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The effectiveness of decommissioning roadside mineral licks on reducing moose (*Alces alces*) activity near highways: implications for moose–vehicle collisions

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Abstract: Roadside mineral licks form when road salt used to de-ice highways in winter runs off road surfaces and accumulates in roadside ditches. Some ungulates are attracted to these roadside licks as they seek to satisfy their mineral requirements. Within the distribution of moose (*Alces alces* (Linnaeus, 1758)) in North America, motorists often encounter moose visiting roadside licks in mid-summer, with many jurisdictions reporting summer peaks in moose–vehicle collisions (MVCs) at these locations. We used camera traps to monitor the moose visitation of 22 roadside locations (including roadside licks, roadside ponds, and dry roadsides) in central British Columbia, Canada, from December 2009 to July 2020. We tested the efficacy of treatment (decommissioning) methods used to reduce moose visitation to roadside licks and roughly estimated decommissioning costs. Moose visitation to roadside licks was greatest from May to July. As we hypothesized, untreated licks were visited more often by moose than decommissioned licks, roadside ponds (absence of road salt), and dry roadsides. Decommissioning roadside licks by replacing or mixing lick waters and soils with materials, such as riprap, cedar mulch, pine logs, or dog (*Canis lupus familiaris* Linnaeus, 1758) fur and human (*Homo sapiens* Linnaeus, 1758) hair, is an effective and inexpensive means of reducing moose visitations to roadside areas and should increase motorist safety where roadside licks are visited by moose.

Key words: *Alces alces*, automobile, camera trap, collision, highway safety, mineral lick, moose, roadside, vehicle, wildlife.

Résumé : Les accumulations de minéraux à lécher en bordure de route se forment quand du sel de voirie utilisé pour le déglaçage des routes en hiver s'écoule de la chaussée et s'accumule dans les fossés. Certains ongulés sont attirés vers ces dépôts pour y obtenir les minéraux dont ils ont besoin. Dans l'aire de répartition de l'orignal (*Alces alces* (Linnaeus, 1758)) en Amérique du Nord, des automobilistes rencontrent souvent des orignaux fréquentant des accumulations de minéraux en bordure de route au milieu de l'été, des pointes estivales de collisions orignal–véhicule (COV) dans ces sites étant signalées dans de nombreuses régions. Nous avons utilisé des pièges photographiques pour surveiller les visites d'orignaux dans 22 sites en bordure de route (dont des accumulations de minéraux, des étangs et des bordures sèches) dans le centre de la Colombie-Britannique (Canada), de décembre 2009 à juillet 2020, vérifié l'efficacité de méthodes de traitement (mise hors service) employées pour réduire les visites d'orignaux aux accumulations de minéraux en bordure de route et estimé le coût approximatif de la mise hors service. C'est de mai à juillet que les visites d'orignaux à des accumulations de minéraux étaient les plus nombreuses. Comme nous l'avions postulé, des orignaux visitaient les accumulations non traitées plus souvent que les accumulations traitées, les étangs en bordure de route (exempts de sel de voirie) et les bordures sèches. La mise hors service de ces accumulations en remplaçant les eaux et les sols par différents matériaux, comme de l'enrochement, du paillis de cèdre, des bûches de conifère, du poil de chien (*Canis lupus familiaris* Linnaeus, 1758) ou des cheveux d'humains (*Homo sapiens* Linnaeus, 1758), ou en les mélangeant à ces matériaux, constitue un moyen efficace et peu coûteux pour réduire le nombre de visites d'orignaux aux bordures de route et devrait accroître la sécurité des automobilistes là où des orignaux visitent des accumulations de minéraux en bordure de route. [Traduit par la Rédaction]

Mots-clés : *Alces alces*, automobile, piège photographique, collision, sécurité routière, minéraux à lécher, orignal, bordure de route, véhicule, espèces sauvages.

Introduction

The use of roadside habitats by wildlife is a global concern for conservation biologists and road safety planners (Groot-Bruinderink and Hazebroek 1996; Rea 2003), because the presence of wildlife in road corridors leads to an increased risk of wildlife–vehicle collisions (WVCs), thus endangering both wildlife and people. In the United States (US) every year, there are between one and two million large animal – vehicle collisions, resulting in over 26 000 human injuries and an estimated 200 human fatalities (Huijser et al. 2008). WVCs also incur significant economic costs. For ungulates in North America, the costs associated with WVCs

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Fig. 1. Camera trap image of a moose (*Alces alces*) using a roadside mineral lick in central British Columbia. Colour version online.

are estimated to be between \$6.2–\$12.8 trillion USD/year (L-P Tardif and Associates Inc. 2003; Huijser et al. 2009). Furthermore, the number of WVCs is increasing in Canada (Vanlaar et al. 2012), and a recent meta-analysis suggests that vehicle-caused mortality of terrestrial wildlife in North America has increased fourfold since 1965 (Hill et al. 2020).

Frequently, animals are killed when attempting to cross roads to access resources, such as food, water, or mates (Coffin 2007). The fencing of roads and the construction of wildlife underpasses or overpasses are effective methods of reducing WVCs but are costly (Clevenger et al. 2001; Sawyer et al. 2012; Gagnon et al. 2015). Where habitat elements used by animals are in close proximity to transportation corridors, they can, at times, be managed to reduce interactions between wildlife and motorists. The number of road-killed butterflies was reduced after the roadside habitat was restored to native prairie vegetation in Iowa, US (Ries et al. 2001). Additionally, multiple US states have used habitat alteration to reduce deer–vehicle collisions, but have often neglected to monitor the effectiveness of these alterations, thereby leading to inconclusive results (Romin and Bissonette 1996).

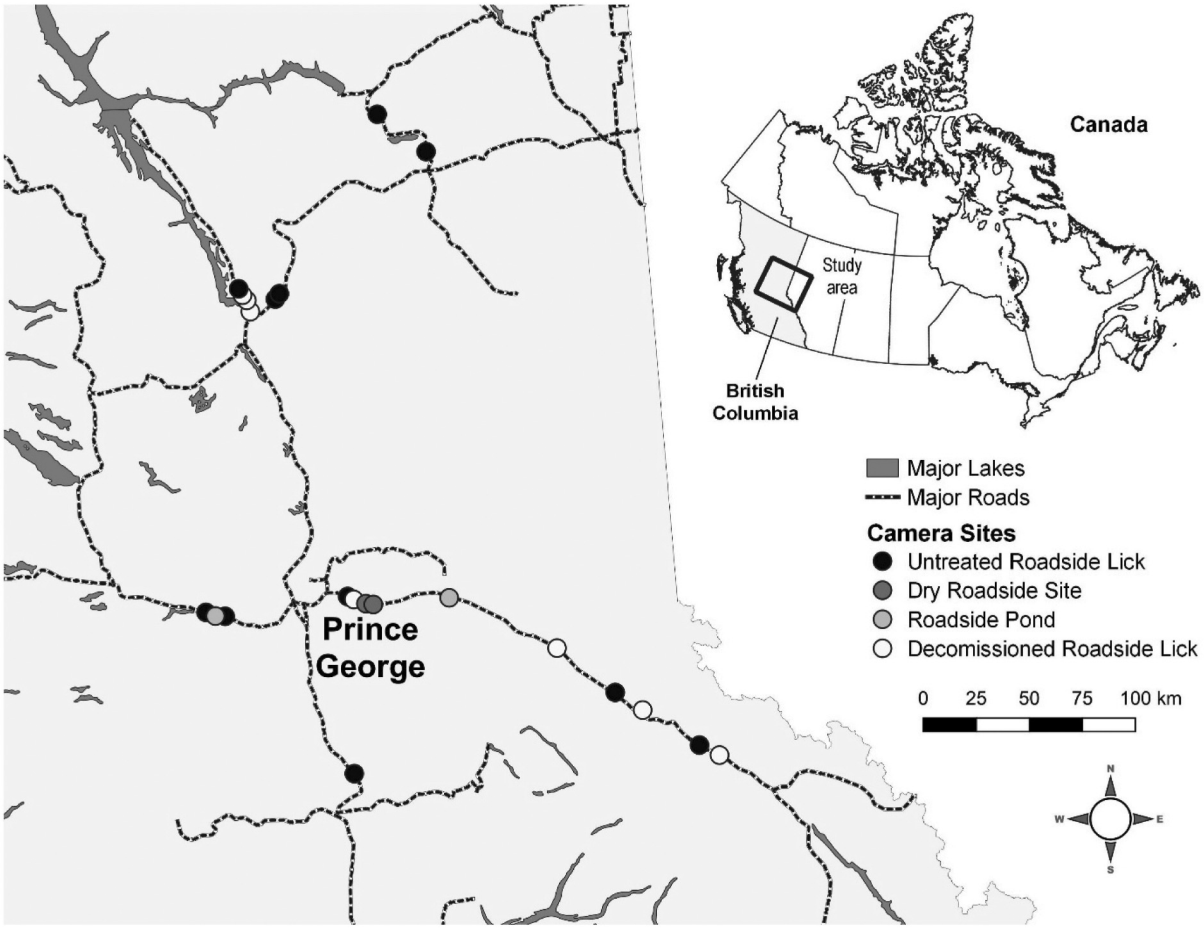
In North America, roadside mineral licks are known to attract moose to transportation corridors (Fig. 1) and increase the probability of moose–vehicle collisions (MVCs) (Dussault et al. 2006). Within transportation corridors, roadside licks can occur naturally. However, they can also be created when winter applications of road salt (commonly formulations of rock salt (NaCl) or occasionally $CaCl_2$ or $MgCl_2$) are washed off the road surface into roadside ditches during springtime runoff, where mineral-rich water accumulates into small water bodies or salt pools (Fraser and Thomas 1982; Grosman et al. 2011) and mixes with roadside soils.

Moose appear to use mineral licks, both near and away from roads, to obtain sodium and other minerals (e.g., iron, calcium, magnesium, sulfates, and carbonates; Ayotte et al. 2006; Leblond et al. 2007). These elements are essential for physiological processes related to muscle and neuron function, pregnancy, lactation, moulting, and antler growth, and to help stabilize rumen function (e.g., pH, microbial community) (Tankersley and Gasaway 1983; Robbins 2001; Ayotte et al. 2006, 2008; Kaspari 2020). Clay soil suspensions also appear to be important in the use of natural licks by moose, but the specific role of these suspensions requires further investigation (Ayotte et al. 2006). The use of natural or roadside licks by moose, however, might simply be a result of water availability and potentially be increased through an attraction to conspecifics (Fraser and Hristienko 1981; Jones and Hanson 1985; Risenhoover and Peterson 1986; Couturier and Barrette 1988; Heimer 1988).

Dussault et al. (2006) suggested that the probability of a vehicle colliding with a moose in Quebec increased by 80% near roadside licks. As a result, road safety managers have attempted to make roadside licks less attractive to moose by placing obstacles such as pallets and boulders on or near licks (Bostwick and DeStefano 2016; Hulsey et al. 2016). Leblond et al. (2007) studied the effects of draining and backfilling licks with rocks on moose visitation to roadside licks. The decommissioning of roadside licks was effective in the short term at reducing the number of moose visits to roadside areas, presumably decreasing the likelihood of MVCs (Leblond et al. 2007). Modelling efforts similarly concluded that removal of roadside licks was the most effective means of decreasing both road crossings by moose near licks and subsequent MVCs (Grosman et al. 2009, 2011).

In British Columbia (BC), Canada, >600 MVCs occur each year (O'Keefe and Rea 2012). Most MVCs in BC occur in December and January (Sielecki 2010; O'Keefe and Rea 2012), but a second, smaller peak is present in summer (Sielecki 2010), which corresponds to the seasonal peak use of licks by moose, although moose do visit licks at roadsides and elsewhere throughout the year

Fig. 2. Locations of untreated and decommissioned roadside mineral licks (n = 18), roadside ponds (n = 2), and dry roadside sites (n = 2) monitored via camera traps for moose (*Alces alces*) visitation in central British Columbia, Canada, from December 2009 to July 2020. Main map is NAD 83/BC Albers (EPSG 3005). Canada map is NAD 83/Canada Lambert Conformal Conic (ESRI 102002). Statistics Canada (2016) provided Cartographic Census Boundary files for provinces and territories. DataBC provided the Digital Road Atlas and Freshwater Atlas.



(Rea et al. 2013). Our objectives were to test the efficacy of decommissioning roadside licks to reduce visitation by moose in central BC, determine whether moose attraction to roadside licks is motivated by mineral or water acquisition, and examine the costs and effectiveness of methods used to decommission roadside licks.

We hypothesized that moose are attracted to roadside licks because of the high concentrations of minerals and other soil suspensions in these roadside waters. We tested this hypothesis by comparing moose use of untreated and decommissioned roadside licks with small, freshwater roadside ponds and dry roadside sites that lacked standing water. We predicted that the use of roadside ponds by moose would be less than that of roadside licks and that decommissioning licks would reduce moose visitation to levels comparable to roadside ponds and dry roadside sites. This suggests that high mineral concentrations are the driving force behind moose attraction to licks and not water alone. We sought to offer new insights into the use of roadside licks by moose and provide management recommendations for decommissioning licks with implications for both moose and human safety.

Materials and methods

Study area

Our study area was located in central BC (Fig. 2) and was primarily within the sub-boreal ecotype (Eastman 1983), where decades of forest harvesting have caused extensive modifications to the landscape (Kuzyk 2016). Highways in our study area transected forest stands of all age classes, including clearcuts, plantations, and mature forests. Mature uncut stands were dominated by coniferous forests of hybrid white spruce (*Picea engelmannii* Perry ex Engelm. × *Picea glauca* (Moench) Voss) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), while secondary successional sites were pioneered by lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson), and trembling aspen (*Populus tremuloides* Michx.) (Meidinger and Pojar, 1991).

The area has been characterized as having a humid continental climate, which is generally wet and cool, with precipitation evenly distributed throughout the year (Meidinger and Pojar 1991). The mean daily temperature was 4.3 °C and ranged from a daily mean of –7.9 °C in January to a daily mean of 15.8 °C in July. The mean annual precipitation was 595 mm, which included 205 cm of snow (Government of Canada 2016). Moose densities varied across the study area with estimates between 0.28 and 0.94 moose/km^2 (Klaczek et al. 2017; Bridger 2018; M. Klaczek and D. Heard, unpublished data). During the study, overall moose abundance declined in central BC (Klaczek et al. 2017).

The highways adjacent to our roadside locations were predominantly undivided, rural, and had up to three lanes and a maximum posted speed limit of 100 km/h (BC MOTI 2020). Most highways were classified as having a level or rolling terrain, with short lengths classified as mountainous (BC MOTI 2020). The industrial de-icing agent (road salt) typically used in winter on these highways is raw, granular sodium chloride that is separated in rock form during the mining of potash and meets the requirements of the Canadian General Specification Board, specification 15-GP-9M and Section 991 of the Standard Specification for Highway Construction (Kleysen Group Ltd., 2020, Esterhazy, Saskatchewan, Canada). Ditch bottoms that collected road salt runoff at the roadside licks in our study were generally 0.5–3.0 m below the road surface and shoulder, depending on the terrain.

Field methods

We identified 18 roadside licks that demonstrated frequent use by moose (wildlife trails, tracks, and overall site disturbance) along highways in central BC (Fig. 2). At each roadside lick, we installed Reconyx PC 900 HyperFire professional covert IR camera traps (Reconyx©, Holmen, Wisconsin, USA) either overlooking the lick or at the edge of the lick (e.g., junction of a trail entering the lick). The pre-treatment area of roadside licks ranged from 20 to 1224 m^2, with a mean area of 280 m^2. Camera traps were set to take three photos in rapid succession, with a 1 s delay between detections after the sensor was triggered.

To test our hypothesis of whether moose were visiting licks because of high mineral concentrations in licks or because of water availability, we installed camera traps on two roadside (freshwater) ponds and two dry roadside sites lacking any standing water, which were located adjacent to highways in our study area. Roadside ponds were slightly larger, on average ($\sim$400 m^2), than the mean area of licks in our study and were filled with deep (>1 m) water year-round, unlike licks, which often contained only a few centimetres of water.

We monitored the roadside locations from December 2009 to July 2020 and visited each roadside location (licks, roadside ponds, and dry roadside sites) approximately once every 4 to 6 weeks to service the camera traps (i.e., replace camera batteries, download images, and ensure cameras were functioning properly). All servicing of camera traps was conducted by a single individual (R.R.) for the duration of the study to minimize potential impacts on moose behaviour and to ensure that the same protocol was used at each service.

In collaboration with the British Columbia Ministry of Transportation and Infrastructure, we decommissioned 8 roadside licks and left the remaining 10 licks untreated. The cost of the decommissioning treatments and the overall cost of the study limited the number of licks that we could decommission and monitor, and therefore, the overall sample size used in the research. We used six techniques to decommission roadside licks to either exclude moose access to lick soils and water (e.g., fencing or rock placement) or render the lick soils and water unpalatable to moose through changes in taste, texture, or smell. The six techniques that we used were (1) chain-link fencing (remove access; n = 1; December 2009); (2) a backhoe to excavate lick soils, cover parent material with geotextile (permeable, synthetic fabric), followed by the placement of <1 inch (1 inch = 2.54 cm) reject rock only (mixed aggregate and sand) (remove access; n = 1; June 2014); (3) a backhoe to position logs (i.e., corduroy) on top of the lick (October 2012) and, once the logs settled, the addition of <1 inch reject rock to a depth of 30–60 cm (remove access; n = 2; September 2014); (4) a backhoe to excavate lick soils, cover parent materials with geotextile, followed by backfilling with cedar (*Thuja plicata* Donn ex D. Don) mulch and placement of a border of $\sim$50 kg angular quarry rock (riprap) (remove access; n = 1; November 2011); (5) a backhoe to excavate lick soils, cover parent material with geotextile, followed by backfilling with riprap (October 2009 and October 2010), and once the riprap settled (2 years after riprap placement), the addition of <1 inch reject rock (remove access; n = 2; October 2011 and October 2012); or (6) a walk-behind front-tine rototiller to incorporate human (*Homo sapiens* Linnaeus, 1758) hair (donated by hair salons) and dog (*Canis lupus familiaris* Linnaeus, 1758) fur (donated by pet groomers) into the lick (for use as a repellent to render licks unpalatable see Castiov 1999; Seamans et al. 2002; n = 1; July 2012) (Figs. 3A–3F; note that technique numbers 1–6 correspond with panel letters A–F, respectively, in the figure). The roadside licks that we selected for decommissioning were located on roadside verges with physiographic features (bank steepness, distance to treeline, and stream proximity and connectedness) amenable to treatment by heavy equipment, such as backhoes and loaders. We obtained treatment cost estimates from the British Columbia Ministry of Transportation and Infrastructure.

We used camera trap images recorded at each location to estimate the number of independent visits by moose per month for each roadside location. Moose were identified from digital photographs (stored and available on hard drives at the University of Northern British Columbia) to species using descriptions provided by Franzmann (1981) and Bubenik (1998). We used body size, leg and tail length, coat colour, presence of a dewlap, and premaxillary and upper lip anatomy to distinguish moose from other species photographed, such as mule deer (genus *Odocoileus* Rafinesque, 1832) and elk (*Cervus elaphus* Linnaeus, 1758) (Fig. 1). Antler architecture and the presence of antler pedicels in bull moose and the presence of a vulvar patch and light brown faces in cow moose were used to delineate sex where possible (Franzmann 1981; Bubenik 1998). However, we did not distinguish between the sexes in the analyses presented here.

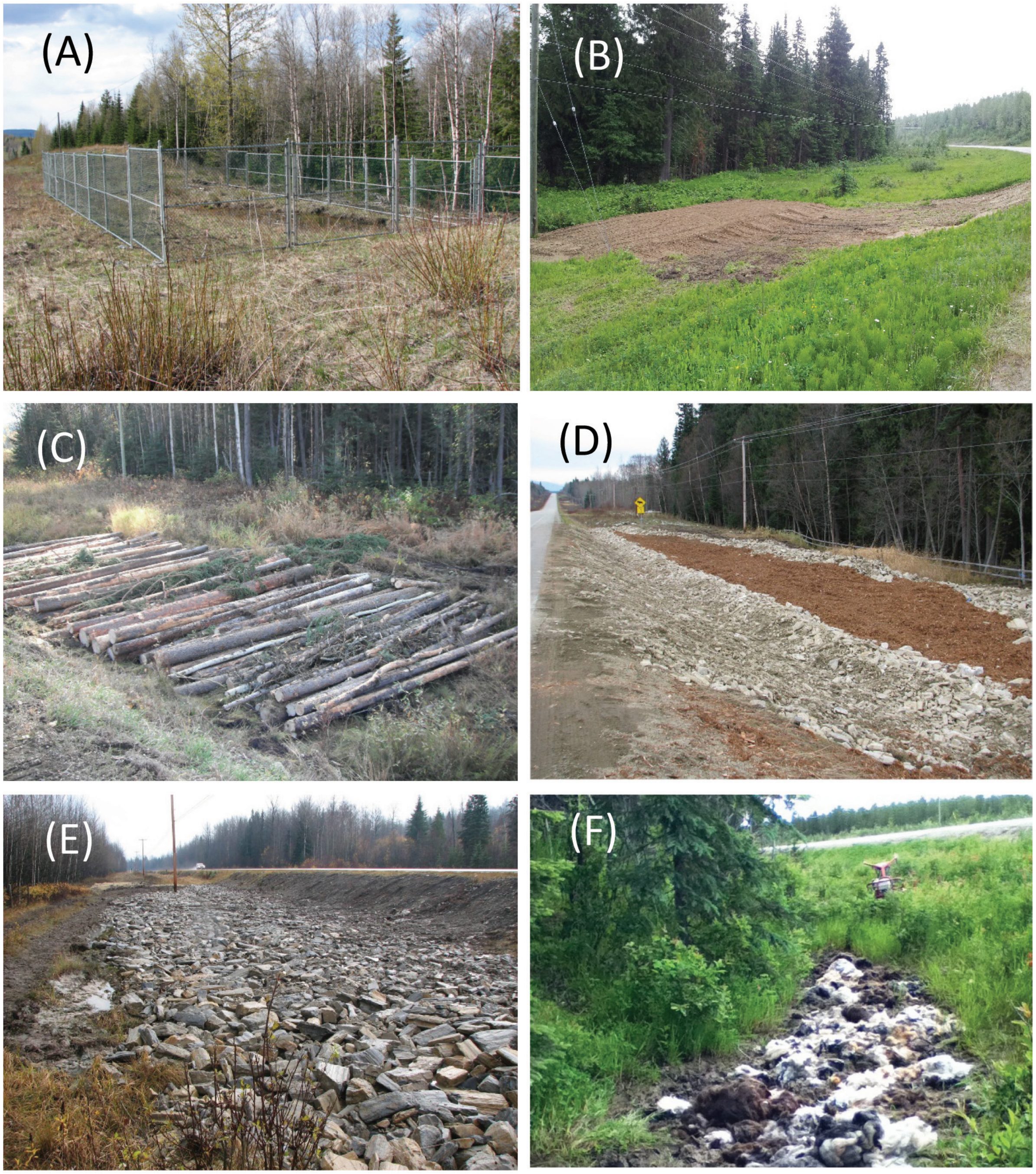
We considered the number of independent moose visits, rather than the number of unique individuals, to be a more useful metric in understanding the risks posed to motorists resulting from frequent use by moose of roadside areas. Independent visits were defined as visits made by a unique individual (as determined by distinguishing marks) or by the same individual but >1 h apart (Leblond et al. 2007; Sollmann 2018). For images captured <1 h apart, when unique individuals could not be identified (e.g., low light conditions or individuals had no distinguishing marks), we conservatively considered this to be a single visit.

Statistical approach

We built zero-altered (hurdle) Poisson generalized additive mixed-effects models (package "gam": Hastie 2020; package "mgcv": Wood 2019) in program R (R Core Team 2019) to determine if moose were using untreated roadside licks more frequently than other location types (decommissioned licks, roadside ponds, and dry roadside sites). We used hurdle models because our response variable (independent visits per month) contained a large number of zeros. Hurdle models assume that the observed phenomenon is comprised of two processes: a first model (zero model) for whether an observation is zero or not, and a second model (count model) for the observed count of all nonzero observations (Zuur et al. 2009). We selected a generalized additive modelling approach because preliminary examinations of the data indicated a nonlinear relationship between month and the number of independent visits per month. Generalized additive models provide more flexibility than generalized linear models by allowing for nonlinear relationships between independent and dependent variables by using a smoothing function (as opposed to a linear function). The use of a smoothing function also allowed us to account for spatial autocorrelation among licks and other types of locations (roadside ponds and dry roadside sites) across our study area by modelling a nonlinear response to the interaction between latitude and longitude.

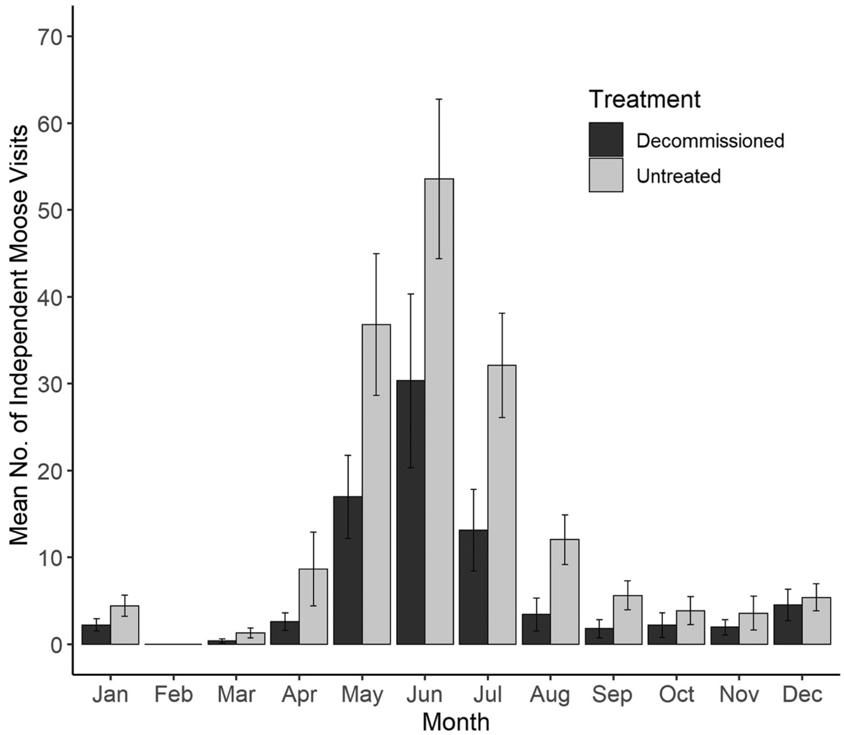
We built competing models using time, location type, and space covariates. To minimize the number of potential models, we constructed a suite of competing models for the zero or nonzero process while treating the counting process as a constant, and a separate suite of competing models for the counting process while treating the zero or nonzero process as a constant. In addition to a nonlinear effect of month, our time covariates

Fig. 3. Techniques used to decommission licks were (A) exclusion chain-link fencing; (B) lick soils replaced with geotextile and reject rock; (C) logs used to cover lick (i.e., corduroy) followed by reject rock (not completed in image); (D) lick soils replaced with geotextile and cedar mulch, bordered with riprap; (E) lick soils replaced with geotextile and riprap, later topped off with reject rock; and (F) human (*Homo sapiens*) hair and dog (*Canis lupus familiaris*) fur mix rototilled into lick soils. Panel letters A–F correspond with techniques 1–6, respectively, that are mentioned in the text. Colour version online.



included a fixed, linear effect for year (since the start of the study) modelled as a continuous covariate to account for the recently observed decline in moose abundance in BC (Klaczek et al. 2017) and subsequent potential decrease in moose visits to roadside licks and other roadside sites. Our location-type covariates included fixed, linear effects for decommissioned licks, roadside ponds, and dry roadside sites modelled using dummy coding with untreated licks as the reference category. We also included an interaction term between year and decommissioned licks in some models to test whether visitation of decommissioned licks decreased over time, which would potentially indicate a lag in the response of moose following decommissioning; fidelity to mineral licks might cause moose to visit mineral licks for several years even after mineral-laden soils and waters were unavailable. Our space covariate was the nonlinear effect of the interaction between latitude and longitude. Because each roadside location contributed multiple observations to the analysis, all candidate models included a random intercept for roadside locations.

Fig. 4. Mean (±95% CIs) number (No.) of independent visits for each calendar month by moose (*Alces alces*) to decommissioned (n = 8) and untreated (n = 10) licks between December 2009 and July 2020 in central British Columbia, Canada. Visits to roadside ponds and dry roadsides were relatively minimal and therefore not included (see Fig. 5).



Additionally, all models included an offset to the number of independent visits per month by the number of active camera trap days per month to account for differences among roadside locations in the number of days that camera traps were active (i.e., unable to record images because of dead batteries, a full memory card, or a camera malfunction) and the absolute number of days in each month.

For each suite of competing models, we identified the most supported model using conditional Akaike's information criterion corrected for small sample sizes (cAIC$_c$; Burnham and Anderson 2002) as recommended by Wood et al. (2016) for models estimated via restricted maximum likelihood. The package "mgcv" (Wood 2019) automatically calculates the conditional log-likelihood of each model, which we used to calculate cAIC$_c$ using the AIC$_c$() command. Once the most supported models were identified, we combined the most supported zero model and count model to build a single final model. We examined the R^2 value of our combined model and ensured model fit by evaluating model diagnostics, such as residual plots.

Results

Between December 2009 and July 2020, camera traps recorded 254 090 images of moose for a total of 16 388 independent moose visits to our 22 roadside locations. On average, we observed 11 011 visits per untreated lick, 623 per decommissioned lick, 35 per roadside pond, and 67 per dry roadside site over the study period. Peak visitations by moose to licks occurred between May and July (Fig. 4), and the number of visits per month (adjusted for active camera trap days) for untreated licks was greater than for decommissioned licks, roadside ponds, and dry roadside sites (Fig. 5).

Our most supported zero model included our time covariates of month and year and our location-type covariates of decommissioned licks, roadside ponds, and dry roadside sites (Table 1). The zero model that included the interaction between year and decommissioned licks had a ΔcAIC$_c$ of 1.22 (Table 1) and potentially garnering support (ΔcAIC$_c$ < 2; Burnham and Anderson 2002). However, because the two top models only differed in a single parameter (interaction term), which accounts for a –2 penalty in the cAIC$_c$ calculation, it indicated that the interaction between year and decommissioned licks added minimal information. Our most supported count model included month and year, our location-type covariates, and the interaction between year and decommissioned licks (Table 1). The nonlinear effect of the interaction between latitude and longitude did not appear in the most supported zero and count models, suggesting that there was no support for the effect of spatial autocorrelation (Table 1). The R^2 value for our combined model was 0.608, and the model diagnostics indicated a reasonable fit.

Our combined model indicated that decommissioning reduced moose visitation, as evidenced by the negative relationship for both the zero and count portions of the model ($p < 0.05$; Table 2). The model also demonstrated that moose visited untreated licks more frequently than roadside ponds and dry roadside sites ($p < 0.05$; Table 2). The negative coefficients for year in the zero and count portions of the model ($p < 0.05$; Table 2) indicated that moose visits to licks declined over the years of the study (Fig. 6). The interaction between year and decommissioning in the count portion of the model suggested that, although mineral-rich waters and soils were unavailable, moose visited licks relatively frequently during the initial summers after decommissioning; however, moose visitations continued to decline as the years progressed ($p < 0.05$; Table 2). Furthermore, the predicted visitation for decommissioned roadside licks declined over time to levels only slightly greater than those observed for roadside ponds and dry roadside sites (Fig. 6). We also observed support for the nonlinear effect of month and the random intercept for location ($p < 0.05$; Table 2).

The estimated costs of decommissioning licks varied significantly by decommissioning techniques and were influenced by lick size and proximity to (i.e., cost of transporting) decommissioning materials used to fill licks (Table 3). Rototilling human

Fig. 5. Mean (±95% CIs) number (No.) of independent visits per month (adjusted for the number of active camera trap days) by moose (*Alces alces*) to decommissioned (n = 8) and untreated (n = 10) licks, roadside ponds (n = 2), and dry roadside sites (n = 2) between December 2009 and July 2020 in central British Columbia, Canada.

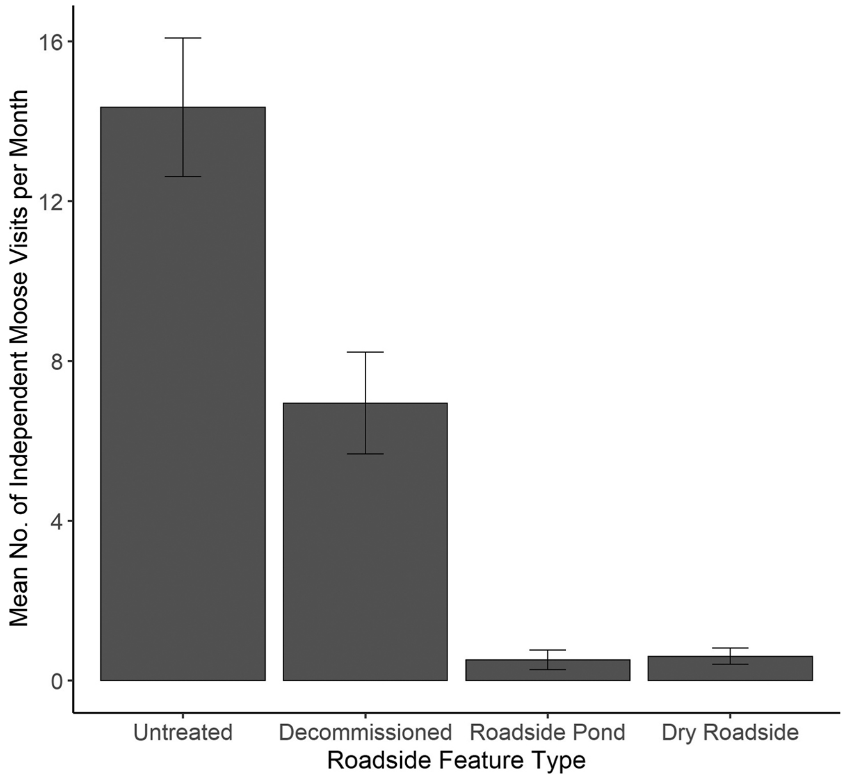


Table 1. Model selection tables using conditional AIC corrected for small sample sizes ($cAIC_c$) for zero and count aspects of zero-altered (hurdle) Poisson generalized additive mixed-effects models explaining the number of independent visits by moose (*Alces alces*) per month to roadside locations (untreated mineral licks, decommissioned licks, roadside ponds, and dry roadsides) in central British Columbia, Canada.

Model name	Model description*	Log-likelihood	k	$cAIC_c$	$\Delta cAIC_c$
Zero model selection					
Time and Type	*S*(Month) + Year + Decommissioned + Dry + Pond	−13 800.25	47.25	27 698.33	0.00
Time × Type	*S*(Month) + (Year × Decommissioned) + Dry + Pond	−13 800.09	48.25	27 699.55	1.22
Time	*S*(Month) + Year	−13 800.70	47.80	27 700.32	1.99
Time and Type and Space	*S*(Month) + Year + Decommissioned + Dry + Pond + *S*(Latitude × Longitude)	−13 800.55	48.72	27 701.13	2.80
Time and Space	*S*(Month) + Year + *S*(Latitude × Longitude)	−13 801.11	48.79	27 702.17	3.84
Time × Type and Space	*S*(Month) + (Year × Decommissioned) + Dry + Pond + *S*(Latitude × Longitude)	−13 800.99	49.72	27 702.34	4.00
Type	Decommissioned + Dry + Pond	−13 961.34	41.98	28 008.57	310.23
Space and Type	*S*(Latitude × Longitude) + Decommissioned + Dry + Pond	−13 961.13	43.59	28 011.52	313.19
Space	*S*(Latitude × Longitude)	−13 961.49	43.75	28 012.59	314.26
Count model selection					
Time × Type	*S*(Month) + (Year × Decommissioned) + Dry + Pond	−7 637.47	48.89	15 375.34	0.00
Time × Type and Space	*S*(Month) + (Year × Decommissioned) + Dry + Pond + *S*(Latitude × Longitude)	−7 637.40	50.41	15 378.40	3.06
Time and Type	*S*(Month) + Year + Decommissioned + Dry + Pond	−7 668.75	47.88	15 435.77	60.43
Time and Type and Space	*S*(Month) + Year + Decommissioned + Dry + Pond + *S*(Latitude × Longitude)	−7 668.69	49.40	15 438.85	63.50
Time	*S*(Month) + Year	−7 673.10	47.75	15 444.20	68.85
Time and Space	*S*(Month) + Year + *S*(Latitude × Longitude)	−7 672.92	48.78	15 446.00	70.65
Type	Decommissioned + Dry + Pond	−13 947.41	42.89	27 982.61	12 607.26
Space and Type	*S*(Latitude × Longitude) + Decommissioned + Dry + Pond	−13 946.73	44.22	27 984.04	12 608.70
Space	*S*(Latitude × Longitude)	−13 961.40	43.72	28 012.32	12 636.98

Note: Smooth terms are in parentheses and preceded by *S*. "Year × Decommissioned" indicates the inclusion of the direct effects of year and decommissioned and is an interaction term. k is the estimated number of parameters.

*All models also contained an offset for the number of active camera trap days per month and a random intercept for roadside mineral licks.

Table 2. Coefficients, standard errors (SE), z values, and p values of linear terms and estimated degrees of freedom (edf), χ^2 values, and p values of smoothing terms for the most parsimonious zero-altered (hurdle) Poisson generalized additive mixed-effects model explaining the number of independent visits by moose (*Alces alces*) per month to roadside locations (untreated mineral licks, decommissioned licks, roadside ponds, and dry roadsides) in central British Columbia, Canada.

Linear terms				
	Estimate	SE	z	p
Zero model				
Intercept	−2.619	0.244	−10.744	<0.001
Year	−0.047	0.015	−3.213	0.001
Decommissioned	−0.690	0.319	−2.160	0.031
Dry	−1.677	0.531	−3.158	0.002
Pond	−2.454	0.569	−4.310	<0.001
Count model				
Intercept	−0.345	0.182	−1.894	0.058
Year	−0.107	0.004	−27.985	<0.001
Year × Decommissioned	−0.055	0.007	−7.831	<0.001
Decommissioned	−0.570	0.232	−2.457	0.014
Dry	−1.832	0.499	−3.675	<0.001
Pond	−2.945	0.581	−5.066	<0.001

Smooth terms			
	edf	χ^2	p
Zero model			
Month	3.982	260.800	<0.001
Random effect: Lick	16.312	190.800	<0.001
Count model			
Month	3.998	8505.700	<0.001
Random effect: Lick	17.794	2568.000	<0.001

Note: Untreated licks are the reference category for the location type. "Year" is year since start of study.

hair and dog fur into lick soils (technique 6) had the lowest cost per lick ($2500 CAD), but one of the higher costs per square metre ($125 CAD; Table 3). The most expensive decommissioning method per lick (technique 4) was using a backhoe to excavate soils, covering the excavated area with geotextile and cedar mulch, bordering with riprap, and later covering with reject rock ($18 300 CAD; Table 3), but the per square metre cost of this approach was the lowest ($18 CAD; Table 3).

Discussion

Our study showed that decommissioned roadside licks in central BC received fewer visits by moose in the months and years after treatment compared to untreated licks, demonstrating that decommissioning licks is an effective means of reducing moose visitation to roadside areas. These findings mirrored those of Leblond et al. (2007), where moose visitation declined within the first year after roadside licks were drained and backfilled with rock in Quebec, Canada. Reduced visits to decommissioned licks by moose were notable, particularly during the summer period, when moose in northern BC are most likely to visit mineral licks (Rea et al. 2013). Additionally, visits to both decommissioned and untreated licks by moose declined significantly during the study period, which is likely related to the overall decline in moose abundance reported for central BC (Klaczek et al. 2017) and corresponds to an observed decrease in MVCs (Leonard Sielecki, Ministry of Transportation and Infrastructure, personal communication).

Moose made fewer visits to roadside ponds and dry roadsides than to untreated and decommissioned licks. The infrequency of moose visits to roadside ponds compared to untreated licks suggested that moose attraction to licks was not related to water availability. Instead, moose were likely to use licks to meet dietary requirements by accessing the high concentrations of salts, other micronutrients, and buffering compounds such as carbonates suspended in lick waters and soils (Jones and Hanson 1985; Ayotte et al. 2006), which is consistent with our hypothesis. Fraser and Thomas (1982) also found less concentrated moose activity in freshwater sources along roadsides when compared to salt pools (i.e., licks) in Ontario, Canada. Furthermore, the occurrence of roadside licks, but not roadside ponds, has been previously associated with MVCs in northern British Columbia (Rea et al. 2014).

Reductions in the number of independent moose visits to decommissioned licks were most pronounced from May through July, which corresponds with the season of highest mineral lick use (Rea et al. 2013). Greater use of roadside licks in late spring and early summer has been associated with an increase in MVCs in multiple jurisdictions (Fraser and Thomas 1982; Leblond et al. 2007; Mountrakis and Gunson 2009). Therefore, decommissioning licks is likely to have the greatest effect on reducing MVCs in late spring and early summer (Rea et al. 2014), but may not decrease the number of MVCs during December and January, when MVCs are most frequent in BC (Sielecki 2010; O'Keefe and Rea 2012). Although licks might, at times, be accessible in warm winters or after a mid-winter thaw, natural mineral licks in BC are most often covered with ice and snow and inaccessible from December through March (Rea et al. 2013). In addition, because road salt use is generally ubiquitous on most northern BC highways during the winter, moose that are seeking salts are not restricted to licks and can directly access road salts on road surfaces and adjacent road shoulders.

In contrast to our predictions, there were more independent moose visits per month to decommissioned licks than roadside ponds and dry roadside sites. Visits to decommissioned licks, however, occurred more frequently just after the roadside licks were decommissioned and tapered off with each passing year. Our model suggested that moose visitation to decommissioned licks was only slightly greater than that to roadside ponds and dry roadside sites by the end of the study. Leblond et al. (2007) suggested that the high fidelity moose have to roadside licks (Wiles and Weeks 1986; Grosman et al. 2011) might cause moose to return to licks for several years after treatment. Thus, even though successful decommissioning will have made mineral-rich lick soils and waters inaccessible or unpalatable, it will likely require several years for moose visitation to decline to levels of visitation comparable to other roadside areas.

All treatment methods used in our study appeared to remain effective at the end of the study. Fencing was erect and stable, and riprap, reject rock, and pine log corduroy treatments remained firmly in place in the summer of 2020. Vegetation eventually overtook treatments with hair and cedar mulch, but lick soils remained unavailable. We recommend continued monitoring of moose visitation patterns to licks to better understand moose behaviours at licks and the long-term effectiveness of each technique (Rea and Rea 2005). Our experience showed that various materials can be used for decommissioning, and there are likely many other suitable materials that remain to be tested (Rea and Rea 2005). Given the efficacy of various techniques and materials, managers should strategically select the most cost-effective techniques and materials for their jurisdiction and potentially specific to individual licks, depending on material availability and transportation costs.

Our study was not explicitly designed to compare the cost-effectiveness of different decommissioning techniques. The treatment selected for an individual roadside lick is often determined by lick size and proximity to materials (i.e., cost of transporting). We began the project using riprap alone because it was used by Leblond et al. (2007), and local contractors were accustomed to using it on other road projects. However, we switched to reject rock, which was left over from other highway projects and free of

Fig. 6. Predicted mean number (No.) of independent moose (*Alces alces*) visits for the month of June to decommissioned and untreated roadside licks, roadside ponds, and dry roadside sites as a function of the year(s) since monitoring of roadside locations that began in December 2009 in central British Columbia, Canada.

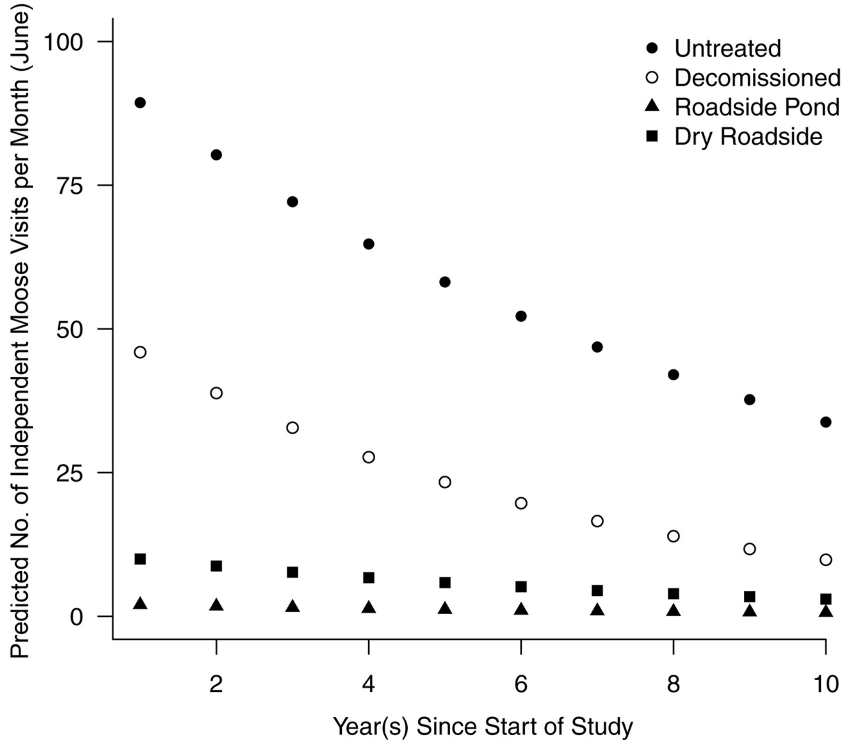


Table 3. Estimated total decommissioning costs and decommissioning costs per square metre (m^2), in Canadian dollars (CAD), for roadside mineral licks by decommissioning technique.

Decommissioning treatment	Approximate cost of decommissioning licks (circa 2015 CAD)	Approximate cost of decommissioning per m^2 (circa 2015 CAD)
(1) Chain-link fencing	$6 500	$130
(2) Reject rock	$6 000	$26
(3) Corduroy and reject rock	$8 250	$126
(4) Cedar bark bordered by riprap	$18 300	$18
(5) Riprap topped with reject rock	$16 850	$43
(6) Human hair and dog fur mix	$2 500	$125
Mean cost per lick	$9 733	$78

Note: Estimated costs include materials (but not fill materials, e.g., rock, bark, logs), transportation of materials, equipment costs, traffic control, and labour, and are affected by lick size and the transportation distance from lick to fill material sources (e.g., quarries).

charge, when sources for riprap were located far from licks and expensive to transport. To keep costs low, where distances to either type of rock were too great, we substituted other commonly available materials (e.g., logs of lodgepole pine killed by mountain pine beetle (*Dendroctonus ponderosae* Hopkins, 1902) for corduroy treatment) or materials that are easy to collect and transport (e.g., human hair and dog fur). The distances between licks and rock quarries and contractor headquarters, types of available materials, the number of pieces of equipment and operators required, and differences in lick size, all made it difficult to accurately estimate and compare costs among treatments.

Our initial design considered only the differences in moose visitation between untreated and decommissioned licks. We acknowledge that our sample sizes were small, with 8 decommissioned and 10 untreated lick locations, but the number of licks was constrained by the costs of decommissioning and monitoring the effects of decommissioning during the 10 plus years of our study. Roadside ponds and dry roadside sites were added as we began to consider how moose visits to roadside licks compared with moose activity at other types of roadside locations. Although sample sizes were small, we still observed significant differences in use between untreated licks and the other types of roadside locations we monitored and we contend that decommissioning had a marked effect on minimizing moose activities near highways. We suggest that future research should focus on increasing the sample size of roadside ponds and dry roadside sites and explicitly focus on collecting data to demonstrate the link between decommissioning licks and MVCs.

Although decommissioning roadside licks presents a considerable monetary expense, the cost of decommissioning must be weighed against the personal, economic, and societal costs associated with MVCs. These costs include human and animal death and injury, lost time from work, vehicle towing and repairs, and incident response costs (attendance, investigation, reporting, site clean-up). Indeed, Huijser et al. (2009) estimated the cost of a single MVC to be $30 773 (2007 USD), which is well above the cost of decommissioning a lick using any of our techniques. Therefore, in locales where the population densities of both moose and motorists are high, such as highways in Ontario, Quebec, and the New England (USA) states that are located near large urban centres (Leblond et al. 2007; Gunson et al. 2011), decommissioning roadside licks (regardless of the specific treatment method) should be considered along with other MVC mitigation techniques, such as promoting public/driver education, installing wildlife warning signage (which influences MVC occurrence), and altering road salt formulations. Allowing managers to consider and use the full suite of techniques available to reduce the potential for MVCs will result in safer highways for motorists and moose, both in BC and in other places where roadside mineral licks occur.

Competing interests statement

The authors declare that there are no competing interests.

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