Research Article

Management of Roadside Salt Pools to Reduce Moose–Vehicle Collisions

MATHIEU LEBLOND,[1] *Université du Québec à Rimouski, Département de biologie, Centre d'études nordiques, 300 allée des Ursulines, Rimouski, PQ G5L 3A1, Canada*

CHRISTIAN DUSSAULT, *Ministère des Ressources naturelles et de la Faune, Direction de la recherche sur la faune, 930 chemin Sainte-Foy, 4e étage, Québec, PQ G1S 2L4, Canada*

JEAN-PIERRE OUELLET, *Université du Québec à Rimouski, Département de biologie, Centre d'études nordiques, 300 allée des Ursulines, Rimouski, PQ G5L 3A1, Canada*

MARIUS POULIN, *Ministère des transports du Québec, Service du soutien technique, Direction générale de Québec et de l'est, 5353 boulevard Pierre-Bertrand, Québec, PQ G2K 1M1, Canada*

RÉHAUME COURTOIS, *Ministère des Ressources naturelles et de la Faune du Québec, Direction du développement de la faune, 880 chemin Sainte-Foy, 2e étage, Québec, PQ G1S 4X4, Canada*

JACQUES FORTIN, *Ministère des transports du Québec, Service du soutien technique, Direction générale de Québec et de l'est, 5353 boulevard Pierre-Bertrand, Québec, PQ G2K 1M1, Canada*

ABSTRACT Wildlife–vehicle collisions cause numerous human fatalities and injuries, and generate considerable expenses in property damage each year. Certain characteristics of the road and its surroundings are known to have an impact on collision probability. Roadside salt pools increase the risk of collision by attracting moose (*Alces alces*) to the side of the road. In the Laurentides Wildlife Reserve of Québec, Canada, roadside salt pools were drained and filled with rocks to deter moose from drinking. We surveyed 12 roadside salt pools during 3 consecutive summers (2003–2005) from mid-May to mid-August. Seven salt pools were managed in autumn 2004, and 5 pools were left untreated. We equipped all 12 sites with electronic apparatus that allowed us to detect moose attendance and study their behavior. We also measured physical, chemical, and environmental characteristics of these pools and other unvisited pools in order to correlate moose attendance with specific habitat criteria. We found that moose mostly attended roadside salt pools from mid-June to mid-July, with a decrease in August. Moose attendance was significantly correlated with visual obstruction toward the road and water availability. Management of the pools caused a decrease in mean length of time moose spent at them. Number of visits decreased significantly at night (by 90%), which was when most visits occurred, but not during the day. The proposed management practice prevented all visiting moose from drinking brackish water. These results suggest that moose should eventually lose interest in treated salt pools, therefore decreasing the risk of moose–vehicle collisions on the road.
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Collisions with several deer (Cervidae) species have been recognized as a road safety problem since the late 1930s (Dickerson 1939, Haugen 1944). Deer–vehicle collisions still cause numerous human fatalities and injuries each year, and result in considerable expenses in terms of property damage and health-care services (e.g., Conover et al. 1995). Continuous improvement and development of road networks to accommodate a growing number of vehicles, in conjunction with increasing deer populations, exacerbates the problem in several areas throughout the world (Oosenbrug et al. 1991, Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996). Temporal and spatial distributions of deer–vehicle collisions are not random. Traffic levels (McCaffery 1973; Joyce and Mahoney 2001; Seiler 2004, 2005), weather conditions (Mysterud 2004, Dussault et al. 2006), and characteristics of the road and its surroundings (Puglisi et al. 1974, Bashore et al. 1985, Finder et al. 1999, Hubbard et al. 2000, Nielsen et al. 2003) all influence the probability of deer–vehicle collisions.

Cervids are known to use natural salt licks to consume minerals, especially sodium (Fraser and Reardon 1980, Tankersley and Gasaway 1983, Risenhoover and Peterson 1986). Sodium is a rare element in continental ecosystems (Botkin et al. 1973), yet it is essential for many vital functions of mammals (Weeks and Kirkpatrick 1976, Belovsky and Jordan 1981). This element, however, is also an important component of deicing salts, and roadside salt pools are created in poorly drained areas where these salts accumulate during snowmelt in spring (Jolicoeur and Crête 1994). The presence of roadside salt pools has often been reported as a factor influencing the occurrence of deer–vehicle collisions because salt pools can attract unusually large numbers of deer to the roadsides (Grenier 1974, Fraser and Thomas 1982, Miller and Litvaitis 1992, Silverberg et al. 2002).

In the Laurentides Wildlife Reserve of Québec, Canada, roadside salt pools were found to increase the likelihood of moose–vehicle collisions by 80% (Grenier 1974). In this area, moose were involved in 40–70 collisions per year for the 12-year period of 1990–2002 (Dussault et al. 2006). In response to this problem, the Quebec Ministry of Transportation decided to drain and fill most problematic roadside salt pools with rocks to render the mineral-rich water inaccessible to moose. The primary objective of this study was to evaluate the efficacy of this management strategy to reduce moose (*Alces alces*)–vehicle collisions in

[1] *E-mail: mathieu_leblond@uqar.qc.ca*

summer. Specific objectives were to document the presence and behavior of moose at roadside salt pools before and after the management intervention, and to determine whether any environmental characteristics of roadside salt pools influenced moose behavior.

STUDY AREA

The Laurentides Wildlife Reserve (7,861 km^2) was intersected by 2 paved roads: provincial highways 175 and 169 that link the regions of Quebec City and Saguenay-Lac St. Jean. At least 100 t/km of salt are spread on these roads annually, which favored the creation and persistence of several roadside salt pools (Grenier 1999). This area was characterized by a mixture of coniferous and mixed-forest stands typical of the boreal region (Dussault et al. 2001). Balsam fir (*Abies balsamea*) and black spruce (*Picea mariana*) dominated at higher altitudes, whereas valleys and low-lying sectors were covered with mixed and deciduous stands, in which paper birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), and yellow birch (*B. alleghaniensis*) were abundant. Commercial logging and a recent spruce budworm (*Choristoneura fumiferana*) epidemic contributed to create a heterogeneous forest mosaic of mature and regenerating stands. The most recent aerial survey that took place in this region found an average moose density of 2.4 moose/10 km^2, with density reaching 8 moose/10 km^2 in highly suitable sectors (St-Onge et al. 1995).

METHODS

Experimental design and management of salt pools

We assessed the timing and frequency of moose visits at 12 roadside salt pools along highways 175 and 169 from mid-May to mid-August during 3 consecutive summers (2003–2005). Seven of these pools were managed by the Quebec Ministry of Transportation in autumn 2004. For ethical reasons, we chose treated salt pools among those available based on their moose–vehicle collision history to improve road safety during the study. The other 5 salt pools were also attended by moose but, for unknown reasons, were apparently less problematic in terms of human safety. These pools were left as is (untreated salt pools), which allowed us to assess annual variations in frequentation. We sampled only 6 treated and 4 untreated salt pools in 2003. Management of roadside salt pools consisted of draining the water with irrigation canals using a mechanical digger and filling pools with a large quantity of rocks that were 10–30 cm in diameter. Rocks were used to prevent moose from reaching any residual water or salt deposits on the soil because soil drainage alone was found to be ineffective (Jolicoeur and Crête 1994).

Roadside salt pool description

We measured water depth at 7 random locations within the pool and visually estimated the proportion of the pool surface that was covered with water using 10% classes (referred to as percentage water surface) on a weekly basis. We collected 2 125-mL samples from each roadside salt pool every 2 weeks during summer of 2003 and took care not to collect urine-contaminated samples (Tankersley and Gasaway 1983). We also collected water samples in unsalted water sources away from highways (lakes or small ponds). With the first set of samples, we estimated salt content of water (mS) using a Hanna conductivity meter (Hanna Instruments 9811; Fisher Scientific, Vancouver, BC, Canada) because water conductivity is highly and linearly correlated with salt content (Bechtold 1996). We added nitric acid to the other set of samples to prevent precipitation and kept these samples in a cool, dry place until analysis. We determined concentrations of major elements found in the water samples (i.e., sodium [Na], potassium [K], calcium [Ca], and magnesium [Mg]) in the laboratory.

During summer of 2003, we also measured a series of physical and environmental variables at roadside salt pools: area (length $\times$ width), distance to the road (from the center of the pool to the road shoulder), elevation relative to the road, cover provided by vegetation at a distance of 15 m (measured as visual obstruction from the center of the pool toward the road), and a second index of visual obstruction of the pool at a distance of 50 m on the road. We measured this last index using a life-size moose silhouette placed in the center of the pool. We then assessed the percentage of the silhouette that was visible by a standing observer from the road. In addition to the roadside salt pools included in our experimental design, we also characterized a series of unvisited or scarcely visited salt pools. These pools were apparently similar to any other pool included in our experimental design but were identified as receiving very little, if any, moose visits after 2 years of regular observation in the study area. We characterized these pools in 2005.

Assessing moose visits to roadside salt pools

To detect and record moose at roadside salt pools, we used movement and heat detectors (Circuitronique Estrie Inc., Sherbrooke, PQ, Canada) that triggered either a Sony (Tokyo, Japan) video camera (called a Vigil) for 4 minutes or a 35-mm photo camera (called a P-BOX). The P-BOXes were equipped with a flash and we equipped some Vigils (33% in 2003, 100% in 2004 and 2005) with infrared lights for night detection. We assessed the detection distance of the movement and heat detectors by using semi-captive moose under various light and weather conditions (C. Dussault, Ministère des Ressources naturelles et de la Faune, unpublished data). We detected about 80% of moose within 10 m. Thus, we used this distance as a guideline for installation of the detection systems around roadside salt pools. We installed the detection systems between 17 May and 31 May and removed them between 16 August and 19 August. We equipped treated salt pools with Vigils only in 2003, but with both Vigils and P-BOXes in 2004 and 2005; we equipped untreated salt pools with P-BOXes only from 2003 to 2005.

We recovered and replaced the videotapes and films during weekly visits to the roadside salt pools. We thus could determine the date and time of each moose visit to pools, as well as the number, sex, and age class (ad, juv, or calf) of observed individuals. We also recorded visit length, as well as time devoted to drinking brackish water by each moose. We used the percentage of time spent drinking (i.e., [time spent drinking/time during which moose was visible] $\times$ 100) as an index of moose behavior at roadside pools.

Data analysis

We grouped all observations into seasonal periods of 14–17 days (e.g., 1–14 Jul, 15–31 Jul, etc.), referred to as fortnights, to facilitate interannual comparisons. We also combined moose visits to roadside salt pools according to daily periods: dawn (1 hr before to 1 hr after sunrise), dusk (1 hr before to 1 hr after sunset), day (between dawn and dusk), and night (between dusk and dawn).

We corrected the frequency and duration of moose visits to roadside salt pools for number of hours during which the detection systems were operational in order to obtain comparable values between sites and time periods (no. of visits/100 hr). We also created another index of moose attendance at roadside salt pools (no. of moose $\times$ hr/100 hr), which included both frequency and duration of visits, by multiplying number of moose present during a visit by length of the visit. We defined a moose visit as the presence of $\geq$1 moose detected simultaneously by $\geq$1 of the 2 available detection systems. If the time between 2 successive detections exceeded 60 minutes, we considered these events as 2 independent visits. Moreover, we also considered the successive presence of 2 different moose within a 60-minute period as 2 independent visits. We considered detection systems inoperative when no moose visits were recorded due to technical problems or when videotapes or films were full. Unfortunately, we could not use data collected at night in 2003 because we only used infrared lights in a few sites that year.

To determine whether environmental characteristics influenced the frequency of moose visits and moose behavior at roadside salt pools, we used Pearson correlations (with Bonferroni-adjusted probabilities) between number of visits/100 hours or time spent drinking and all quantitative variables measured at salt pools. We calculated separate correlation coefficients for each year before management intervention, that is, 2003 and 2004. For variables likely to vary during the summer, that is, percentage water surface, water depth, and conductivity, we calculated correlations using fortnight as the sample unit. For all other variables that were permanent attributes of the pools and thus only measured once during the study, we made correlations using mean number of moose visits/100 hours or mean time spent drinking at each site.

To determine the fortnightly and daily patterns of moose visits to roadside salt pools, we used analysis of variance for repeated measures with fortnight and daily period as independent variables and number of visits/100 hours as the dependent variable. We carried out this analysis only in 2004 to allow simultaneous use of night and day data. We tested the effect of salt pool management on frequency and duration of moose visits with analyses of variance for repeated measures, using number of moose visits/100 hours or number of moose $\times$ hours/100 hours as the dependent variable and year, fortnight, and pool type (treated vs. untreated) as independent variables. We made separate analyses for day (2003, 2004, and 2005 data) and night (2004 and 2005 data) periods.

To normalize the distribution of residuals, we employed a $\ln(x + 0.001)$ transformation. We then conducted statistical analyses with SAS Version 8.00 (SAS Institute, Cary, NC) and considered effects significant at $P \leq 0.05$.

RESULTS

Moose visits to roadside salt pools

Both mean number of moose visits/100 hours (cover provided by vegetation at 15 m: $r \geq 0.607$, $P \leq 0.005$; visual obstruction index at 50 m: $r \geq 0.615$, $P \leq 0.007$) and mean time spent drinking (cover provided by vegetation at 15 m: $r \geq 0.443$, $P \leq 0.050$; visual obstruction index at 50 m: $r \geq 0.450$, $P \leq 0.047$) were positively correlated with the 2 indices of visual obstruction during the 2 years before management (i.e., 2003 and 2004). Number of visits/100 hours was also correlated with pool area (in 2003 only: $r = 0.650$, $P = 0.004$), percentage water surface (in 2004 only: $r = 0.265$, $P = 0.028$), water depth (in 2004 only: $r = 0.429$, $P < 0.001$), and water conductivity (in 2004 only: $r = -0.482$, $P < 0.001$). Distance to the road and elevation relative to the road were not significantly correlated with either index of moose attendance for the 2 years. Chemical analysis of water samples indicated that sodium was the most abundant salt in roadside salt pools (890 ppm Na compared to 78 ppm Ca, 7 ppm K, and 3 ppm Mg). Sodium was also more concentrated in roadside salt pools than in water samples collected away from highways, where the mean concentration was 29 ppm.

The remote detection systems captured 670 independent moose visits to roadside salt pools over the study (2003 = 125; 2004 = 405; 2005 = 140), and we estimated that $\geq$50 different moose visited surveyed salt pools each year.

In 2004, number of moose visits/100 hours to roadside salt pools depended on the fortnightly ($F_{18} = 4.04$, $P < 0.001$) and daily period ($F_9 = 5.19$, $P < 0.001$). Number of visits/100 hours was relatively high from mid-June to mid-July ($\bar{x} = 0.56 \pm 0.22$) and decreased considerably later in the summer (0.12 ± 0.05). Visits were also more frequent during the night (0.64 ± 0.24) than during the day (0.19 ± 0.07), regardless of the fortnight ($F_{54} = 0.98$, $P = 0.515$).

Overall, 39.7% of visits were made by adult females, compared to 20.0% for juveniles and 15.4% for adult males. These proportions varied somewhat from year to year (2003: 42.4% ad F, 23.2% juv, 20.8% ad M, and 13.6% unknown age; 2004: 44.0% ad F, 18.5% juv, 15.6% ad M, and 22.0% unknown age; 2005: 25.0% ad F, 21.4% juv, 10.0% ad M, and 43.6% unknown age). Most visits were made by solitary moose, but we also observed groups of 2 (2003 = 17.6%, 2004 = 19.8%, 2005 = 8.6%) or 3 moose (2003 = 2.4%, 2004 = 3.7%, 2005 = 1.4%). The majority of moose groups consisted of an adult female with offspring, but 55 visits (8.2%) were made by individuals of various sexes and ages.

In 2003 and 2004, almost all visits to roadside salt pools lasted <1 hour and tended to last <15 minutes (70.0%

Table 1. Results of analyses of variance testing the effect of the management practices on frequency and duration of moose visits to roadside salt pools of the Laurentides Wildlife Reserve, Québec, Canada, during the day (including dusk and dawn; 2003–2005) and night (2004 and 2005).

		Day				Night[a]				
		$\bar{x}$ no. of visits/100 hr		No. of moose × hr/100 hr			$\bar{x}$ no. of visits/100 hr		No. of moose × hr/100 hr	
Source	df	F	P	F	P	df	F	P	F	P
Yr	2	1.27	0.308	5.92	0.011*	1	11.00	0.009*	9.90	0.012*
Fortnight	6	4.07	0.002*	1.77	0.121	6	6.83	<0.001*	2.19	0.058
Type of pool[b]	1	13.25	0.005*	24.59	<0.001*	1	7.13	0.026*	10.44	0.010*
Yr × fortnight	12	0.52	0.897	1.44	0.158	6	0.89	0.504	2.92	0.015*
Yr × type of pool	2	2.55	0.109	6.23	0.009*	1	13.21	0.005*	15.40	0.004*
Fortnight × type of pool	6	0.37	0.896	0.72	0.639	6	1.19	0.328	1.27	0.286

[a] We carried out night analysis on 2004–2005 data only.
[b] Type of pool refers to treated or untreated pools.
* Significant at $P \leq 0.05$.

[371/530]). In 2005, an even larger proportion of visits lasted <15 minutes (87.9% [123/140]) than those in the previous years ($G = 20.59$, df = 1, $P < 0.001$). Before management, 42.9% (85/198) of visits captured by the Vigil were triggered by moose that did not drink water. Individuals that drank devoted about 21.1% of their time to that activity. Following pool management, we did not observe any moose drinking water.

Influence of pool management on moose visits

The 2 indices of moose attendance at roadside salt pools at night gave similar results when we assessed the effect of management (Table 1). Number of visits/100 hours not only varied across the summer (fortnight: $F_{6,54} = 6.83$, $P < 0.001$), but was higher in 2004 (before management; 1.49 ± 0.35) than in 2005 (after management; 0.19 ± 0.04; $F_{1,9} = 11.00$, $P = 0.009$; Fig. 1). The interaction between year and pool type was significant, indicating that moose attendance at night decreased from 2004 to 2005, but in treated pools only.

Number of visits/100 hours at roadside salt pools during the day varied across the season (fortnight: $F_{6,54} = 4.07$, $P = 0.002$) but not between summers ($\bar{x} = 0.20 \pm 0.05$ in 2003, 0.48 ± 0.1 in 2004, and 0.19 ± 0.04 in 2005; $F_{2,16} = 1.27$,

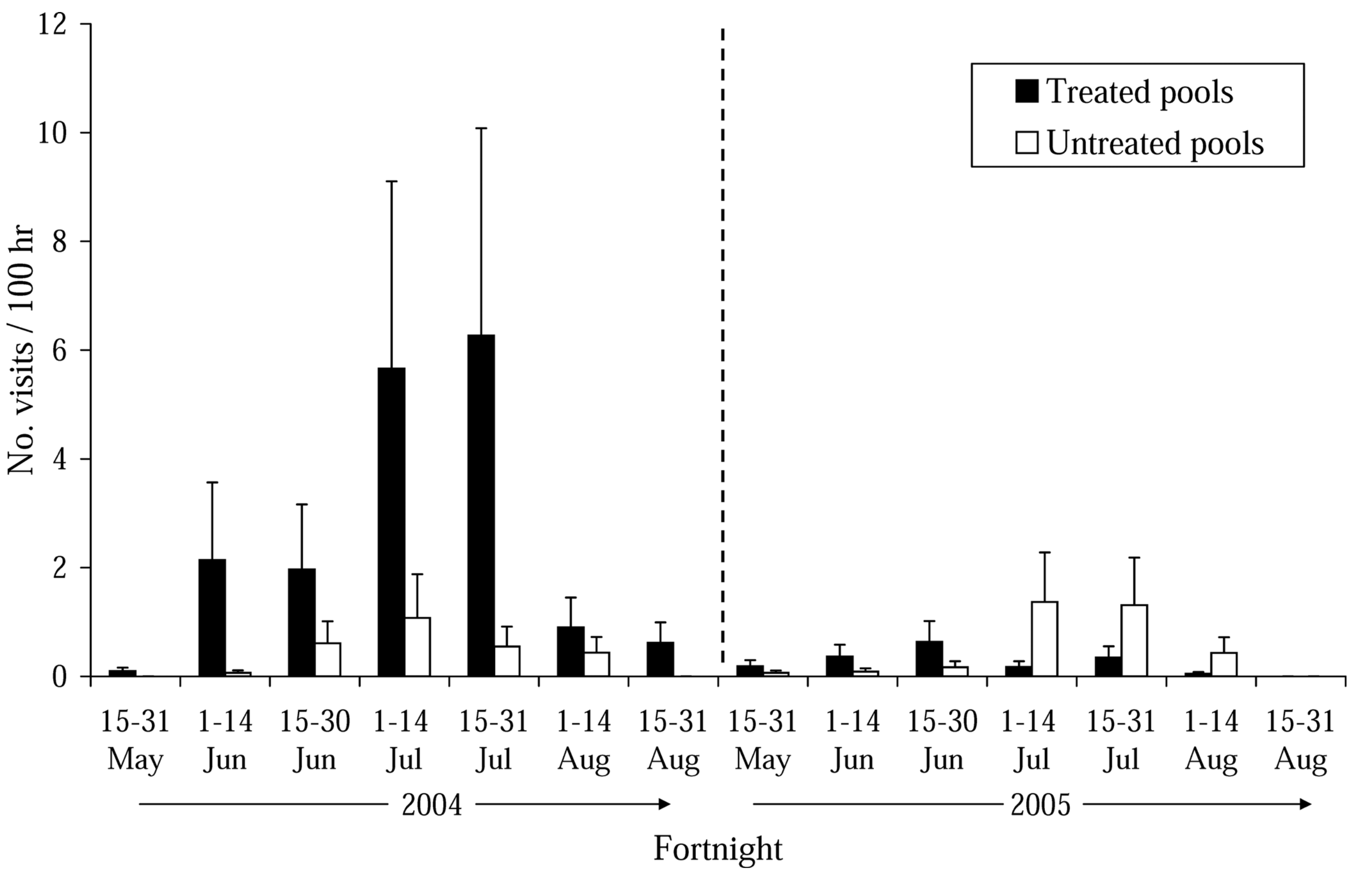

Figure 1. Number of moose visits/100 hours ($\bar{x}$ + SE) during the night at treated and untreated roadside salt pools of the Laurentides Wildlife Reserve, Québec, Canada, by fortnight in 2004 and 2005. The dotted line indicates the time of pool management intervention.

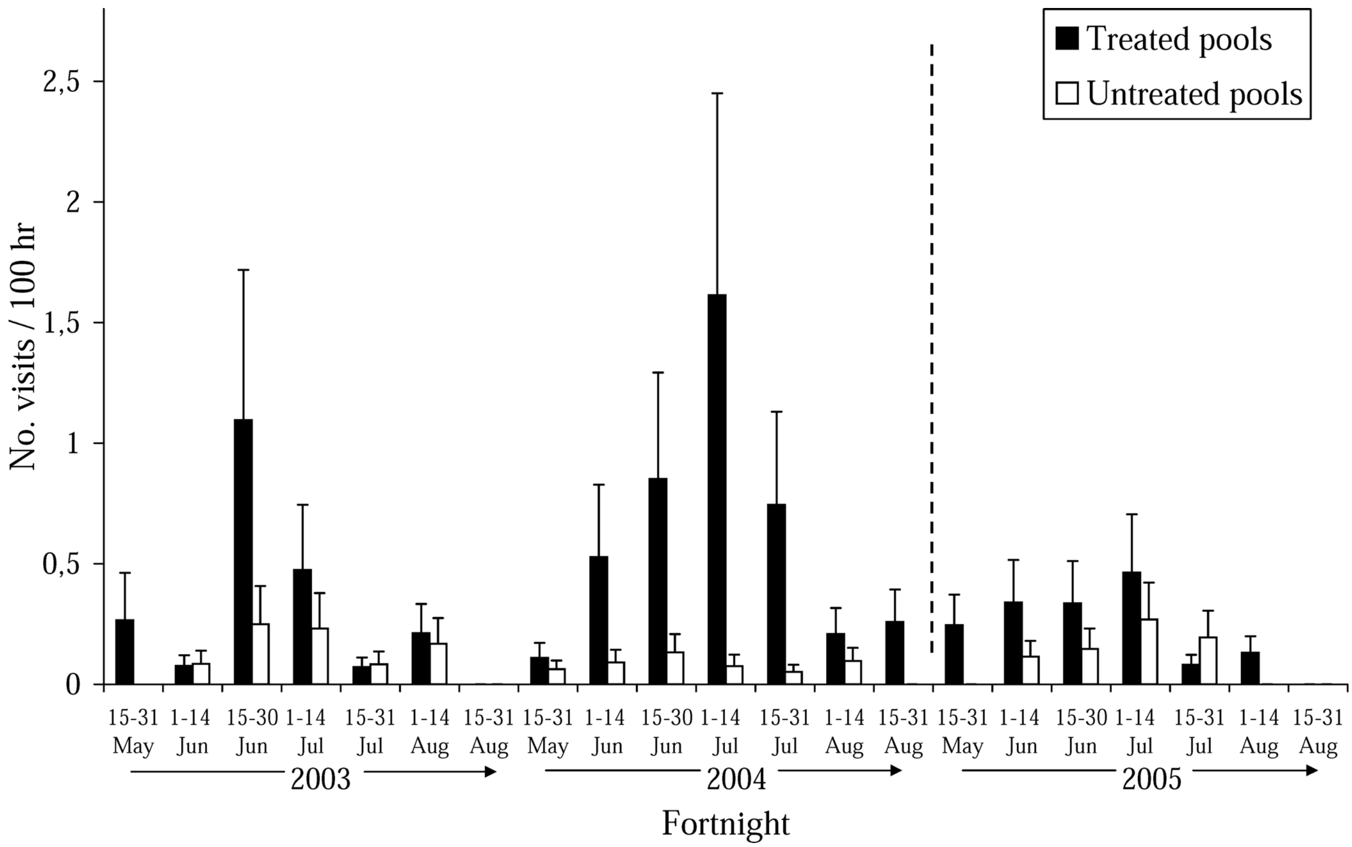

Figure 2. Mean number of moose visits/100 hours + SE during the day (including dusk and dawn) at treated and untreated roadside salt pools of the Laurentides Wildlife Reserve, Québec, Canada, by fortnight, 2003–2005. The dotted line indicates the time of pool management intervention.

$P = 0.308$; Table 1, Fig. 2). The second index combining frequency and duration of visits (i.e., no. of moose × hr/100 hr), however, was significantly lower in 2005 (0.02 ± <0.01) than in 2003 (0.11 ± 0.01) and 2004 (0.18 ± 0.02), for treated pools only (Table 1). Seasonal patterns of moose visits to untreated pools was similar to that of treated pools during both the day ($F_{6,54} = 0.37$, $P = 0.896$) and night ($F_{6,54} = 1.19$, $P = 0.328$) and did not change during the study, despite management of other pools (d: $F_{12,98} = 0.52$, $P = 0.897$; night: $F_{6,57} = 0.89$, $P = 0.509$).

DISCUSSION

The most obvious effect of management of roadside salt pools was a reduction in duration of moose visits, although frequency of visits also decreased at night (we recorded 10 times more night visits in 2004 than in 2005). Moose–vehicle collisions in the Laurentides Wildlife Reserve peak at night (Dussault et al. 2006), and a decrease in moose visits to salt pools at this time of day should reduce the risk of collision. Another effect of management was the inability of moose to attain brackish water or soil through rocks in treated pools.

Use of salt licks by cervids has often been found to be positively related to water conductivity and dissolved salt concentration (Hebert and Cowan 1971, Tankersley and Gasaway 1983, Moe 1993). Contrary to expectations, however, the relationship between frequency of visits and water conductivity was negative in our study (statistically significant in 2004 only). Sodium concentrations were high in all sampled roadside salt pools, indicating that salt was widely available along the highways. Alternatively, other factors such as visual obstruction may have been more important to moose habitat selection (as demonstrated by the importance of vegetative cover). The influence of pool area, percentage water surface, and water depth on moose frequentation suggests that moose attended salt pools to drink mineral-rich water. Hence, we conclude that moose use roadside salt pools to drink sodium-rich water but choose pools with respect to vegetative cover instead of salt concentration in areas where salt is abundant.

The proportion of juveniles observed at roadside salt pools corresponded approximately to the relative proportion of juveniles in the population and the sex ratio of moose was biased towards adult females, which reflected the observed ratio in the population (St-Onge et al. 1995). The high proportion of individuals of unknown sex–age recorded in 2005 (43.6%) was partly due to the brevity of visits and insufficient time for identification. Duration of moose visits to roadside salt pools was highly variable but mostly lasted <15 minutes, and visits decreased in length after management. Median visit length was 6 minutes before and 4 minutes after pool management. Deer visits to natural salt licks are generally >15 minutes (15–30 min; Weeks 1978, Tankersley and Gasaway 1983, Risenhoover and Peterson

1986). Several observations in this study suggest that moose were disturbed by passing vehicles when at roadside salt pools (Silverberg et al. 2003). First, moose preferred pools where visual obstruction between the pool and road was high. Second, moose visits were more frequent at night than day (fewer vehicles pass during night), and third, 28% of moose visits to roadside salt pools ended with flight of the moose in reaction to a passing vehicle, all suggesting that moose avoided traffic disturbance.

The fortnightly pattern of moose visits to roadside salt pools in the Laurentides Wildlife Reserve was similar to patterns observed for moose or other cervid species (e.g., Carbyn 1975, Holl and Bleich 1987, Couturier and Barrette 1988). The increase in visits to salt licks in early summer is often related to mineral deficiencies (particularly Na) in the diet (Hebert and Cowan 1971, Atwood and Weeks 2002), resulting from consumption of opening buds in spring. Freshly opened leaves have a high potassium and water content, which leads to considerable sodium loss through the feces (Fraser and Hristienko 1981). The observed peak in moose visits to roadside salt pools likely corresponds to this period of bud opening, which occurred 8–10 June for paper birch and trembling aspen. In addition, sodium requirements increase in spring. Moulting, somatic growth in juveniles, antler growth in males, and gestation and lactation in adult females all require increased sodium intake in cervids (Weeks and Kirkpatrick 1976, Belovsky and Jordan 1981, Pletscher 1987). We first observed calves at salt pools between 10 June and 19 June, which corresponded precisely with peak adult female attendance.

Most studies in North America have demonstrated a notable decrease in moose attendance at natural salt licks from late July until the end of summer. This change may be due to a shift in the feeding behavior of cervids to more sodium-rich aquatic vegetation (Jordan et al. 1973) or to a decrease in salt preference (Fraser et al. 1982). Our study indicated that moose used roadside salt pools even when aquatic vegetation was available (see also Fraser et al. 1982). Possibly, the extremely high salinity of water found in salt pools ($\bar{x} = 890$ ppm) was more attractive than the mean salinity of aquatic plants (e.g., 500 ppm on Isle Royale, USA; Botkin et al. 1973). Also, brackish water is relatively easy to consume, whereas aquatic plants have an extremely low net energy content per unit of filled rumen (Belovsky and Jordan 1981) and may be rich in toxic heavy metals (Ohlson and Staaland 2001).

A high proportion (42.9%) of moose that visited our sites did not drink the water. Moreover, moose that drank water spent little time doing so and passed the remaining time in movement, feeding, or alert behavior. Because groups accounted for 19% of moose visits, we hypothesize that salt pools are important gathering places for some individuals (Panichev et al. 2002). We rarely observed aggressive interactions at roadside salt pools, contrary to that described at natural mineral licks (Couturier and Barrette 1988).

Our results suggest that the management of roadside salt pools may reduce attendance by moose. It was not possible, however, to evaluate how this change in moose behavior related to collision risk. It is likely that moose gradually stop frequenting these sites and that this behavioral change takes place over 1 year or longer. Indeed, a moose must return at least once to notice the pool's destruction. Other measures have been tested to reduce moose attendance at salt pools. Addition of chemical repellents (e.g., putrescent compound, creosote, and isobutyric acid) was found to be a short-term solution that required frequent reapplication (Fraser and Hristienko 1982). Other researchers have proposed use of deicing salts that are less attractive to cervids than NaCl (e.g., urea, ethylene glycol, or $CaCl_2$; Fraser and Thomas 1982); however, the cost of these salts can be prohibitive, especially where winter conditions are severe. From this point of view, the draining and filling of roadside salt pools appears to be a valuable solution. A longer study would allow assessment of the long-term efficacy of our pool management strategy and its impact on moose–vehicle collisions.

MANAGEMENT IMPLICATIONS

Our results indicate that draining roadside salt pools and filling them with rocks may reduce the risk of moose–vehicle collisions where roadside salt pools are common. Our results also indicated that removal of vegetation that creates visual obstruction between salt pools and the road could be considered an alternative or complementary management strategy where drainage and filling with rocks is problematic. This strategy would likely increase disturbance of moose by vehicles and could reduce frequency of moose visits to these salt pools. Removal of vegetation could also increase driver vision, allowing drivers to better avoid moose on the road.

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