting component was constrained to a constant effect through LEH. Unfortunately, we have no data to relate the behaviour of the other two components (non-regulated hunting and predators) to usage of access and so cannot speculate further on the potential role played by the MPB outbreak in the population decline except to reiterate that one or the other or both of these unknown sources of mortality must have increased during the MPB outbreak to an unsustainable level and perhaps remains so.

KEY CONCLUSIONS AND RECOMMENDATIONS

Key Conclusions

1. Given that there were statistically significant declines in moose populations in 5 of 12 WMUs and that these WMUs are distributed in RMZs on both sides of the Fraser River, we considered that to be sufficient evidence to concur with the Regional biologists' assessment of a regional-wide decline in number of moose within the Cariboo Region.
2. With the possible exception of GMZ5B, the population density of moose within the Region is below the management objective and steps should be taken to improve this management condition.
3. Although partially a response to changes in hunting regulations, the apparent increase in the bull ratio within moose populations across the Region seems also to be at least partially a response to an apparent increase in mortality to cows; the latter change (i.e., over that estimated in AAH models) was found to be a necessary modification in order to improve how the demographic models track the dynamics in observed moose population statistics. Similarly, the calf ratios within moose populations across the Region have declined through time and are

now close to or below the management objective. With the apparent increase in cow mortality noted above, the estimated mortality to calves (i.e., over that used in AAH models) was found to also be a necessary modification in order to have demographic models better track the dynamics in observed moose population statistics. It seems apparent that the combination of increased cow and calf mortalities would be a determining mechanism in the affirmed decline of moose in the Region. It also points out the potential for the mortality agent to be sex-selective and most active when males are occupying a different (and perhaps safer) range than cows and calves.

4. Moose apparently underwent an increase in vulnerability (to at least regulated hunting) in the early 2000s coinciding with: (a) a 75% decline in the number of hunters and (b) elevated levels of MPB-killed forests. The conclusion about vulnerability and regulated hunting is plausible because the fewer number of regulated hunters (compared to pre-1999) experienced a significant increase in hunting success (both moose and mule deer) in four successive years during that period, however, regulated hunters took only half the number of moose compared to harvest rates pre-1999.
5. A subsequent decline in hunter success back to pre-1999 levels (at different rates for moose than for mule deer), in the absence of any recovery of factors contributing to vulnerability of moose, seems to indicate a hunting response to the declining moose population.
6. It is plausible that, if the increase in vulnerability of moose was more general than just to regulated hunters alone, the change could have led to increases in mortality from unregulated hunters and/or predation and, consistent with the points above, this subsequently led to an unsustainable reduction of cows and calves and a moose population decline.
7. An alternative (or perhaps additional) explanation to the mechanism for decline would be that forest harvest and the MPB epidemic caused a pulse of poor habitat, leading to poor productivity and calf survival. However, this supposition was not supported by data; in particular in GMZ5B where moose habitat declined during 2000-2005 then returned to normal in the subsequent period and in RMZ5D habitat increased during 2000-2005 and the dropped to normal in the subsequent period and yet populations in both RMZs declined through these periods.
8. If the key conclusions noted above are correct then, in the absence of changes in moose harvest policy (i.e., both regulated and unregulated) or predator management, we would expect to see continued decline of the moose population in all GMZs except perhaps GMZ5A.
9. The conclusions we make above are largely deductive rather than inductive because there are no direct and independent data to prove an increase in vulnerability of moose, no direct data to demonstrate an increase in cow and/or calf mortality, and we found insufficient information on what could have been the potential source of the increased mortality (i.e., unregulated hunt, predation, malnutrition) – all points would require more investigation and, in many cases, whole new independent research studies.
10. The SRB survey data is a necessary tool for use in managing moose populations and in support for the determination of AAH. However, a reduction in the number of SRB surveys conducted has compromised the utility of this tool to the point where it is of much lesser value than it could be. More surveys conducted within a well-planned monitoring design are necessary to be able to properly assess future trends in moose populations at a Regional level.

Recommendations for Further Research

Although our analysis to date has been as extensive as possible, we feel there are further analyses that could help substantiate these findings. The tasks we recommend could be continued are as follows:

1. Assessment of population decline
    a. Further indicators to assess could be the number or frequency of population parameter changes regardless of statistical significance;
2. Population demographics model:
    a. Confirm from SRB data, that cows and calves have declined at a faster rate than bulls;
    b. Extend investigation of parameter space around cow and calf morality rates;
    c. Investigate the potential for a contribution to population decline that could have come from decreases in carrying capacity (presumably by increasing accuracy of the habitat model). This could be accomplished by adding a general climate moisture modifier to the forest age criteria used to judge the quality of moose habitat (i.e., as per Dawson and Hoffos);
3. Apparent correlation between CPUE and MPB:
    a. As an alternative to investigating the potential for relationships based on the amount of timber affected by MPB, investigate this potential effect through an expression of the amount of remaining, productive old forest;
    b. Explore if the apparent correlation between CPUE and MPB was experienced in other regions of the province but at different times and independent of LEH regulation changes;
    c. As a component of 3b, meet with biologists in other regions to explore the possibility of, and merits of, a meta-data analysis;
4. Expand and restructure the factor analysis used to help explain the population decline:
    a. Further work to develop data that was previously unavailable (i.e., time-stamped road networks, summer and winter weather);
    b. Further work to compile a RMZ-specific data set for weather parameters;
    c. Further work to develop indices of predator effects;
    d. Use the expertise of regional habitat models (e.g., that of Dawson and Hoffos) to improve accuracy of habitat predictions and the changes that would have occurred during the analysis period;
    e. Reformat the survey questionnaire in a way that can be used to collect data on factor dynamics (spatially and temporally) and send to First Nations as well as a wider group of biologists;
    f. Use the resulting data from expert judgement to explore concordance among RMZ-level factors and competing hypotheses for the population decline;
5. Management recommendations:
    a. Use a conceptual belief network to help articulate the relative importance of factors contributing to population decline
    b. Based on the conceptual model, draw linkages to recommended management actions
6. Outreach support:
    a. Develop a slide deck for presentation to stakeholder groups

   b. Attend meetings as required to deliver results of the analysis and management recommendations

Management Recommendations

Although more work is clearly required to understand potential causes of the declines in moose in the Cariboo region (see below), the findings to date suggest that the following changes may improve management for moose in the Cariboo region and potentially work to reduce or reverse the current decline.

1. Based on current information, increase management effort to reduce mortality on cows and calves by:
   a. reducing vulnerability of cows and calves through strategic reductions in accessibility;
   b. reduce kills of cows and calves by:
      i. encouraging voluntary reduction in FN harvests of cows and calves
      ii. targeted management of wolf populations where cow:calf ratios continue to be low.
2. Establish designed monitoring programs to assess effectiveness of actions.
   a. Implement management actions with a factor-based design (i.e., where contrasts in management actions can be made and responses by moose are measured with known precision).
   b. Implement monitoring of chosen indicators (e.g., could mean negotiating sharing of information among First Nations, hunting stakeholders and Government). This in particular should focus at minimum on gaining new information of the nature of FN harvest of moose including specifications about age and sex of animals taken, wounding losses, and general locations of hunting effort.
   c. Calf recruitment surveys should be conducted and written up with the same sampling and reporting rigor that is given to SRB surveys.
3. Establish research to investigate:
   a. Habitat use by moose in MPB and non-MPB affected areas (controlling for other factors).
   b. Natural mortality rates
   c. Habitat productivity and effect on reproduction
   d. Sources of variability in the BC sightability model as it is applied in the Cariboo Region during SRB surveys.

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APPENDIX A. DESCRIPTION OF DATA SOURCES

Stratified Random Block Surveys

Moose populations in ten (10) of the 16 WMUs in Region 5 have been surveyed one or more times over the time period of this study, using a stratified random-block (SRB) survey design following BC provincial standards (RISC 2002) that have been adapted from Gasaway et al. (1986) and Oswald (1982). The survey method consists of: (1) a stratification survey (usually using fixed-wing aircraft) that stratifies sample units into several habitat categories (termed strata) based on expected moose density as indicated by number of moose and moose tracks observed, followed by (2) low-level helicopter surveys for randomly selected sample units within each strata that record numbers, sex, activity of all observed moose as well as percentage and type of vegetation cover surrounding the moose. Each SRB survey usually occurs over several consecutive days, and generally occur in midwinter (Dec.-January) when moose tend to be in larger congregations and are less mobile.

Factors that can affect the accuracy and precision of the raw SRB surveys are: (1) the experience of observers; (2) weather; and (3) cost constraints. For example, observers need to be trained to observe sex-distinguishing characteristics (such as vulva patches) to enable accurate bull:cow counts. Factors affecting the accuracy of extrapolations from SRB data include: the sightability factor, and the level of precision.

Table A-18. Summary of locations and years surveyed for the SRB moose surveys undertaken in the Cariboo Region from 1994-2012.

GMZ	Area (km^2)	WMUs Surveyed	Survey Name	Survey Years	Mean Area Surveyed (km^2)	% of GMZ surveyed (approx)
East of Fraser River						
5A	10,758	5-15A		2004	3,115	53.2%
		5-15B		2008	845	
		5-15C		2008	801	
		5-15D		2008	958	
5B	16,535	5-01	100 Mile House	1996, 2000	1,968	80.3%
		5-02A	Alkali Lake	1996, 1998, 2001	2,565	
		5-02B	Horsefly River	1994, 1996, 2000, 2006	2,044	
		5-02C	McIntosh Lakes	1994, 1997	960	
		5-02C	Rose Lake	2001, 2011	3,152	
		5-02D	Quesnel River	1994, 1999	2,604	
West of Fraser River						
5C	32,093	5-12	Anahim East	1995, 1997, 2002, 2012	2,160	50.8%
		5-13A	Alexis Creek	1995, 2003	3,861	
		5-13B	Baker Creek	1999	4,560	
		5-13C	Kluskus	1997, 2008	3,256	
		5-14	Mackin Creek	1994, 2001	2,504	
5D	24,543	5-03	Gaspard	1997	1,408	29%
		5-04	Upper Big Creek	1994	400	
		5-04	Big Creek	1995, 1998,	4,324	

GMZ	Area (km^2)	WMUs Surveyed	Survey Name	Survey Years	Mean Area Surveyed (km^2)	% of GMZ surveyed (approx)
		5-06	Anahim West	2005, 2012 1995	960	
5E	32,609	5-11	Tweedsmuir	1995	1,273	3.9%

Composition Surveys

Table A-19. Location and years for the moose composition surveys undertaken in the Cariboo Region (1998-2007).

GMZ	WMUs Surveyed	Survey Name	Survey Years
5A	5-15A	Crooked Lake	2001, 2003
	5-15B	Niagara River	2001, 2003, 2007
	5-15C	Cariboo River	2001, 2003
	5-15 B&C	Cariboo River	1997, 2000
5B	5-01	100 Mile House	2007
	5-02A	Alkali Lake	1997, 2007
	5-02B	Horsefly River	1998, 2007
	5-02C	Rose Lake	1998
	5-02D	Quesnel River	1998, 2007
5C	5-14	Mackin Creek	2007
5D	5-03	Gaspard	2007
5E	Not recorded	Coastal	2001

APPENDIX B. DESCRIPTION OF THE MOOSE DEMOGRAPHY MODEL

Introduction

The primary objective for management of moose populations in British Columbia is to maintain sustainable moose populations that meet the needs of First Nations (FNs), licenced hunters and the guiding industry. In the Cariboo region, as elsewhere, moose populations are periodically assessed using Stratified Random Block [SRB] surveys supplemented with compositional surveys to estimate population status by GMZ (Lirette 2011). Harvest data from the annual LEH hunter questionnaire is compiled and analyzed to corroborate the population trends and estimates calculated from the survey data. The population metrics derived from these multiple sources (densities from SRB surveys, bull:cow ratios and calf:cow ratios from both SRB and composition surveys, hunter kills per unit effort from hunter returns) are combined and used to estimate the annual allowable harvest rate (AAH) using the Big Game Harvest Management and Moose Harvest Management Procedures (4-7-01.07.1 and 4-7-01.07.03 respectively (Lirette 2011). As part of this process, the risks of not achieving population objectives are typically assessed using short-term population projections using models derived from White and Lubow (2002) or other frameworks.

Empirical data for management of moose populations is usually limited, and consequently harvest quotas are often set with incomplete information. Although there are a wide range of techniques for estimating wildlife population status from sex ratios, calf:cow ratios, etc., all require an independent estimate of population abundance to be valid and/or independent estimates of age-specific survivorship to be helpful (Cooper et al. 2002). Population modeling accounting for such factors is one important tool for managing ungulate populations in the face of these uncertainties, and for assessing the effects of uncertainties in limiting factors on population trends.

For our purpose of assessing the relative roles of different factors on the demographic processes of recruitment, and survival of moose, we chose to implement a recently described moose population dynamics model whose results could be used to compare observed patterns in the key metrics used to assess the status of moose populations in the different GMZs (bull:cow ratios, calf:cow ratios, density) with projected patterns obtained from the model under different mortality assumptions. The modeling approach is conceptually similar to the structure of the White and Lubow (2002) model, although there is some additional structure in the models that can allow for such analyzes as evaluating optimal harvest quota levels. We did not use the models for this purpose in our study.

Model Overview

Ungulate population dynamics are generally influenced by the combined effects of density dependence, harvesting, predation, and stochastic variation in environmental factors (Xu and Boyce 2010 and references cited therein). Density dependence operates by limiting survival and reproduction inversely with population density (Eberhardt 2002). The effects of density-dependence and environmental variation often co-occur in ungulate populations, such that the impacts on population growth of environmental factors (severe winters, excessively hot summers, winter ticks, diseases), typically increases with population density (Milner et al. 1987; Samuel 2007). Predation can be an important limiting factor in ungulates (Van Ballenberghe 1987). Research on moose-predator systems involving wolves, grizzly and black bears in North America suggest that predators are a major source of calf mortality in many moose populations, removing 3-55% or more calves annually (Ballard and Van Ballenberghe 1998), and 4-14% of adults (Boutin 1992). Moose populations are also harvested for meat, antlers, hides and trophies. Excessive exploitation of moose populations, especially when combined with significant uncertainty associated with predation and environmental variation can lead to increased risk of substantial reductions in local populations (Xu and Boyce 2010).

Moose populations are typically described and monitored by sex and developmental stage classes, with calves and adult males and females 1+years typically monitored in composition and SRB surveys. Harvesting selectivity is usually age- and sex-specific as well. Therefore, modelling of moose populations for assessing factors affecting population growth is best done when stage- and sex-specific vital rates are included. However, this approach can also lead to a large number of unknown parameters for any given moose population (Xu and Boyce 2010).

Here, we implemented a stage- and sex- specific moose demography model based on a model for harvest management for moose originally developed by Xu and Boyce (2010) and used to evaluate both moose harvesting and monitoring strategies Boyce et al. (2012). The key components of the model are: 1) a simple stage and sex structure that uses data available from monitoring and harvest returns (i.e. calves and 1+ year old males and females); 2) stage-structured density dependence; and 3) estimates of range carrying capacity; and 4) populations are initiated from density and herd composition estimates obtained from surveys, along with mortality patterns estimated from typical hunting mortality data. With the model, we tested different potential patterns of mortality on moose using simple assumptions of estimated density-dependent reproduction and compared results against empirically estimated densities, bull:cow and calf:cow ratios. We caution that the model results are intended as tests of hypotheses and not as predictions of past or future moose population dynamics.

Model Components

Moose in British Columbia breed in the late-September and early October rut season, with calves born approximately 8.5 months later in June. The heaviest mortality period for calves is the first two months after birth, and calves must survive both summer and autumn to be included in winter surveys (usually January-March depending on snow conditions). Licenced harvesting begins in late September, continuing through November, while harvesting by First Nations harvest can occur throughout the year.

Moose were classed in 3 classes (or stages): 1) young/calves of both sexes; 2) females/cows (including female yearlings and adults) and 3) males/bulls (including male yearlings and adults. These 3 classes were represented in a stage-based transition matrix A_t used to update the model population size from N_t to N_{t+1} (Xu and Boyce 2010). That is, both male and female calves were tracked as a pooled calf stage, and then the transition matrix was structured to differentially recruited them into the adult male and female stages in different rows of the transition matrix.

The basic model equations used to represent moose population dynamics are given in Xu and Boyce (2010: see equations 2-8 and S5-S10) and are summarized below. The equations used to represent reproduction and stage-dependent mortality assume that the early to mid-winter survey period represents the change from *t* to *t+1* and are:

$$R_t = \propto_0 exp\left(p\left[1-\left(\frac{N_t}{K}\right)^{\gamma_0}\right]\right) \quad (1)$$

(see Xu and Boyce 2010 where R_t is the density-dependent recruitment rate at time *t*. R^* = α_o *exp*(*p*) is the maximum expected recruitment at low population density. N_t is the population size at time *t*, *K* is the habitat carrying capacity, γ_i is the density-dependent exponent in recruitment and survival for male and female calves, and α_i is a coefficient representing the relative abundance of the 3 population stages at carrying capacity. Survival rates of female calves and male calves at low population density $S_{i,t}$ is estimated with:

$$S_{i,t} = \frac{s_i}{exp\left(\alpha_i\left(\frac{N_t}{K}\right)^{\gamma_i}\right)} \quad (2)$$

The transition model with stage-specific harvests is given by:

$$\begin{pmatrix} n_{y,t+1} \\ n_{f,t+1} \\ n_{m,t+1} \end{pmatrix} = \begin{pmatrix} 0 & R_t & 0 \\ \delta S_{CF,t} & S_F & 0 \\ (1-\delta)S_{CM,t} & 0 & S_M \end{pmatrix} \begin{pmatrix} n_{y,t} \\ n_{f,t} \\ n_{m,t} \end{pmatrix} - \begin{pmatrix} H_{y,t} \\ H_{f,t} \\ H_{m,t} \end{pmatrix} \quad (3)$$

where δ is the proportion of females among calves at recruitment, $S_{CF,t}$ and $S_{CM,t}$ are density-dependent survival rates for female and male calves-to-yearlings respectively at time *t* and $S_{F,t}$ and $S_{M,t}$ are survival rates for adult females and males respectively. These survival rates are assumed to be density-independent. $H_{y,t}, H_{F,t}$ and $H_{M,t}$ represent harvest mortality of calves (sexes combined), females, and bulls respectively. Note that the effects of natural mortality (including effects of predators and other unknown mortality) on each stage is treated in the survival terms, and separated from the regulated and non-regulated hunting mortalities. For the purposes of this study, assumed FN harvests by class are represented separately from the regulated hunting kills and are not assumed to be included in natural mortality in contrast to Xu and Boyce (2010), and Boyce et al. (2012).

The model as described above is deterministic. The structure of the model is easily extended to be stochastic. The model was implemented in R.

Parameter Estimates

Population parameters for the model that can be estimated from results of SRB and composition surveys in the Cariboo region are total abundance, sex ratios of bulls and cows, and relative proportions of calves to cows. For each GMZ, we used observed ratios for the specified year (if available) or estimates derived from the smoothed fits to the data if not) to apportion abundance (N_0) into the three stages for the initial model year 0. Although very limited data exists to estimate carrying capacities of each GMZ (see Hatter 2004), we made the assumption that carrying capacity was likely to be related to area of winter habitat capability (see also Lirette 2011, see below). While a maximum density of 1.5 moose km^2 (Hatter 1998) is possible, actual carrying capacities in the Region are likely considerably lower than this. This maximum density is slightly higher than the maximum density observed in the 1994-2012 time series of densities in the Region available to us (1.43 moose/km^2), and thus is consistent with the assumptions described in Boyce et al (2012). Parameters representing regulated hunting mortalities are directly estimated from the hunting data (see main text). We included a 15-20% % wounding loss in estimated mortalities resulting from regulated hunting, consistent with the government estimates of this loss rate. Consistent with our interpretation of the assumptions of government models, a wounding loss rate was not applied to FN hunting.

Other parameters needed for the model (e.g., recruitment coefficient, number of females and males per calf at carrying capacity, and coefficients regulating relative abundance of different stages at carrying capacity, density dependence exponents) are less easily derived from available data, because they either require an analysis of model stationarity at carrying capacity and/or estimates from specific field studies. Both of these sources of data were well beyond the scope of this study. Therefore, we used an average of the WMA-specific estimates given in Table 1 in Xu and Boyce (2010) for these parameters, recognizing that this approach introduces uncertainty into the modelling and is a known limitation. Thus, the results of the modeling to date must be treated with caution and cannot be used either to predict future population sizes in the Cariboo region or estimate optimal harvests until site-specific carrying capacity and stationarity parameters can be estimated.

Estimated Carrying Capacities

Bergerud (1992:1011) indicated that *K* for moose in food-limited systems is 1500 moose/1000 km^2 (or 1.5 moose/km^2) or greater. In systems where moose are the principal prey of wolves, K is much lower - about 300 moose/1000 km^2 (0.3 moose/km^2) and may be even lower in some systems. Currently, the only currently published estimate for carrying capacity *K* for moose in the Region 5 GMZs is 0.42 moose/km^2 (Lirette 2011). Government currently works with no estimates of K in the Cariboo Region (M. Ramsay *pers comm*. Feb 22, 2013). For this analysis, we assumed:

1. that 1.5 moose/km^2 (a provincial estimate) is a reasonable surrogate value for habitat-limited (i.e. food-limited) *K* under good conditions in the Cariboo region.
2. that winter is the food-limiting season, as is suggested by Lirette (2011).
3. that good conditions are represented by a WHR rating = 1 (highest) under the WHR standards, and poor conditions by WHR rating = (lowest). Because WHR ratinga are categorical and relative (WHR Standards) assume that 1.5/6 = 0.25 is a reasonable bin size for each rating class. Thus the midpoint value of moose density for WHR class 6 (low) = 0.125 moose/km^2, and for WHR class 1 (highest) = 1.375 moose/km^2.
4. use the area-weighted average LIWCAPWT (Winter Capability Weighted Average interpretation) values for each GMZ to estimate food-limited K for moose by interpolation.
5. That for GMZ5b, this estimated value should be at least equal to or larger than the estimate by Lirette (2011). While Lirette did not describe the basis for his estimate, it may be based on a combination of food and predator limited arguments.

Table A-20. Area-weighted mean LIWCAPWT values for each GMZ, together with CV%, and converted to a proportion of the maximum moose density/km2 estimate of K.

GMZ	Mean LIWCAPWT (CV%)	Estimated K (moose/km^2)	Range of K	Independent estimate of K (e.g., Lirette 2011)	Max value of moose/km^2 obs'd since 1994[1]
GMZ5A	3.83 (32.7%)	0.65	0.44-0.86		(insufficient data)
GMZ5B	2.92 (63.4%)	0.89	0.33-1.46	0.42	1.3
GMZ5C	3.63 (55.5%)	0.68	0.30-1.06		0.6
GMZ5D	3.39 (63.7%)	0.72	0.26-1.36		0.65

[1] Data prior to 1994 was not examined.

We checked that the estimated value is within the error range for any observed estimates of the high density observed in each GMZ in the last few decades. The resulting *K* estimates are: (1) generally above the 0.4 sustained density level assumed in their management, and are (2) generally above current density estimates.

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APPENDIX C. DESCRIPTION OF SPATIAL DATA

As part of our assessment of spatial factors that may be related to trends in moose population numbers in the Cariboo region we. applied a winter moose model to identify areas of high-quality moose habitat across the study area. The moose model was an adaptation of one used in several provincially sponsored moose surveys in British Columbia such as those performed by Walker et al. (2006) and McNay et al. (2013 in prep.). In order to gauge recent changes in moose habitat availability we applied the model three times using landscape conditions at the end of each of the focus periods of our analysis of the spatial data (years 1999, 2005, and 2012).

Data Preparation

Several data sources were used to prepare all of the spatial and tabular inputs required to obtain the spatial data inputs for the analyses of moose habitat conditions.

Digital Elevation Model (DEM)

We used a 25m DEM to prepare three datasets:

- A binary raster distinguishing all cells above 1200m a.s.l. from areas below 1200m a.s.l.
- A binary raster distinguishing all cells with a slope gradient <5% from areas with a higher gradient.
- A raster that depicts 'warm slopes'. Warm slopes were identified using the Area Solar Radiation Tool in the ArcGIS (ESRI, 2010) Spatial Analyst extension. Those areas with a global winter solar radiation input greater than 91,593Wh/m^2 were considered to be 'warm'. The threshold of 91,593Wh/m^2 was chosen as it represents a previously determined threshold for broadly identifying warm slopes in central British Columbia as used by McNay and Sutherland (2009).The solar radiation input was calculated using the procedures described in Appendix XXD.

Freshwater Atlas (FWA)

We used the British Columbia FWA[21] to generate three simple spatial inputs related to the moose model:

- Wetlands
- Lakes
- 250m buffer of all streams that are 5th order or greater

Vegetation Resource Inventory (VRI)

In contrast to the previously described datasets which we considered static through time, VRI changes considerably over the timeframe covered in this project. As a result we prepared separate VRI datasets for 1999, 2005, and 2012 to address the changes that were occurring to forest cover on the landscape.

[21] http://geobc.gov.bc.ca/freshwater_atlas.html

The 2013 and 2005 VRI data were straightforward to prepare as they were spatially-complete with no missing data. We clipped the provincial VRI datasets to the extent of the study area. In the case of the 2013 VRI we also applied a proprietary form in MS Access (Microsoft, 2010) to generate Non-productive site codes because that attribute is no longer maintained in VRI but is still used by the moose model.

The 1999 VRI dataset required more work to produce. The earliest VRI dataset that was available for our use dated to 2002 and it contained several mapsheets worth of missing information that needed to be filled in. We first set about filling in the missing information with data from the 2005 VRI as it was the most temporally close VRI to 2002 that was not missing this information. We recalculated stand ages for these missing areas to their 2002 values and added them to the 2002 VRI. Stand ages were then recalculated for the whole study area back to 1999 values.

While this gave us a complete spatial coverage for 1999, some processing of the attributes was still required to account for polygons that had been harvested between 2000 and 2005 but would still be standing in 1999. Because the precise age of the stand has no effect beyond 40 years in the moose model, stand ages for these cut blocks were set uniformly to 100 years as it is safe to assume that any commercially-viable stand in this region would be at least this old and certainly beyond 40 years of age.

Tree species information for the cutblocks also needed to be filled in. Since this information was no longer available we substituted a likely candidate for a lead species in each cutblock with a locally dominant species. The locally dominant species was determined by converting the VRI to a 100m raster and determining the most frequently occurring species within a 500m radius of each cell. The locally dominant species map resulting from this process was then clipped to the extent of the cutblocks and the species information was assigned to the cutblocks via a spatial intersection.

By following these procedures we were able to generate complete VRI datasets for each of the three years being focused on in this project. The only areas we were unable to account for were those within Tree Farm License boundaries as public VRI information is not collected in these areas and was thus impossible for us to include in our analysis.

Moose Model Application

The moose application required that we perform a spatial union of all of the inputs described above and execute a series of queries to identify moose habitat. Moose habitat was identified in three strata labeled as S1 (high quality), S2 (moderate quality), and S3 (nil to low quality). The criteria for defining the strata are given below:

- Stratum 1 is any area that is:
    - <1200m a.s.l. with a stand age of 5 – 40 years
    - <1200m a.s.l. and shrub dominated (i.e. Non-productive code = M, OR, NPBR; or Non-forest descriptor = NCBR or NSR)
    - <1200m a.s.l. and has a deciduous leading stand of any age on an identified ‘warm slope’
    - <1200m a.s.l. and is within 250m of a 5^{th} order or greater stream with a gradient of <5%

    - <1200m a.s.l. as is a wetland identified in the freshwater atlas
    - not a lake
- Stratum 2 is any area that is <1200m a.sl. and is forested with an age <5 years or >40 years and not already assigned to stratum 1
- Stratum 3 is any remaining area not assigned to strata 1 or 2

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APPENDIX D. SOLAR RADIATION RASTER CREATION

(Note: italics indicate filenames)

This input raster to the Multi-Species HSM depicts winter global solar radiation input.

1. Launch ArcMap and load in a 25m DEM of your buffered study area. A minimum buffer of 5000m is preferred. If your buffered study area has a large north-south extent (>20-30km) you will want to split it into overlapping latitudinal bands to improve the accuracy of results since the 'Area Solar Radiation' tool we will be using only calculates the latitude value for the centroid of the grid rather than for each row of cells. Past experience has yielded good results using bands with a 30km north-south extent including a 5km buffer on both the north and south extents (i.e. a 20km band with a 5km buffer). The 5km buffers should overlap into the non-buffered portions of the adjacent subset. You will also want to create a seamless set of grids that represent the unbuffered subsets for use later in this procedure. The subsets can be generated efficiently using the 'Fishnet' tool. From there the buffered DEMS can be created by using the following tools in the *xSpurOfTheMomentTools.tbx* in the following order:
    1. 111117 1 - Split features into separate shapefiles
    2. 111117 2 - Buffer Subset Shapefiles by 5km
    3. 111117 3 - Large Areas Clip DEM to Subset Shapefiles (2)
2. For each subset, apply the 'Area Solar Radiation' tool in Spatial Analyst with the following parameters:
    a. Input raster = your DEM or latitude-based subset
    b. Output = *srwraw_<subset_name>*
    c. Start Day = 32 (February 1)
    d. End Day = 90 (March 31 (non-leap year)
    e. Leave all other parameters at their defaults
    f. Run the tool.
3. If you have no latitude-based subsets, skip to the last step. Otherwise load all of your subset *srw_raw* rasters into ArcMap and clip them to match the extent of your unbuffered subset rasters. Take care to ensure that the resulting rasters are aligned and have no gaps between them.
4. Create a seamless mosaic using the 'Mosaic to New Raster' tool with the following parameters:
    a. Input rasters: all clipped subset solar radiation rasters
    b. Output location: place output in your project's default file geodatabase
    c. Raster Dataset Name with Extension: srw_rawall
    d. Spatial Reference: determined by your project requirements
    e. Pixel Type: 32-bit unsigned
    f. Cellsize: 25m
    g. Number of Bands: 1
    h. Mosaic Operator: MEAN
    i. Mosaic Colourmap Mode: MATCH

5. In the event that some small gaps do exist between the unbuffered subset rasters (i.e. no bigger than 1 cell-width), create a raster of average values in the *srw_rawall* raster using the Focal Statistics tool with a 3x3 rectangular neighbourhood. Save the output as *srw_rawavg*.

6. Use *srw_rawavg* to fill in any potential gaps in the *srw_rawall* raster with the following expression in the Raster Calculator to create a raster called *srw_rawfinal*:

   Con(IsNull("srw_rawall"), "srw_rawavg", "srw_rawall")
7. Reclassify *srw_rawfinal* such that the resulting raster is composed of the following classes and save the ouput raster as *srw25*.

***srs_rawfinal* Values**	***srs25* Raster Values**
>131,435 Wh/m^2	0
108,416 – 131,435	1
91593 – 108,415	2
74,771 – 91,592	3
53,520 – 74,770	4
36,001 – 53,520	5
0 – 36,000	6

8. Resample *srw25* to a 100m raster using the *buf_msk* raster to define the analysis mask, extent, and cell size. Save the resulting raster as *srw*.

APPENDIX E. INTERPRETATION OF RESULTS FROM RPART

Why Use Recursive Partitioning?

Recursive Paritioning (or r*part*) is a statistical modelling technique based on the concepts and procedures of classification and regression trees (Breiman et al. 1984). Recursive partitioning (or classification and regression tree-building) can be helpful in analysis of ecological problems where one is searching for ways to find parsimonious and explanatory associations among many variables. Ecological datasets are often complex, unbalanced, and may contain missing values. Furthermore, ecological data may be strongly non-linear, and may contain unknown interactions. Tree models can complement or represent an alternative to analysis of ecological data by more traditional techniques such as multiple regression, logistic regression, log-linear models etc. (De'ath and Fabricus 2000). For such data, one or more assumptions of traditional technques are usually violated. Robust and flexible analytical methods are required to reveal structure in the data, if any exists. In addition, the methods should also be intuitive to understand and the results be interpretable in terms of ecological processes. Tree models and extensions to them (e.g., Random Forest models) are frequently used in analyses of large (ensemble) datasets, such as climate variable data (see Wang et al. 2012 for a recent example from British Columbia).

How Recursive Partitioning Works

Recursive trees explain the variation in values of a single response variable in relationship to one or more explanatory variables. Tree-building may be thought of as a method of variable selection (Venables and Ripley 1994). The recursive partitioning method constructs a branching tree model of the data by repeatedly splitting the data into ever-smaller subsets of more homogeneous variable values, using a simple rule based on the most important explanatory variable in distinguishing the particular subsets at hand. Note that transformations of the data are not needed by recursive tree-model-fitting. The data is split, and split again, until there is little remaining variance than can be explained by any further splits. At each split the data is partitioned into two mutually homogenous groups each of which is homogenous as possible with respect to the response variable, given the associated explanatory variables. Trees that try to explain variation in categorical response variables use a classification approach, while trees that try to explain variation in numerical response variables (as was done in this study.) use a regression approach. In both cases, the model can be used as a prediction model to predict future values of the response variable, given additional datasets, or additional explanatory variables collected on the basis of the tree model's structure.

Left to itself, the tree-building procedure will continue as long as there is further variations to be explained by splitting subsets. As this usually results in "over-fitting the data", the procedure is usually constrained to stop when the rate of variation being explained by additional splits is smaller than a threshold value. Over-fit tress can also be "pruned" back to result in simpler models taking into account the number of explanatory variables and the variation explained by each one. The analysis objective is to partition the response variable into homogenous groups, while also keeping the tree model reasonably small revealing the most statistically informative factor-response relationships in the data. This is analogous to the procedure of assessing the change in AIC by adding additional terms to a statistical model fit to data when applying model selection methods (e.g., Burnham and Anderson 2002).

The model-fitting procedure operates by undertaking random partitions of each remaining subset in relation to the explanatory variables until the best-fitting a split can be found, or the constraints on making further splits cannot be overcome. Thus any given explanatory variable may be found to contribute to identifying splits in a number of subsets, even if it isn't always the "best-fitting" variable. The importance number indicates the number of times the factor was included in the model-fitting procedure, and is an indicator of its potential influence on the structure of the data, although it is not possible to further evaluate why and how they are important, unless they appear in the tree itself. Typically, factors with high importance numbers are represented as splitting variables in the tree, but if a factor is correlated with other factors, it may not appear in the tree but still have high importance value. This is an indicator of high-order interactions and/or correlated relationships in the dataset.

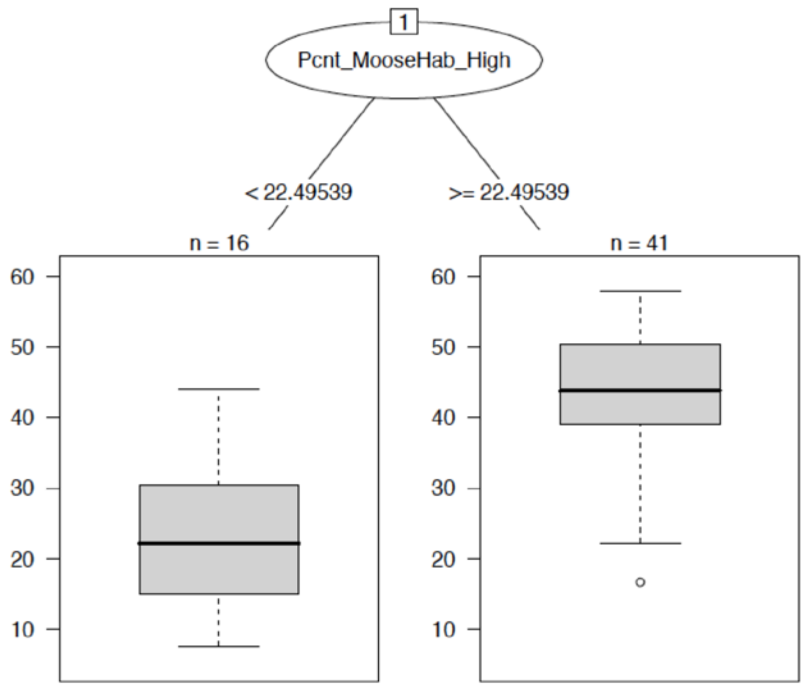
How to Read a Tree Model

The "tree" that results from a recursive partitioning analysis is a node and branch model of the structure in the relationship between explanatory variables and the response variable (see the figure in Example 1 below; also see Figures 23-28 in main report). Tree models are typically presented graphically, with nodes (groups of values) presented as either ovals or as intersections depending on the plotting program used, and branches as lines connecting nodes.. The root node (representing the original dataset) is at the top, and each partitioned subset is below the node above it, connected by a branch. At the bottom of the tree are the final subsets of the data. Within each node is listed the explanatory factor (as text) with the greatest ability to determine the split[22]. The threshold value of that factor in determining the split associated with the node below each branch is given as text overlaid on the branch line. The threshold values of each factor as given in the split can be evaluated in terms of its ecological interpretation. Splits are usually arranged so that nodes on the left have smaller values of the response variable than do nodes on the right. The number (sample size) and distribution of response variables in the final splits is shown below each terminal node. The distribution is shown with a median line (in black) and 50% quartiles (dark gray boxes), the 95% quartiles as whiskers (where shown) and outliers (where present) as open circles. The number of observations in each final split is shown. Associated with each tree model is the amount of variation explained by the model. If the fitted model is to be used for prediction rather than exploration and interpretation[23], then additional information about the goodness-of-fit and probabilities of observing values of the response variables given the explanatory variables can be extracted from the model.

Example 1. The very simple 1-split tree figure below is the "pruned" tree model given in the right panel of Figure 24. The response variable is calf:cow ratios. It illustrates the components of tree-model diagrams as described above. In this model, interpretation is

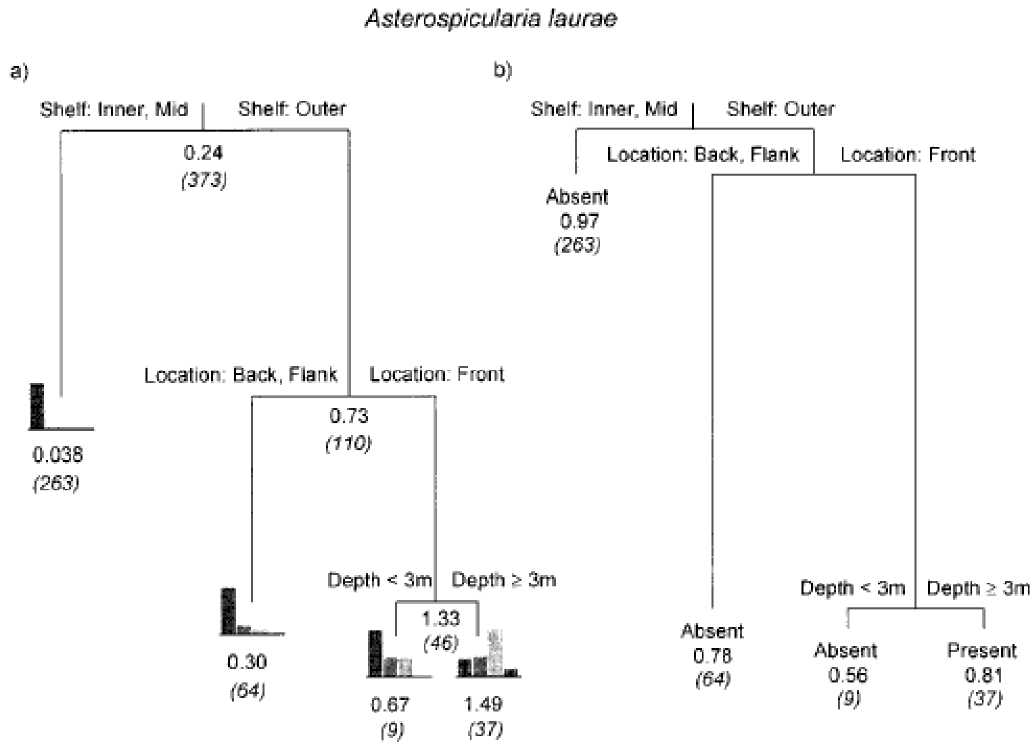
[22] The number given in the node enclosed by the square box is a node index number and has no meaningful interpretation in terms of the model.
[23] Model-fitting using recursive partitioning trees in this study was intended only for exploration and interpretation, not for prediction.

very simple: high calf:cow ratios in surveys are more likely to be found in areas where the percentage of suitable moose habitat can be classed as high value.exceeds 22.5%. The actual threshold value may or may not have general ecological importance, and is best interpreted cautiously until additional studies are done.



Example 2. This is a published example of a tree-model fit to distribution and presence/absence data for an uncommon soft coral species (De'ath and Fabricus 2000). The explanatory variables used in the model are cross-shelf position, location and depth on a coral reef (see De'ath and Fabricus 2000 for more details on their study and the ecological of the study species). Note that the plotting method they used is an older one than those now available, so the form of the tree appears somewhat differently than in Example 1.

The authors interpret this model as suggesting that the coral species is least abundant (left nodes) on inner and mid-reef shelves and most abundant on front shelves on outer reefs at depths ≥ 3 m. Identification of restrictions in environmental conditions related to high abundance in corals was one objective of the tree model approach. From this model, the authors formulated some additional hypotheses about how different physical variables not measured in this study could act as determinant of coral distribution.



(Source for the above figure : De'ath and Fabricus 2000).

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