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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. Our research used camera traps to monitor moose visitation of 22 roadside locations (including roadside licks, roadside ponds, and dry roadsides) in central British Columbia, Canada from December 2009–July 2020, 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–July. As we hypothesized, untreated licks were visited more often by moose than decommissioned licks, roadside ponds (absent 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

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). Wildlife-vehicle collisions also come with significant economic costs. For ungulates in North America, the costs associated with WVCs are estimated to be between \$6.2–12.8 trillion USD/year (Tardif and Associates Inc. 2003; Huijser et al. 2009). Further, 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 4-fold 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). 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 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 often neglected to monitor the effectiveness of those 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 in roadside ponds 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, molting, antler growth, and to help stabilize rumen function (e.g., pH, microbial community) (Tankersley and Gasaway 1983; Robbins 2001; Ayotte et al. 2006; Ayotte et al. 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). 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 collision 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 on moose visitation to roadside licks after draining and backfilling licks with

rock. 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 frequent licks (at roadsides and elsewhere) throughout the year (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 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 any standing water. We predicted that 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—thus suggesting 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 areas transected forest stands of all age classes, including clearcuts, plantations, and mature forest. Mature uncut stands were dominated by coniferous forests of hybrid white spruce (*Picea engelmannii* (Perry ex. Engelm.) x *Picea glauca* (Moench (Voss))) and subalpine fir (*Abies lasiocarpa* (Hook. (Nutt.))), while secondary successional sites were pioneered by lodgepole pine (*Pinus contorta* var. *latifolia* (Douglas ex Loudon)) 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). Mean daily temperatures were 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. 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/km² (Klaczek et al. 2016, unpublished data; Klaczek et al. 2017; Bridger 2018). 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/hr (BC MOTI 2020). Most highways were classified as having 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, SK, Canada). Ditch bottoms that collected road salt run-off at the roadside licks in our study were generally 0.5–3.0 m below the road surface and shoulder, depending on 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) 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 20–1224 m², with a mean area of 280 m². Camera traps were set to take three photos in rapid succession, with a one-second delay between detections after the sensor was triggered.

To test our hypothesis of whether moose were visiting licks because of high mineral concentrations at 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 (~400 m²) than the mean area of licks in our study and were filled with deep (> 1m) water year-round, unlike licks that in dry summers often contained only a few cm of water.

We monitored our roadside locations from December 2009–July 2020 and visited each roadside location (licks, roadside ponds, and dry roadside sites) approximately once every four to six 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. Rea) for the duration of the study to minimize potential impacts on moose behaviour and to ensure the same protocol was used at each servicing.

In collaboration with the British Columbia Ministry of Transportation and Infrastructure, we decommissioned eight 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 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 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 ~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 (two 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 hair (donated by hair salons) and dog 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) (Fig. 3). The roadside licks 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 to 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 in Franzmann (1981) and Bubenik (1998). We used body size, leg and tail length, coat colour, presence of a dewlap as well as premaxillary and upper lip anatomy to distinguish moose from other species photographed such as mule deer (*Odocoileus* (Rafinesque, 1832) spp.) and elk (*Cervus elaphus* (Linnaeus, 1758)) (Fig. 1). Antler architecture and the presence of antler pedicels in bull moose and the presence of a vulva 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 hour apart (Leblond et al. 2007; Sollmann 2018). For images captured <1 hour 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/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 a zero or not, and a second model (count model) for the observed count of all non-zero observations (Zuur et al. 2009). We selected a generalized additive modelling approach because preliminary examinations of the data indicated a non-linear relationship between month and the number of independent visits/month. Generalized additive models provide more flexibility than generalized linear models by allowing for non-linear relationships between independent and dependent variables via the use of 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 non-linear 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 non-zero 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 non-zero process as a constant. In addition to a non-linear effect of month, our time covariates 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 if visitation of decommissioned licks decreased through 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 non-linear effect for the interaction of latitude and longitude. Because each roadside location contributed multiple observations to the analysis, all candidate models included a random intercept for roadside location. Additionally, all models included an offset to the number of independent visits/month by the number of active camera trap days/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 AIC for small sample sizes (AIC_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 the conditional AIC_c (cAIC_c) using the AIC_c() command. Once the most supported models were identified, we then 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 1 1011 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 ΔcAICc of 1.22 (Table 1), also potentially garnering support ($\Delta\text{cAICc} < 2$, Burnham and Anderson 2002). However, since the two top models only differed in a single parameter (interaction term), which accounts for a -2 penalty in the cAICc 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 non-linear effect of the interaction between latitude and longitude did not appear in the most supported zero and count models, suggesting that there was not support for the effect of spatial autocorrelation (Table 1). The R^2 value for our combined model was 0.608 and 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 -

values <0.05 , Table 2). The model also demonstrated that moose visited untreated licks more frequently than roadside ponds and dry roadside sites (p -values <0.05 , Table 2). The negative coefficients for year in the zero and count portions of the model (p -values <0.05 , Table 2) indicated that moose visits to licks declined over the years of the study (Figure 6). The interaction between year and decommissioning in the count portion of the model suggested that, despite mineral-rich waters and soils being unavailable, moose visited licks relatively frequently during the initial summers after decommissioning, but that moose visitations continued to decline as the years progressed (p -values <0.05 , Table 2). Further, the predicted visitation for decommissioned roadside licks declined through time to levels only slightly greater than those observed for roadside ponds and dry roadside sites (Figure 6). We also observed support for the non-linear effect of month and the random intercept for location (p -values <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 hair and dog fur into lick soils (6) had the lowest cost per lick (\$2 500 CAD), but one of the higher costs per m^2 (\$125 CAD, Table 3). The most expensive decommissioning method per lick (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 m^2 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 years of the study, 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 (pers. comm. Leonard Sielecki, Ministry of Transportation and Infrastructure).

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 using 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 aligned with our hypothesis. Fraser and Thomas (1982) also found less concentrated moose activity at freshwater sources along roadsides when compared to salt pools (i.e., licks) in Ontario, Canada. Further, 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). Also, because road salt use is generally ubiquitous on most northern BC highways during the winter, moose 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 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 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 research appeared to remain effective through 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 be strategic in selecting 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 was 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 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 the corduroy treatment) or materials 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 eight 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 visitations to roadside licks compared with moose activity at other types of roadside locations. Although sample sizes were small, we still saw significant differences in use between untreated licks and the other types of roadside locations we monitored and contend that decommissioning had a marked effect on minimizing moose activities near highways. We suggest that future research be directed at 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), well above the costs of decommissioning a lick using any of our techniques. Therefore, in locales where population densities of both moose and motorists are high, such as highways in Ontario, Quebec, and the New England 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 influence 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 leave highways in BC, and other places where roadside mineral licks occur, safer for both motorists and moose.

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Figure Captions

Figure 1. Camera trap image of a moose (*Alces alces* (Linnaeus, 1758)) using a roadside mineral lick in central British Columbia.

Figure 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* (Linnaeus, 1758)) visitation in central British Columbia, Canada, from December 2009–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.

Figure 3. Techniques used to decommission licks were: (1) exclusion chain-link fencing, (2) lick soils replaced with geotextile and reject rock, (3) logs used to cover lick (i.e., corduroy) followed by reject rock (not completed in image), (4) lick soils replaced with geotextile and cedar mulch, bordered with riprap, (5) lick soils replaced with geotextile and riprap, later topped off with reject rock, and (6) human (*Homo sapiens* (Linnaeus, 1758)) hair and dog (*Canis lupus familiaris* (Linnaeus, 1758)) fur-mix rototilled into lick soils.

Figure 4. Mean (\pm 95% CIs) number (No.) of independent visits for each calendar month by moose (*Alces alces* (Linnaeus, 1758)) to decommissioned ($n = 8$) and untreated ($n = 10$) licks between December 2009 and July 2020 in central British Columbia, Canada. Note: Visits to

roadside ponds and dry roadsides were relatively minimal and, therefore, not included (see Figure 5).

Figure 5. Mean (\pm 95% CIs) number (No.) of independent visits per month (adjusted for the number of active camera trap days) by moose (*Alces alces* (Linnaeus, 1758)) 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.

Figure 6. Predicted mean number (No.) of independent moose (*Alces alces* (Linnaeus, 1758)) 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 began in December 2009 in central British Columbia, Canada.

Figures



Figure 1.

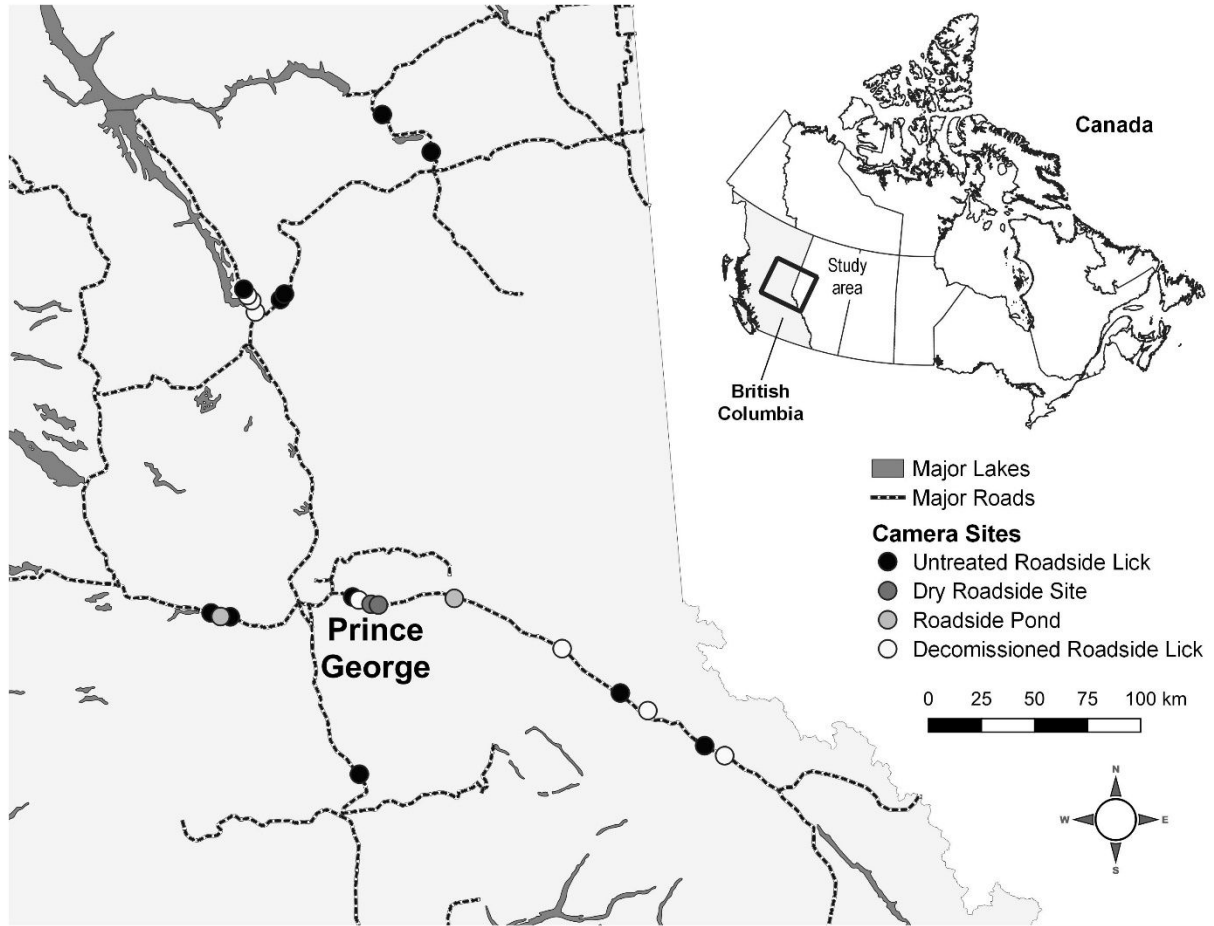


Figure 2.

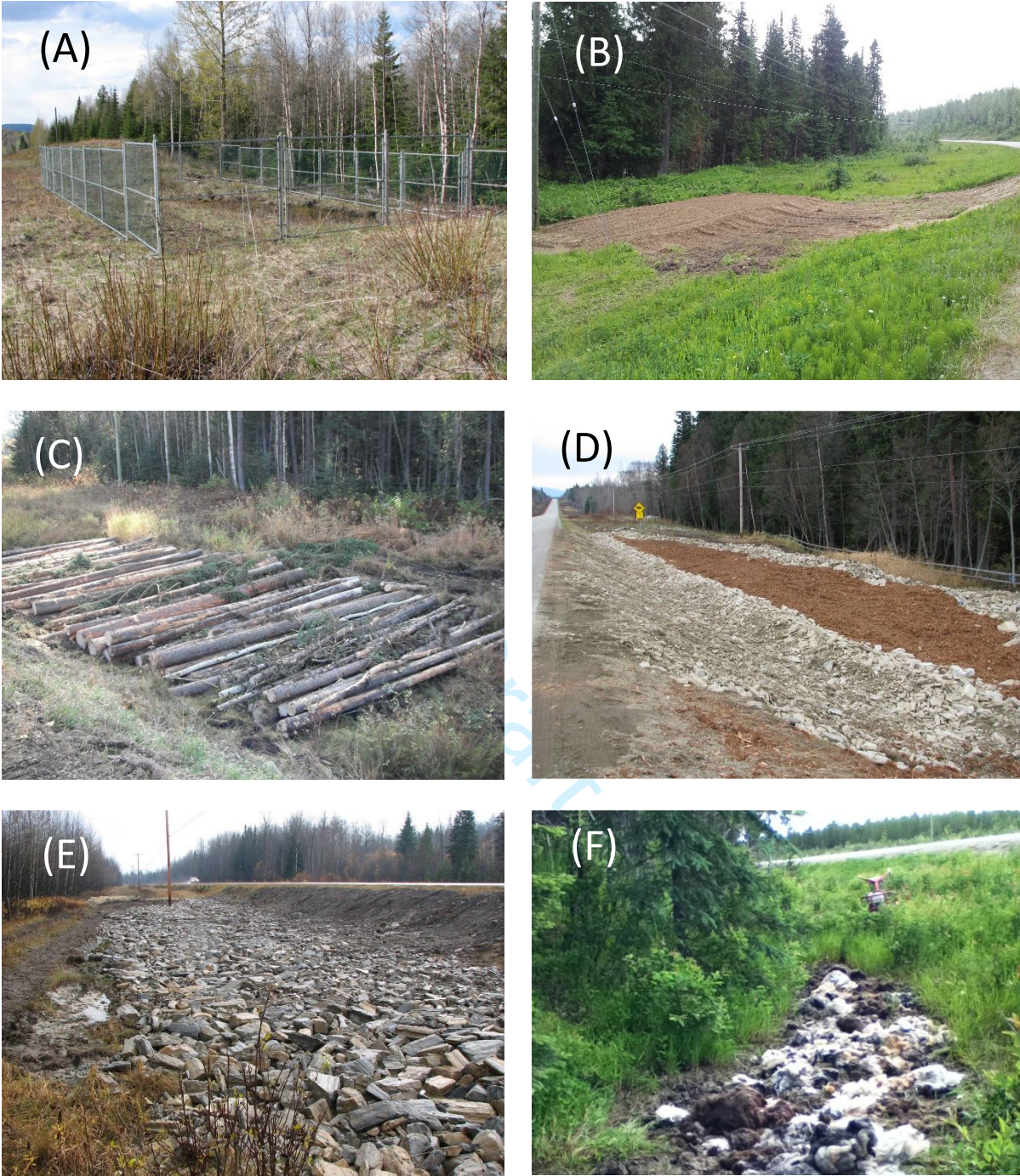


Figure 3.

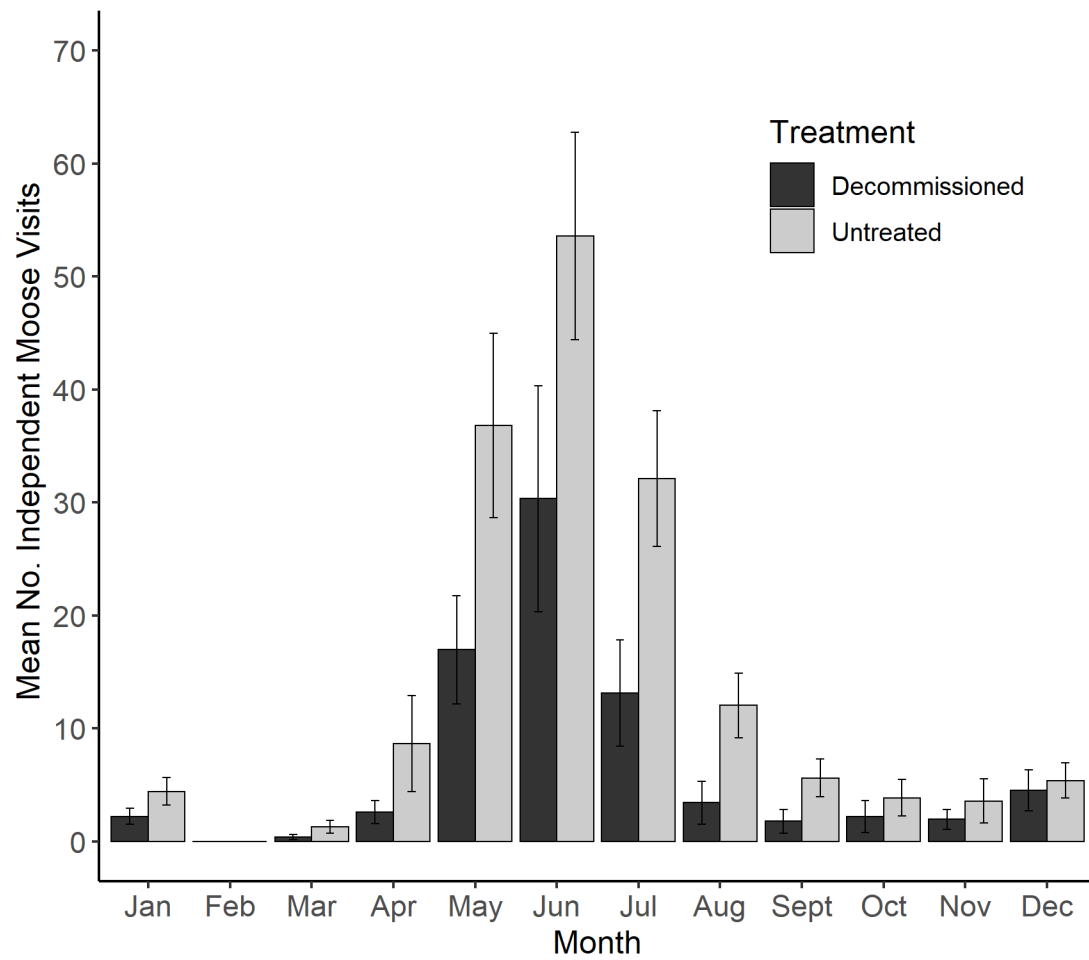


Figure 4.

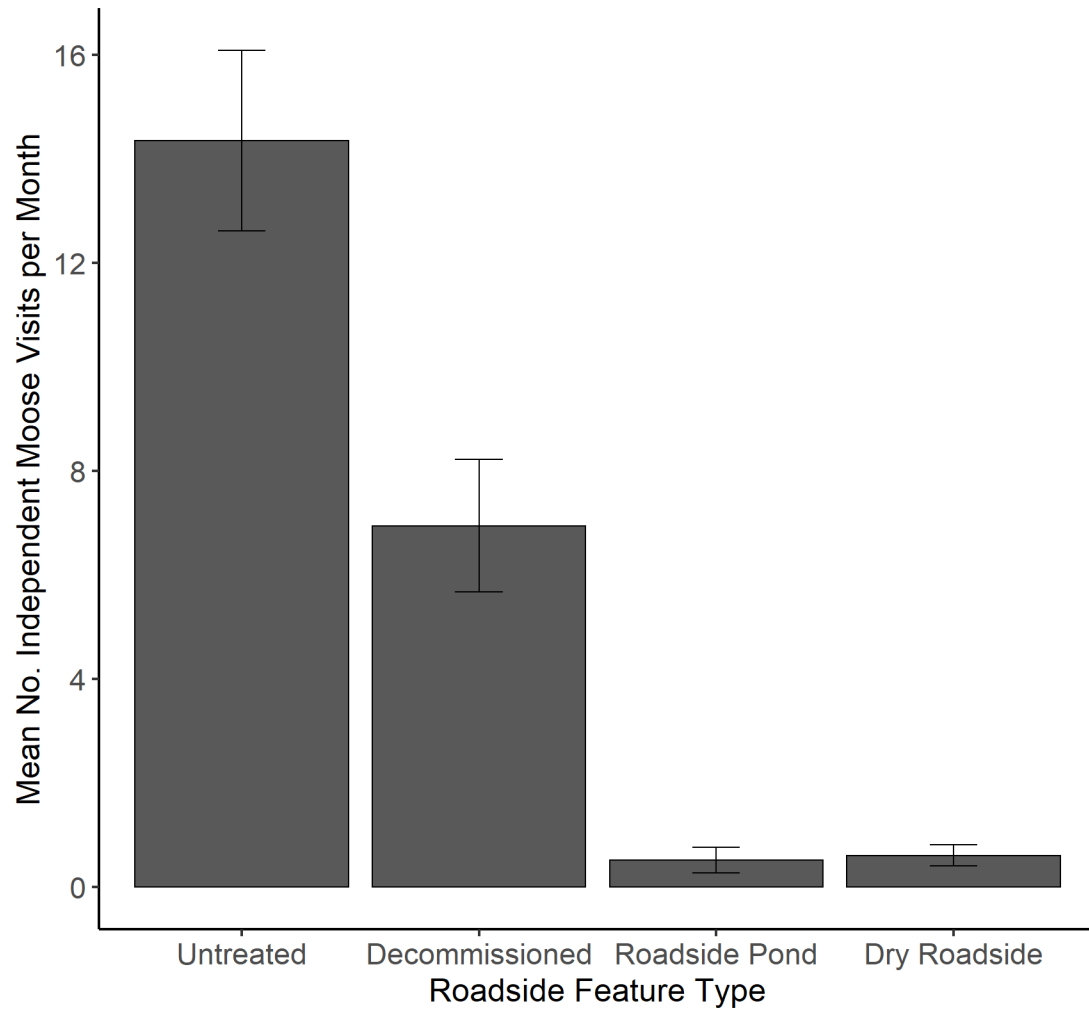


Figure 5.

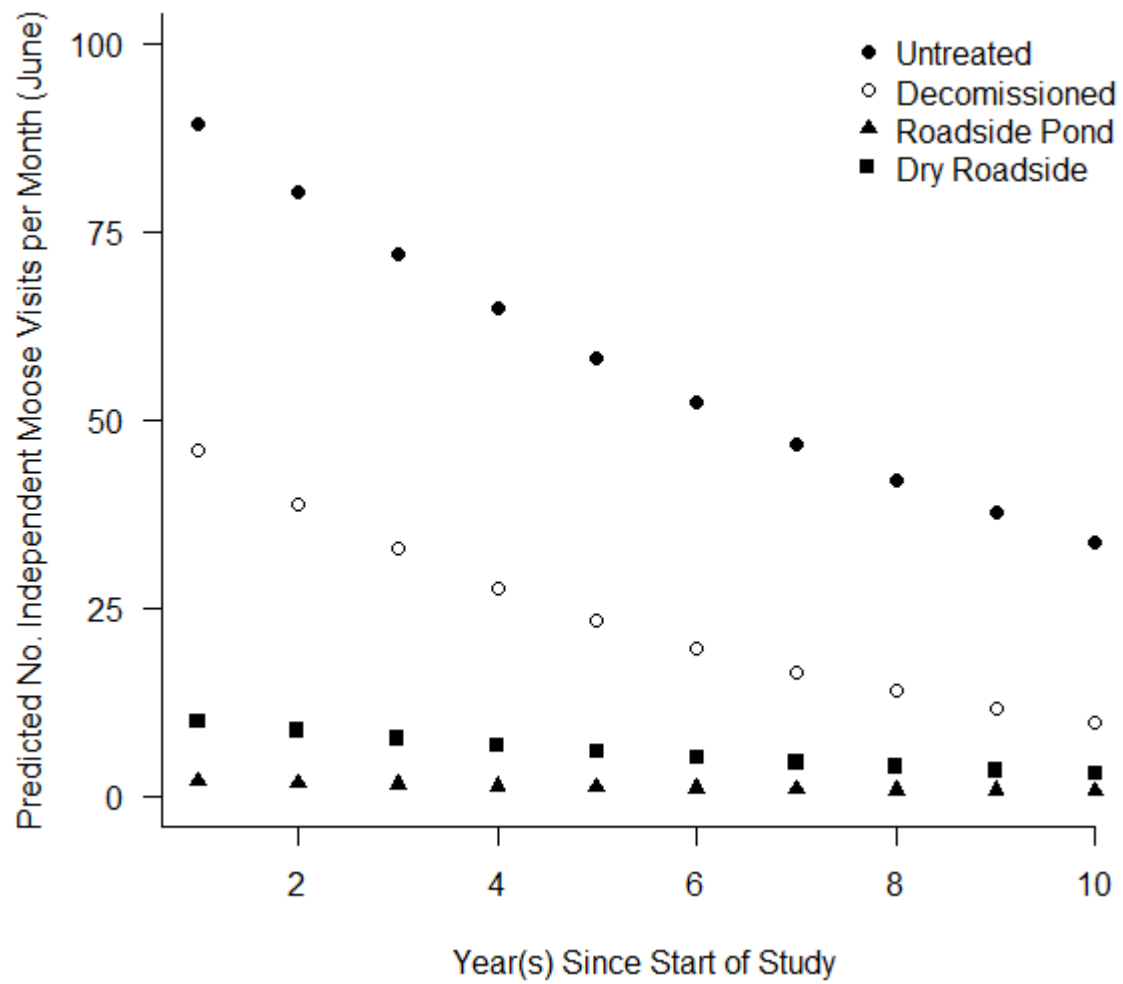


Figure 6.

1 **Table 1.** Model selection tables using conditional AIC for small sample sizes (cAICc) for zero and count aspects of zero-altered
 2 (hurdle) Poisson generalized additive mixed-effects models explaining the number of independent visits by moose (*Alces alces*
 3 (Linnaeus, 1758)) per month to roadside locations (untreated mineral licks, decommissioned licks, roadside ponds, and dry roadsides)
 4 in central British Columbia, Canada. Smooth terms are in parentheses and preceded by S. (Year x Decommissioned) indicates the
 5 inclusion of the direct effects of Year and Decommissioned and an interaction term. Estimated number of parameters = k . Latitude =
 6 Lat. Longitude = Long.

 Zero Model Selection Table

Model Name	Model Description*	Log-likelihood	k	cAICc	Δ cAICc
Time and Type	S(Month) + Year + Decommissioned + Dry + Pond	-13800.25	47.25	27698.33	0.00
Time x Type	S(Month) + (Year x Decommissioned) + Dry + Pond	-13800.09	48.25	27699.55	1.22
Time	S(Month) + Year	-13800.70	47.80	27700.32	1.99
Time and Type and Space	S(Month) + Year + Decommissioned + Dry + Pond + S(Lat. x Long.)	-13800.55	48.72	27701.13	2.80
Time and Space	S(Month) + Year + S(Lat. x Long.)	-13801.11	48.79	27702.17	3.84
Time x Type and Space	S(Month) + (Year x Decommissioned) + Dry + Pond + S(Lat. x Long.)	-13800.99	49.72	27702.34	4.00
Type	Decommissioned + Dry + Pond	-13961.34	41.98	28008.57	310.23
Space and Type	S(Lat. x Long.) + Decommissioned + Dry + Pond	-13961.13	43.59	28011.52	313.19
Space	S(Lat. x Long.)	-13961.49	43.75	28012.59	314.26

 Count Model Selection Table

Model Name	Model Description*	Log-likelihood	k	cAICc	Δ cAICc
Time x Type	S(Month) + (Year x Decommissioned) + Dry + Pond	-7637.47	48.89	15375.34	0.00
Time x Type and Space	S(Month) + (Year x Decommissioned) + Dry + Pond + S(Lat. x Long.)	-7637.40	50.41	15378.40	3.06
Time and Type	S(Month) + Year + Decommissioned + Dry + Pond	-7668.75	47.88	15435.77	60.43

Time and Type and Space	S(Month) + Year + Decommissioned + Dry + Pond + S(Lat. x Long.)	-7668.69	49.40	15438.85	63.50
Time	S(Month) + Year	-7673.10	47.75	15444.20	68.85
Time and Space	S(Month) + Year + S(Lat. x Long.)	-7672.92	48.78	15446.00	70.65
Type	Decommissioned + Dry + Pond	-13947.41	42.89	27982.61	12607.26
Space and Type	S(Lat. x Long.) + Decommissioned + Dry + Pond	-13946.73	44.22	27984.04	12608.70
Space	S(Lat. x Long.)	-13961.40	43.72	28012.32	12636.98

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

7

Draft

8 **Table 2.** Coefficients, standard errors (SE), z -values, and p -values of linear terms
 9 and estimated degrees of freedom (edf), χ^2 -values, and p -values of smoothing terms
 10 for the most parsimonious zero-altered (hurdle) Poisson generalized additive mixed-
 11 effects model explaining the number of independent visits by moose (*Alces alces*
 12 (Linnaeus, 1758)) per month to roadside locations (untreated mineral licks,
 13 decommissioned licks, roadside ponds, and dry roadsides) in central British
 14 Columbia, Canada. Note: Untreated licks are the reference category for location
 15 type. Year since start of study = Year.

Linear Terms				
Zero Model	Estimate	SE	z -value	p -value
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	Estimate	SE	z -value	p -value
Intercept	-0.345	0.182	-1.894	0.058
Year	-0.107	0.004	-27.985	<0.001
Year x 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				
Zero Model	edf	χ^2 -value	p -value	
Month	3.982	260.800	<0.001	
Random Effect: Lick	16.312	190.800	<0.001	
Count Model	edf	χ^2 -value	p -value	
Month	3.998	8505.700	<0.001	
Random Effect: Lick	17.794	2568.000	<0.001	

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19 **Table 3.** Estimated total decommissioning costs and decommissioning costs per m² for roadside
 20 mineral licks by decommissioning technique. Note: Estimated costs include materials (but not fill
 21 materials, e.g., rock, bark, logs), transportation of materials, equipment costs, traffic control and
 22 labour and are affected by lick size and the transportation distance from lick to fill material
 23 sources (e.g., quarries).

Decommissioning Treatment	~Cost of Decommissioning Licks (circa 2015 CAD)	~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

24

25