UNIVERSITÉ DU QUÉBEC À RIMOUSKI

ÉVALUATION DE MESURES D'ATTÉNUATION DES ACCIDENTS ROUTIERS IMPLIQUANT L'ORIGNAL

MÉMOIRE
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AVANT-PROPOS

Les chapitres II (Management of Roadside Salt Pools to Reduce Moose-Vehicle Collisions) et III (Electric Fencing as a Measure to Reduce Moose-Vehicle Collisions) ont été soumis et acceptés par la revue scientifique « Journal of Wildlife Management ». Les articles ont été intégrés en version finale anglaise. Mes co-auteurs sont Christian Dussault, chercheur au MRNF – secteur faune et co-directeur de mon projet de maîtrise, Jean-Pierre Ouellet, professeur-chercheur à l'UQAR et directeur de mon projet de maîtrise, Marius Poulin, MTQ, responsable du projet de mise en place des mesures d'atténuation évaluées dans cette étude, Réhaume Courtois, chercheur au MRNF – secteur faune et Jacques Fortin, MTQ, responsable de terrain. Toutes ces personnes m'ont assisté dans la réalisation de cette étude, soit au cours des trois années de terrain, soit lors de la rédaction des rapports, articles et mémoire.

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RÉSUMÉ

Chaque année, les accidents routiers impliquant la grande faune sont à l'origine de pertes de vies humaines, de nombreux blessés et de coûts importants en dégâts matériels. Dans cette étude, de nouvelles mesures d'atténuation ont été évaluées afin de réduire le risque d'accident routier impliquant l'orignal (*Alces alces*), soit l'aménagement des mares salines artificielles en bordure des routes et la clôture électrique. L'étude s'est déroulée dans la réserve faunique des Laurentides, un territoire où il survient de 40 à 70 accidents impliquant l'orignal chaque année.

Les mares salines artificielles augmentent le risque de collision routière en attirant l'orignal en bordure des routes. Nous avons fait le suivi de 12 mares de bord de route durant trois étés consécutifs (2003-2005). Sept de ces mares ont été drainées et empierrées à l'automne 2004 afin d'empêcher l'orignal de s'y abreuver. Nous y avons installé des appareils de détection afin de recenser les visites et étudier le comportement des orignaux. Nous avons aussi mesuré les caractéristiques physiques, chimiques et environnementales de ces mares. Nous avons observé que la fréquentation des mares salines par les orignaux était corrélée au couvert latéral procuré par la végétation et à la disponibilité en eau. L'aménagement des mares salines a permis de diminuer le temps moyen passé aux mares par les orignaux. Le nombre de visites a diminué significativement durant la nuit, soit la période durant laquelle le plus de visites étaient recensées. Enfin, l'aménagement a empêché les orignaux de boire l'eau salée des mares. Ces résultats suggèrent que les orignaux devraient délaisser les mares salines aménagées avec le temps, diminuant ainsi le risque d'accident routier.

Nous avons aussi testé l'efficacité de la clôture électrique à réduire le risque d'accident routier impliquant l'orignal à l'aide de relevés de pistes hebdomadaires et de la télémétrie GPS dans deux secteurs clôturés (5 et 10 km). Le nombre de pistes d'orignal recensées le long de la route dans les secteurs clôturés a diminué de *ca.* 80 % suite à l'installation des clôtures électriques. Environ 30 % des pistes d'orignal observées du côté de la route par rapport à la clôture ont été laissées par des orignaux qui ont traversé la clôture alors qu'elle était électrifiée ; la plupart des orignaux (38 %) ont accédé au corridor routier par des ouvertures ou par les extrémités de la clôture. Les clôtures électriques étaient moins efficaces durant les chutes de courant occasionnelles.

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INTRODUCTION GÉNÉRALE

La problématique des accidents routiers impliquant la grande faune fait obstacle à la sécurité routière depuis longtemps (Dickerson 1939, Haugen 1944). Chaque année, ces accidents sont à l'origine de pertes de vies humaines, de nombreux blessés et de coûts importants en dégâts matériels. Aux États-Unis, par exemple, Conover et al. (1995) ont estimé à 211 le nombre annuel de mortalités humaines associées aux accidents routiers impliquant la grande faune, en plus des 29 000 blessés et des coûts estimés à plus d'un milliard US$. Le développement et l'amélioration continuels du réseau routier qui doit accommoder un nombre grandissant de véhicules, associés à l'augmentation de la densité de la plupart des grands cervidés, contribuent actuellement à intensifier le problème dans plusieurs régions du monde (Oosenbrug et al. 1991, Groot Bruinderink et Hazebroek 1996, Romin et Bissonette 1996). Le Québec ne fait pas exception à cette tendance mondiale; selon les relevés officiels, les routes du Québec furent le théâtre d'environ 2 540 accidents impliquant la grande faune par année au cours des années 90, dont 200 impliquaient l'orignal (*Alces alces*), 2 300 le cerf de Virginie (*Odocoileus virginianus*) et 40 l'ours noir (*Ursus americanus*; Munro et al. 2001). Ces valeurs sont conservatrices puisque certains accidents ne sont pas rapportés, particulièrement lorsqu'ils ne causent que des dégâts mineurs (Romin et Bissonette 1996). Au Québec, comme ailleurs dans le monde, le nombre réel d'accidents impliquant la grande faune pourrait être jusqu'à deux fois plus élevé que celui rapporté (Conover 1997).

La masse corporelle élevée et la grande taille de l'orignal en font l'espèce causant les blessures les plus graves et engendrant le plus de dommages matériels (Figure 1.1). C'est dans la réserve faunique des Laurentides que les accidents routiers impliquant l'orignal sont les plus nombreux au Québec. L'orignal y a été impliqué dans 40 à 70 accidents par année entre 1990 et 2002 (Poulin 1999, Poulin et Fortin 2005). Dans cette réserve, les 310 accidents impliquant l'orignal survenus entre 2000 et 2004 ont causé plus de 6,7 millions CAN$ en dommages. La réduction de l'incidence des accidents routiers impliquant la grande faune est un objectif important pour le Ministère des Transports au Québec, comme dans beaucoup d'autres juridictions (Clevenger et al. 2001). Afin de proposer des mesures d'atténuation adaptées et efficaces, il est nécessaire de comprendre les facteurs qui favorisent l'occurrence de ces accidents.

La répartition temporelle et spatiale des accidents routiers impliquant la grande faune n'est pas aléatoire. Les mois de mai à août correspondent à la période la plus propice aux accidents dans la réserve faunique des Laurentides (Grenier 1974, Dussault et al. 2006) ainsi que dans d'autres régions du monde (Fraser 1979, Lavsund et Sandegren 1991, Belant 1995, Farrell et al. 1996, Joyce et Mahoney 2001). Ces accidents peuvent survenir à toute heure de la journée, mais le risque est maximal durant la nuit, suivi par le crépuscule et l'aube (Dussault et al. 2006), dû à l'activité accrue des cervidés et à la visibilité réduite qui prévalent en ces périodes de la journée (Haikonen et Summala 2001). La densité du trafic (McCaffery 1973, Joyce et Mahoney 2001, Seiler 2004, 2005), le climat (Mysterud 2004, Dussault et al. 2006) et certaines caractéristiques de l'environnement autour des routes (Puglisi et al. 1974, Bashore et al. 1985, Finder et al.

1999, Hubbard et al. 2000, Nielsen et al. 2003, Malo et al. 2004, Seiler 2005, Dussault et al. 2006) peuvent avoir un impact sur la probabilité d'occurrence des accidents. Dans la réserve faunique des Laurentides, Dussault et al. (2006) ont démontré que la densité de l'orignal, la pente moyenne du terrain de chaque côté de la route, la présence d'un corridor de déplacement (*i.e.*, vallées transversales de part et d'autre de la route) et la présence de mares salines avaient un effet sur la probabilité d'occurrence des accidents routiers impliquant l'orignal. Or, bien qu'il soit impossible d'intervenir sur les facteurs reliés à la topographie, la destruction des mares salines au bord des routes pourrait s'avérer une mesure d'atténuation efficace.

L'utilisation des mares salines naturelles par les cervidés afin de combler leurs besoins en minéraux est bien documentée (Hebert et Cowan 1971, Fraser et Reardon 1980, Tankersley et Gasaway 1983, Risenhoover et Peterson 1986, Couturier et Barrette 1988). Le sodium est un élément rare dans les écosystèmes continentaux (Botkin et al. 1973), où il se retrouve en plus grande concentration dans les plantes aquatiques (Jordan et al. 1973). Belovsky et Jordan (1981) ont démontré que les orignaux de l'Isle Royale ne pouvaient combler que 7 à 14 % de leurs besoins en sodium en ingérant la végétation terrestre. Ce sel est recherché par les cervidés puisqu'il est nécessaire à plusieurs fonctions vitales : maintien de l'équilibre du pH, de la pression osmotique et du volume sanguin, fonctionnement des cellules musculaires et nerveuses, croissance, reproduction, lactation, production de poils et maintien de la masse corporelle et de l'appétit (Weeks, Jr. et Kirpatrick 1976, Belovsky et Jordan 1981, Robbins 1993). Les cervidés sont donc attirés par les mares salines naturelles, une source très concentrée en sodium brut.

Toutefois, dans certains sites mal drainés en bordure des routes, des mares salines artificielles se forment parfois suite à l'accumulation du sel de déglaçage utilisé en hiver dont le chlorure de sodium (NaCl) est le principal constituant. Dussault et al. (2003) rapportent des concentrations moyennes de sodium de l'ordre de 890 ppm dans les mares salines en bordure des routes de la réserve faunique des Laurentides, soit des concentrations passablement plus élevées que ce que peuvent trouver les orignaux dans les plantes aquatiques (*e.g.*, 500 ppm sur l'Isle Royale, Botkin et al. 1973) ou dans des mares salines naturelles (*e.g.*, 162 ppm en Indiana (Weeks, Jr et Kirkpatrick 1976) ; 91 ppm sur l'Isle Royale (Risenhoover et Peterson (1986)) et artificielles (*e.g.*, 336 ppm en Ontario (Fraser et Thomas 1982) ; 202 ppm en Nouvelle-Angleterre (Pletscher 1987) ; 629 ppm au New-Hampshire (Miller et Litvaitis 1992)) fréquentées par les cervidés. Tel qu'observé dans la réserve faunique des Laurentides (Grenier 1974, Dussault et al. 2006), en Ontario (Fraser et Thomas 1982) et aux États-Unis (Miller et Litvaitis 1992), la présence de mares salines peut induire un achalandage inhabituel des orignaux en bordure des routes, augmentant la probabilité d'accident routier.

Certains aménagements pour les mares salines au bord des routes ont déjà été testés dans le but de réduire l'occurrence des accidents routiers impliquant les cervidés. Jolicoeur et Crête (1987, 1994) ont démontré que l'assèchement des mares salines par l'amélioration du drainage n'était pas une mesure d'atténuation efficace à long terme lorsque employée seule. En effet, les orignaux continuaient de fréquenter les mares suite à leur drainage et créaient, par piétinement, de nouvelles mares d'eau stagnante qui conservaient une salinité élevée. Ce résultat démontre que le sol des mares salines est gorgé de sel et que la pluie et la fonte des neiges permettent la création ou le rétablissement de mares salines à proximité dans les dépressions où le drainage est faible. L'utilisation de substances chimiques repoussantes (*e.g.*, matières en putréfaction, créosote, acide isobutyrique) pour repousser les cervidés loin des mares salines a été évaluée par Fraser et Hristienko (1982). Ces derniers ont démontré que l'utilisation de ces substances pouvait être efficace à court terme mais que les traitements devaient être appliqués fréquemment étant donné la dissipation rapide des odeurs. Donc, cette méthode pourrait être considérée pour corriger un problème temporaire dans une mare saline particulièrement problématique, mais elle est trop fastidieuse et coûteuse pour régler un problème à long terme ou à une échelle régionale. D'autres auteurs ont même proposé de changer la composition des sels de déglaçage et d'utiliser des sels moins attractifs pour les cervidés (*e.g.*, urée, éthylène glycol ou $CaCl_2$; Fraser et Thomas 1982). Toutefois, le coût de ces sels peut être prohibitif, surtout dans les secteurs où les conditions hivernales sont difficiles. La recherche de solutions au problème des mares salines au bord des routes demeure d'un grand intérêt. Afin de proposer des mesures d'atténuation adaptées et efficaces, une meilleure compréhension du comportement de l'orignal aux mares salines s'avère aussi essentielle.

Plusieurs études ont été réalisées afin d'évaluer d'autres mesures d'atténuation des accidents routiers impliquant la grande faune dans les régions où les mares salines n'étaient pas la source du problème (Tableau 1.1). La clôture métallique, associée ou non à des passages à faune, a été testée dans plusieurs régions. Son efficacité est généralement reconnue (Falk et al. 1978, Ward 1982, Ludwig et Bremicker 1983, Clevenger et al.

2001, mais voir Feldhamer et al. 1986) bien que son prix élevé puisse être prohibitif dans certaines situations. D'autres mesures d'atténuation se sont également avérées efficaces, comme l'utilisation des grilles d'exclusion (Belant et al. 1998, Peterson et al. 2003) et la gestion adaptée de la végétation en bordure des routes (Rea 2003). D'autres méthodes ont procuré des résultats peu convaincants ou mitigés, tel l'éclairage des routes (Reed 1981), l'utilisation de miroirs (Queal 1967, Beauchamp 1970, Gilbert 1982) ou de réflecteurs (Waring et al. 1991, Reeve et Anderson 1993, Ujvári et al. 1998, mais voir Schafer et Penland 1985), les sifflets à ultrasons (Romin et Dalton 1992, mais voir Muzzi et Bisset 1990), les dispositifs sonores actionnés au passage des voitures (Ujvári et al. 2004), les panneaux de signalisation dynamique (Pojar et al. 1975, Gordon et al. 2004) et la diminution de la vitesse des voitures (Bertwistle 1999).

Devant les constats réalisés dans la réserve faunique des Laurentides et la littérature disponible sur le sujet, le Ministère des Transports du Québec a adopté un plan spécial d'interventions dans le but de réduire les risques de collisions sur ce territoire. Les interventions sur le terrain ont consisté en l'aménagement des mares salines les plus problématiques en les asséchant par drainage et en les comblant de pierres pour éviter que les orignaux reviennent les fréquenter. De plus, dans les secteurs à risque élevé où les mares salines n'étaient pas nécessairement à l'origine du problème ou aux endroits où l'aménagement des mares salines s'avérait difficile à réaliser, le Ministère des Transports du Québec a opté pour l'installation de clôtures électriques, une méthode présentant de multiples avantages potentiels, mais peu connue.

En effet, l'utilisation de la clôture électrique comme mesure d'atténuation des accidents routiers impliquant la grande faune est encore très récente et relativement peu répandue. Cette méthode fut testée au Nouveau-Brunswick, où un seul accident impliquant l'orignal est survenu au cours d'une période de 5 ans suivant son installation sur un segment d'autoroute à haut risque (Redmond 2005). Elle est aussi utilisée comme mesure d'atténuation des accidents routiers en Arizona depuis 2004, et le sera bientôt au Nouveau-Mexique, au Montana et en Alaska (Redmond 2005). La plupart des études évaluant la clôture électrique ont testé son efficacité à restreindre l'accès de diverses espèces animales à des champs de culture, des plantations ou des proies sessiles. Ces clôtures électriques entouraient généralement une aire relativement petite. McKillop et Sibly (1988), dans leur revue de littérature sur l'utilisation de la clôture électrique, citent 86 études traitant de plus de 42 espèces animales, domestiques et sauvages, dont les déplacements ont été entravés par ce type de clôture. Toutefois, aucune étude complétée à ce jour n'a évalué la clôture électrique dans un contexte de réduction des accidents routiers.

Ce mémoire présente les résultats d'une étude de 3 ans dont l'objectif principal était d'évaluer l'efficacité de nouvelles mesures d'atténuation des accidents routiers impliquant l'orignal : l'aménagement des mares salines en bordure des routes par drainage et empierrement et la clôture électrique. Dans le chapitre concernant l'aménagement des mares salines (Chapitre II), les objectifs spécifiques suivants étaient poursuivis : 1) évaluer le taux de fréquentation des mares salines en bordure des routes avant et après l'aménagement et 2) décrire les caractéristiques physiques et chimiques des mares salines et établir une relation entre ces paramètres et la fréquentation des mares salines par l'orignal. Dans le chapitre concernant la clôture électrique (Chapitre III), les objectifs spécifiques suivants étaient poursuivis: 1) évaluer le fonctionnement de la clôture électrique, 2) évaluer l'effet de la clôture électrique sur le taux de fréquentation des bords de la route par l'orignal et 3) évaluer l'efficacité de la clôture électrique à empêcher le passage des orignaux. Les coûts associés à la construction et à l'entretien de la clôture électrique sont aussi présentés en complément, afin de permettre une évaluation complète de cette mesure d'atténuation.

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Tableau 1.1. Efficacité (++, très efficace ; +, efficace ; +/–, résultats partagés ; –, pas d'effet) de différentes mesures d'atténuation des accidents routiers impliquant la faune testées dans la littérature.

Mesure d'atténuation	**Efficacité**	**Référence sélectionnée**
Clôture métallique	++	Clevenger et al. 2001
Passages à faune	++	Ng et al. 2004
Grilles d'exclusion	+	Peterson et al. 2003
Gestion adaptée de la végétation en bordure des routes	+	Rea 2003
Substances chimiques repoussantes	+	Fraser et Hristienko 1982
Réflecteurs	+ / –	Schafer et Penland 1985
Sifflets à ultrasons	+ / –	Romin et Dalton 1992
Miroirs	–	Gilbert 1982
Panneaux de signalisation dynamique	–	Pojar et al. 1975
Diminution de la vitesse des voitures	–	Bertwistle 1999
Dispositifs sonores actionnés au passage des voitures	–	Ujvári et al. 2004
Contrôle des populations (abattage)	–	DeNicola et al. 1997

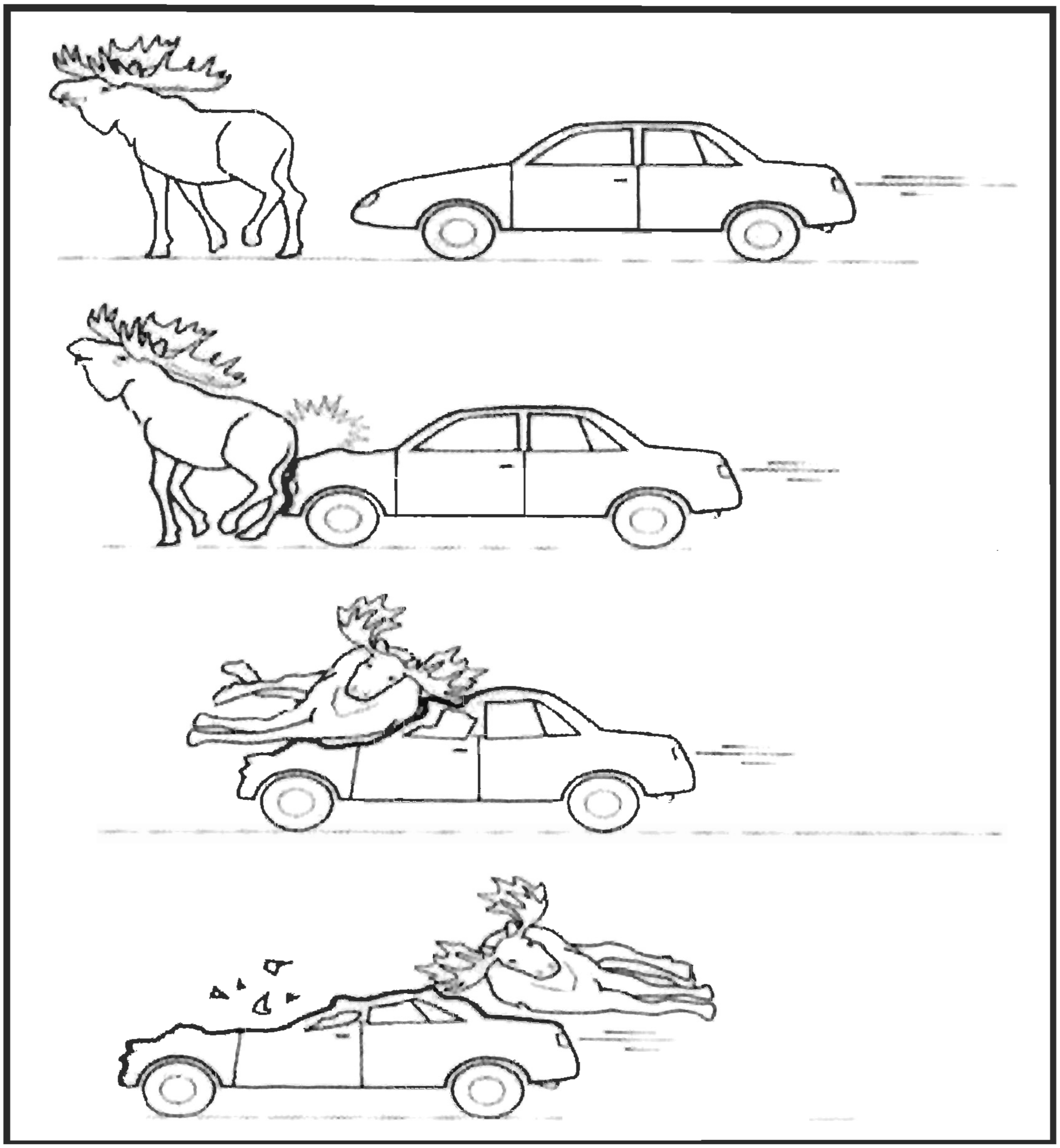

Figure 1.1. Séquence schématisée d'un accident routier impliquant l'orignal pouvant occasionner des blessures graves. La voiture fauche les jambes de l'animal, dont le corps percute le pare-brise et le toit de la voiture, occasionnant des blessures à la tête et au haut du corps des passagers (Tiré de Pynn et Pynn 2004).

CHAPITRE II

MANAGEMENT OF ROADSIDE SALT POOLS TO REDUCE MOOSE-VEHICLE COLLISIONS

ARTICLE ACCEPTÉ DANS LE « JOURNAL OF WILDLIFE MANAGEMENT »

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2.1 Résumé

Les mares salines artificielles augmentent le risque de collision routière en attirant l'orignal (*Alces alces*) en bordure des routes. Dans la réserve faunique des Laurentides, Québec, des mares salines furent drainées et empierrées afin d'empêcher l'orignal de s'y abreuver. Nous avons fait le suivi de 12 mares de bord de route durant trois étés consécutifs (2003-2005). De ces mares, sept ont été aménagées à l'automne 2004 et cinq ont été laissées non-traitées. Nous avons installé des appareils de détection dans toutes les mares afin de recenser les visites et étudier le comportement des orignaux. Nous avons aussi mesuré des caractéristiques physiques, chimiques et environnementales dans ces mares ainsi que dans des mares non visitées, afin de déterminer si certaines variables environnementales influencaient leur fréquentation. La fréquentation des mares salines par les orignaux était corrélée au couvert latéral procuré par la végétation et à la disponibilité en eau. L'aménagement des mares salines a permis de diminuer le temps moyen passé aux mares par les orignaux. Le nombre de visites a diminué significativement durant la nuit, soit la période durant laquelle le plus de visites étaient recensées, mais pas durant le jour. Enfin, l'aménagement a empêché les orignaux de boire l'eau salée des mares. Ces résultats suggèrent que les orignaux devraient délaisser les mares salines aménagées avec le temps, diminuant ainsi le risque d'accident routier.

Mots-clés : *Alces alces*, collision routière, mare saline, orignal, Québec, sécurité routière.

2.2 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 towards 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.

Key words : *Alces alces*, moose, moose-vehicle collision, Québec, road safety, roadside salt pool.

2.3 Introduction

Collisions with several deer 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 healthcare 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, exacerbate 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, Jr. and Kirpatrick 1976, Belovsky and Jordan 1981). This element, however, is also an important component of de-icing 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 since 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 Quebec, Canada, roadside salt pools were found to increase the likelihood of moose-vehicle collisions by 80% (Dussault et al. 2006). In this area, moose were involved in 40 to 70 collisions per year for the 12-year period of 1990 to 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-vehicle collisions in 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.

2.4 Study Area

The Laurentides Wildlife Reserve (7,861 km^2) was intersected by two 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 2.2 moose / 10 km^2, with density reaching 8 moose / 10 km^2 in highly suitable sectors (St-Onge et al. 1995).

2.5 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 three 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 five 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 six treated and four 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 to 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 seven 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 two 125-ml samples from each roadside salt pool every two 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 using a Hanna conductivity meter (Hanna Instruments 9811 – mS, Fisher Scientific, Vancouver, Canada) since 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 we kept these samples in a cool, dry place until analysis. We determined concentrations of major elements found in the water samples (i.e., sodium, potassium, calcium and magnesium) in the laboratory.

During summer of 2003, we also measured a series of physical and environmental variables at roadside salt pools: area (length × 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 towards 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 two 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, Canada) that triggered either a SONY video camera (called a Vigil) for 4 min 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 and 31 May and removed them between 16 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 (adult, juvenile 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] × 100) as an index of moose behavior at roadside pools.

Data Analysis. – We grouped all observations into seasonal periods of 14 to 17 days (e.g., 1-14 July, 15-31 July, etc.), referred to as fortnights, to facilitate inter-annual comparisons. We also combined moose visits to roadside salt pools according to daily periods: dawn (1 h before to 1 h after sunrise), dusk (1 h before to 1 h 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 (number of visits / 100 h). We also created another index of moose attendance at roadside salt pools (number of moose × hours / 100 h), 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 one or more moose detected simultaneously by at least one of the two available detection systems. If the time between two successive detections exceeded 60 min, we considered these events as two independent visits. Moreover, we also considered the successive presence of two different moose within a 60-min period as two 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 Bonferonni-adjusted probabilities) between number of visits / 100 h or time spent drinking and all quantitative variables measured at salt pools. We calculated separate correlation coefficients for each year before management intervention, i.e., 2003 and 2004. For variables likely to vary during the summer, i.e., 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 h 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 h 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 h or number of moose × hours / 100 h 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 1999) and considered effects significant at $P \leq 0.05$.

2.6 Results

Moose Visits to Roadside Salt Pools. – Both mean number of moose visits / 100 h (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 two indices of visual obstruction during the 2 years before management (*i.e.*, 2003 and 2004). Number of visits / 100 h 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 at least 50 different moose visited surveyed salt pools each year.

In 2004, number of moose visits / 100 h 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 h was relatively high from mid-June to mid-July (mean: 0.56 ±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 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 % adult females, 23.2 % juveniles, 20.8 % adult males and 13.6 % unknown age; 2004: 44.0 % adult females, 18.5 % juveniles, 15.6 % adult males and 22.0 % unknown age; 2005: 25.0 % adult females, 21.4 % juveniles, 10.0 % adult males and 43.6 % unknown age). Most visits were made by solitary moose, but we also observed groups of two (2003 = 17.6 %; 2004 = 19.8 %; 2005 = 8.6 %) or three 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 sex and age.

In 2003 and 2004, almost all visits to roadside salt pools lasted less than an hour and tended to last less than 15 min (70.0 % [371/530]). In 2005, an even larger proportion of visits lasted less than 15 min (87.9 % [123/140]) than 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 two indices of moose attendance at roadside salt pools at night gave similar results when assessing the effect of management (Table 2.1). Number of visits / 100 h 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 2005 (after management; 0.19 ±0.04; $F_{1,9} = 11.00$, $P = 0.009$; Figure 2.1). 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 h at roadside salt pools during the day varied across the season (fortnight: $F_{6,54} = 4.07$, $P = 0.002$), but not between summers (means of 0.20 ±0.05 in 2003, 0.48 ±0.1 in 2004, and 0.19 ±0.04 in 2005; $F_{2,16} = 1.27$, $P = 0.308$; Table 2.1, Figure 2.2). The second index combining frequency and duration of visits (*i.e.*, number of moose × hours / 100 h), however, was significantly lower in 2005 (0.02 ±<0.01) than 2003 (0.11 ±0.01) and 2004 (0.18 ±0.02), for treated pools only (Table 1.1). 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 (day: $F_{12,98} = 0.52$, $P = 0.897$; night: $F_{6,57} = 0.89$, $P = 0.509$).

2.7 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 min and visits decreased in length after management. Median visit length was 6 min before and 4 min after pool management. Deer visits to natural salt licks are generally >15 min (15 - 30 min; Weeks, Jr. 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 (less 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 sodium) in the diet (Hebert and Cowan 1971, Atwood and Weeks, Jr. 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 our study area. 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, Jr. and Kirkpatrick 1976, Belovsky and Jordan 1981, Pletscher 1987). We first observed calves at salt pools between 10 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 (mean of 890 ppm) was more attractive than the mean salinity of aquatic plants (*e.g.*, 500 ppm on Isle Royale, Botkin et al. 1973). Also, brackish water is relatively easy to consume while 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 one 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 de-icing 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.

2.8 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 moose visit frequency in these salt pools. Removal of vegetation could also increase driver vision, allowing drivers to better avoid moose on the road.

2.9 Acknowledgments

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Table 2.1. Results of ANOVAs testing the effect of the management practices on frequency and duration of moose visits to roadside salt pools of the Laurentides Wildlife Reserve during the day (including dusk and dawn, 2003-2005) and night (2004 and 2005).

	Day					Night[a]				
		Mean no. of visits / 100 h		No. of moose × hours / 100 h			Mean no. of visits / 100 h		No. of moose × hours / 100 h	
Source	df	*F*	*P*	*F*	*P*	df	*F*	*P*	*F*	*P*
Year	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*
Year × fortnight	12	0.52	0.897	1.44	0.158	6	0.89	0.504	2.92	0.015*
Year × 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 $P \leq 0.05$.

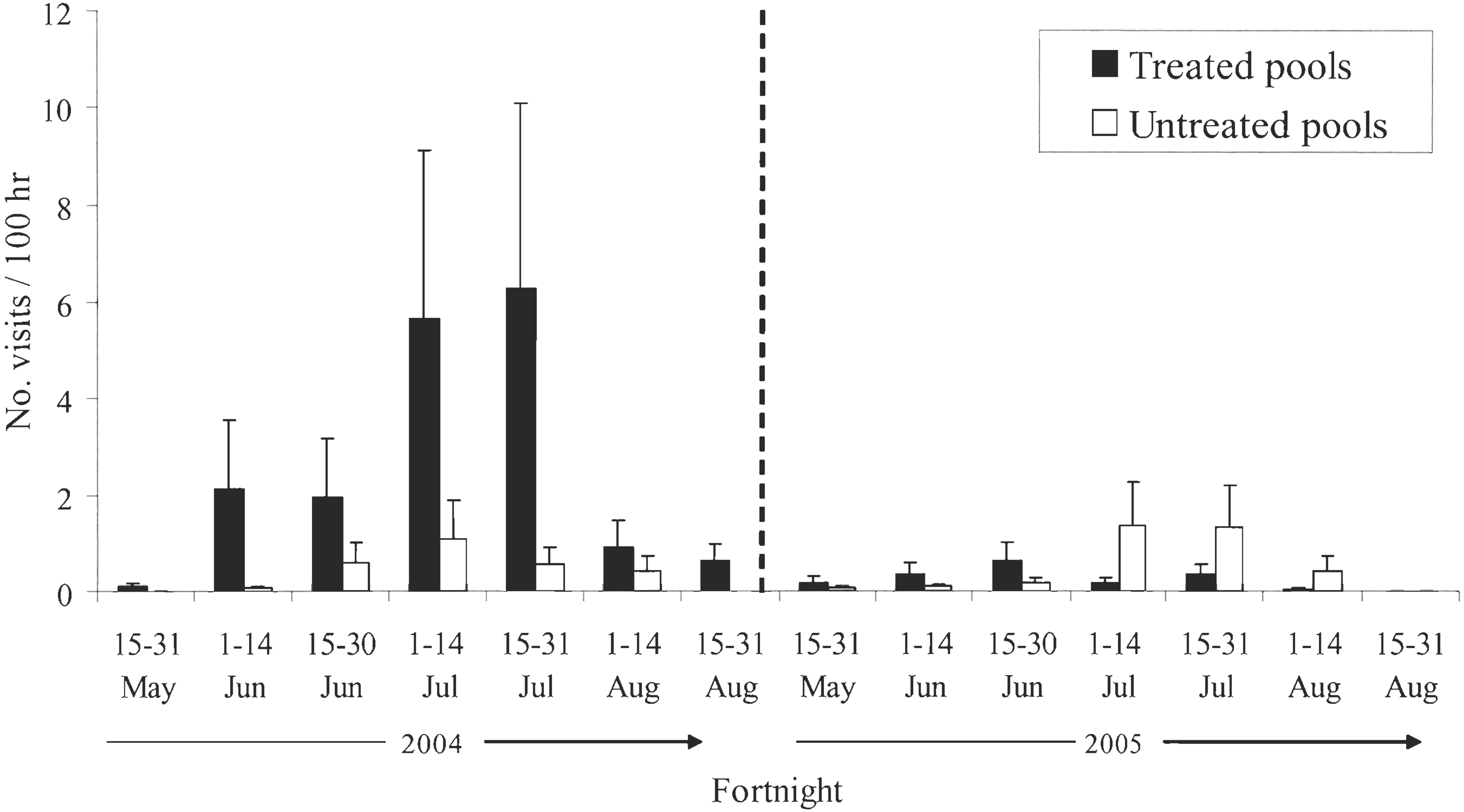

Figure 2.1. Mean number of moose visits / 100 h + SE during the night at treated and untreated roadside salt pools of the Laurentides Wildlife Reserve by fortnight in 2004 and 2005. The dotted line indicates the time of pool management intervention.

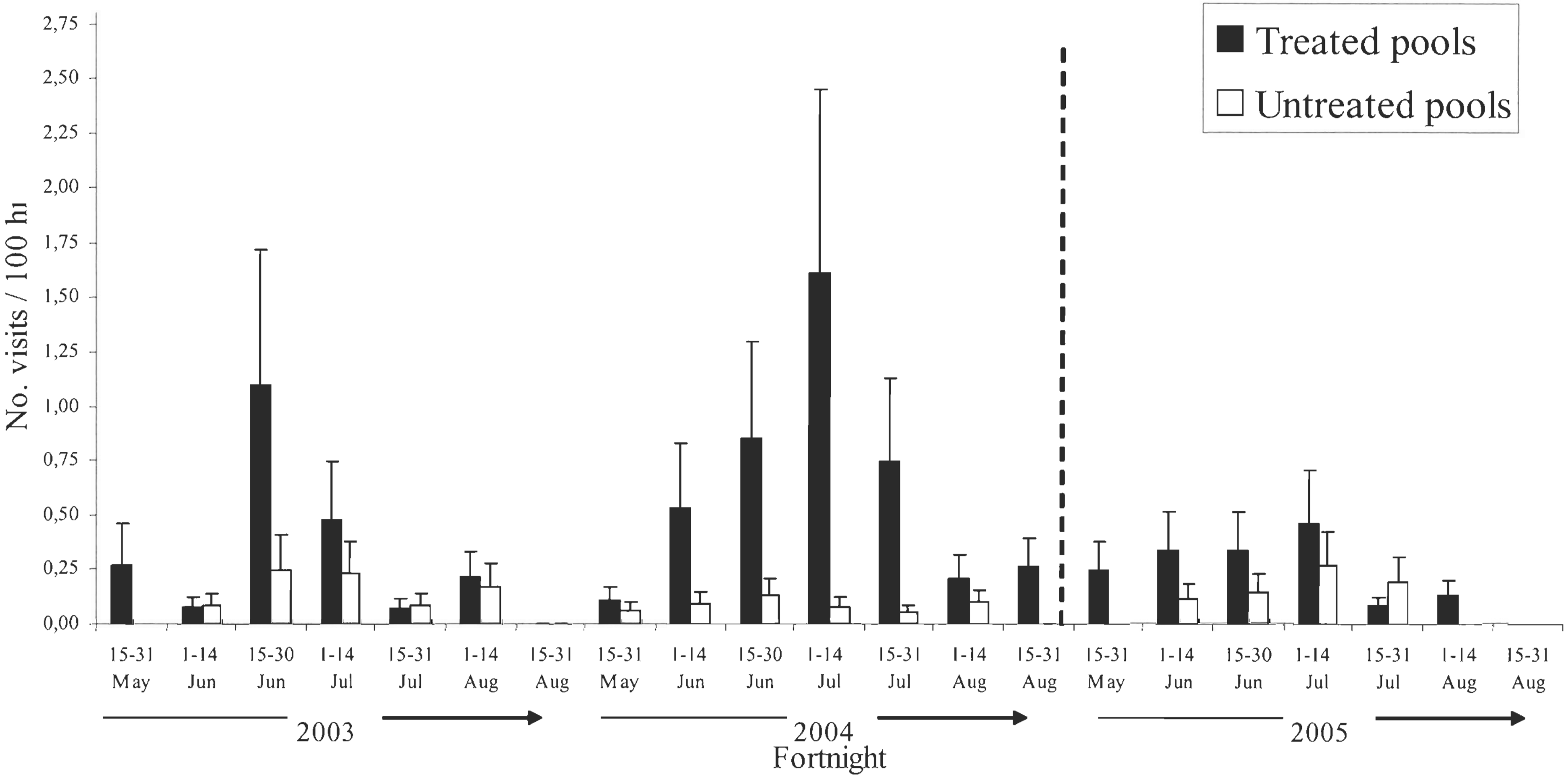

Figure 2.2. Mean number of moose visits / 100 h + SE during the day (including dusk and dawn) at treated and untreated roadside salt pools of the Laurentides Wildlife Reserve by fortnight 2003-2005. The dotted line indicates the time of pool management intervention.

CHAPITRE III

ELECTRIC FENCING AS A MEASURE TO REDUCE MOOSE-VEHICLE COLLISIONS

ARTICLE ACCEPTÉ DANS LE « JOURNAL OF WILDLIFE MANAGEMENT »

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3.1 Résumé

Nous avons testé l'efficacité de la clôture électrique à réduire le risque d'accident routier impliquant l'orignal (*Alces alces*) à l'aide de relevés de pistes hebdomadaires et de la télémétrie GPS dans deux secteurs clôturés (5 et 10 km). Le nombre de pistes d'orignal recensées le long de la route dans les secteurs clôturés a diminué de *ca.* 80 % suite à l'installation des clôtures électriques. Environ 30 % des pistes d'orignal observées du côté de la route par rapport à la clôture ont été laissées par des orignaux qui ont traversé la clôture alors qu'elle était électrifiée ; la plupart des orignaux (38 %) ont accédé au corridor routier par des ouvertures (*e.g.*, aux intersections avec des chemins forestiers) ou par les extrémités de la clôture. Les clôtures électriques étaient moins efficaces durant les chutes de courant occasionnelles. Les clôtures électriques ont aussi empêché 78 % (7/9) des orignaux portant des colliers GPS de traverser la route dans les secteurs clôturés. Nous suggérons l'utilisation de disjoncteurs afin de prévenir les chutes de tension. Nous suggérons aussi d'éviter de laisser des ouvertures dans la clôture électrique lors de son installation, à moins que des structures anti-ongulés y soient employées.

Mots-clés : *Alces alces*, clôture électrique, collision routière, orignal, Québec, sécurité routière.

3.2 Abstract

We tested the effectiveness of electric fences to reduce moose (*Alces alces*)-vehicle collisions in two fenced sectors (5 and 10 km) using weekly track surveys and GPS telemetry. Number of moose tracks along highways decreased by *ca*. 80 % following fence installation. Only 30 % (16/53) of moose tracks observed on the road side of the fence were left by moose that crossed an operational fence; moose mostly entered the fenced corridor through openings (*e.g.*, secondary roads) or at fence extremities. Electric fences also prevented 78 % (7/9) of collared moose from crossing the highway in fenced sectors. Fences were less effective during occasional power failures. We suggest that circuit breakers should be used to prevent power failures and that there should be no opening along the fence line unless anti-ungulate structures are used.

Key Words : *Alces alces*, electric fence, moose, moose-vehicle collision, road safety, Québec.

3.3 Introduction

Road collisions involving large mammals have been recognized as an obstacle to road safety since the late 1930s (Dickerson 1939). Each year, these collisions cause numerous human fatalities and injuries and generate considerable expense in terms of property damage. Conover et al. (1995) estimated there were 211 annual fatalities related to deer-vehicle collisions, in addition to 29,000 people injured and costs of more than $ 1 billion US in the USA. Continuous improvement and development of road networks to accommodate a growing number of vehicles in conjunction with growing deer populations exacerbate this problem in several areas throughout the world (Oosenbrug et al. 1991, Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996). Reducing the occurrence of deer-vehicle collisions has thus become a primary objective in many jurisdictions worldwide (*e.g.*, Clevenger and Waltho 2000, Clevenger et al. 2001).

Several methods have been evaluated to reduce ungulate-vehicle collisions. Metal wired fencing has been tested in many regions and its effectiveness is generally recognized (Falk et al. 1978, Ward 1982, Ludwig and Bremicker 1983, Clevenger et al. 2001, but see Feldhamer et al. 1986) although costs can be prohibitive. The use of electric fences as a measure to reduce collisions with wildlife is relatively recent and not yet widespread. Such fences have been erected in 2001 in New Brunswick (Canada) and 2004 in Arizona (USA), and will soon be tested in other states such as New Mexico, Montana and Alaska (G. Redmond, Maritime College of Forest Technology, unpublished report). Electric fences have also been erected in the Laurentides Wildlife Reserve, Québec, where we conducted this study.

In this study, our objective was to test the potential of an electric fence to reduce the risk of moose (*Alces alces*)-vehicle collisions. Our specific objectives were to evaluate the reliability and resistance of the electric fence and its capacity to reduce moose road crossings. We also calculated the costs relative to construction and maintenance of the electric fence to assess the cost-benefit ratio of this mitigation measure.

3.4 Study Area

Highways 169 (60 km) and 175 (140 km) were the only two provincial roads crossing the Laurentides Wildlife Reserve (7,861 km^2). They linked the regions of Québec City and Saguenay-Lac St. Jean (Figure 3.1). These highways generally contained a single lane in each direction, except along steep uphill slopes where passing lanes were available. Maximum speed was fixed at 90 km/h and mean daily traffic was 2,800 vehicles in the northern segment of Highway 175 and 1,460 vehicles on Highway 169 (Dussault et al. 2006). The most recent aerial survey that took place in this region was performed by helicopter in winter 1993-94. Estimated mean moose density was 2.4 moose / 10 km^2 ± 21 %. The total moose population was estimated at 1,595 individuals (St-Onge et al. 1995). Between 40 and 70 moose-vehicle collisions occurred annually on Highways 175 and 169 between 1990 and 2002, which represented one fourth of all collisions of this type in the province of Québec. Three people died in moose-vehicle collisions on these Highways between 2000 and 2004 (*ca.* 2 % of moose-vehicle collisions caused fatalities; M. Poulin, Ministère des Transports du Québec, unpublished report).

3.5 Methods

Two separate electric fences (ElectroBraid^{TM} Fence Limited, Yarmouth, Canada) were erected in the Laurentides Wildlife Reserve. The first one was 5 km in length and constructed on both sides of Highway 175 in fall 2002 (henceforth referred to as F175). The second fence was 10 km long and erected on both sides of Highway 169 in fall 2004 (F169). Electric fences were composed of 5 polyester fiber cables on which copper wires were twisted. Cables were spaced by 30 cm and reached a total height of 1.5 m from the ground. Fence cables were supported by fiberglass posts that were spaced 10 m apart. Electric power was obtained from a conventional power line (110 V) and a Speedrite Panther 36,000 transformer (Tru-Test Limited, Auckland, NZ). The fourth cable from the ground was not powered but connected to metal rods buried in the ground every 800 m and served as a ground. Electric fences were linked to a breaker (ElectroBraid, 125 V, 60 Hz, 100 W) that cut off the power when a significant drop in voltage occurred. Power failures were automatically reported to a phone operator via an automatic dialing device. One wildlife-crossing structure was constructed for each fence. An underpass was set up on each side of a river under a bridge along the fence of Highway 175 (23 m long x 16 m wide x 7 m high). On Highway 169, moose were allowed to cross directly on the roadway through openings in the fence (30 m long x 15 m wide). We installed movement and heat detectors (Circuitronique Estrie Inc., Sherbrooke, Canada) that triggered dynamic warning road signs at the crossing of a moose.

We assessed occurrence of moose along roadsides by track surveys conducted weekly from mid-May to mid-August during three consecutive summers (2003-2005).

We chose to conduct our surveys during summer because moose-vehicle collisions peak in this period (Dussault et al. 2006). Because F169 was installed during the observational study, it was possible to compare surveys made before (summers 2003 and 2004) and after fence erection (summer 2005). On Highway 175, however, the fence was erected before the study so we compared differences between the numbers of moose tracks on each side of the fence (*i.e.*, the road side *vs.* the forest side relative to the fence). For each fenced sector, we also surveyed an adjacent road segment of equal length (*i.e.*, 5 km on Highway 175 and 10 km on Highway 169) to serve as controls. The control sectors were located in similar environments in terms of vegetation and topography as fenced sectors. During each weekly survey, we recorded the number of tracks, their location and their direction relative to the fence. We carefully searched for indications that a moose had crossed the fence (*e.g.*, loose cables and lifted posts). We then erased all tracks during surveys to avoid recording them twice. We also measured the voltage on the 4 powered cables with a voltmeter (Tru-Test Limited) at 10 sampling stations regularly spaced along fences. We immediately repaired any structural damage or power failure to maintain the fences in working order. Although voltage was variable along the fence (range = 0.2 to 10.0 kV), it exceeded the value necessary for the fence to work properly (5.0 kV according to the manufacturer) in 71 % (963 / 1,352) of readings made when fences were electrified.

We did not use track data collected during the first survey of each summer because we could not determine the period during which the observed tracks had been made, which would have led to potentially overestimated track counts. We therefore analyzed

11 weekly track surveys per year. For F175, we compared number of moose tracks on the forest side with that on the road side relative to the fence. We calculated 95 % confidence intervals (C.I.s) of the differences to determine whether an interval included zero, which would have indicated no difference. We assessed the effectiveness of F169 with the Before-After Control-Impact (BACI) approach developed by Green (1979) and improved by Stewart-Oaten et al. (1986). We used a t-test comparing the difference in number of moose tracks between the control and fenced sectors on each survey for the period before and after fence erection. Because track counts were not normally distributed, we compared the observed t-value to a t-distribution obtained by re-sampling (1,000 random permutations).

For both fenced areas, we used a G-test to determine if the proportion of moose tracks inside fenced sectors depended on whether the fence was electrified or not (power failures sometimes occurred). We also assessed the probability that no moose-vehicle collision would occur along each fenced sector for three consecutive years (*i.e.*, the duration of this study) using the Poisson probability distribution and moose-vehicle collision data collected by the Ministère des Transports du Québec between 1990 and 2002. Statistical analyses were performed using SAS (Version 8.00; SAS Institute 1999) and effects were considered significant at $P \leq 0.05$.

As part of a more detailed project studying moose behavior relative to highways, we equipped 47 adult moose ($\geq$2.5 yr old) with Global Positioning System (GPS) telemetry collars (Lotek Wireless Inc., Newmarket, Ontario). We captured moose <20 km from an electric fence between early February and late March and monitored them for one (*n* = 23), two (*n* = 15) or three years (*n* = 9). We followed standard techniques approved by the Animal Welfare Committee of the Ministère des Ressources naturelles et de la Faune du Québec (certificate no. 97-05), based on the Canadian Council on Animal Care (1984) guidelines. We immobilized moose with a mixture of carfentanil and xylazine (Delvaux et al. 1999). We programmed collars to record a location every 2 or 3 h and location accuracy was estimated to be <30 m, 95 % of the time (Cain III et al. 2005). The number of collared individuals directly impacted by electric fences was too low to allow statistical analysis, however, we plotted individual movements relative to electric fences on digital maps using ArcGIS 9.0 (ESRI, Redlands, USA).

We used the following equations to estimate the time (in years) it would take for the electric fences to be profitable in our study area:

$$(1)\ \ Y_F = \frac{\text{FENCE}}{N_{\text{COLL}}(\text{COLL} + \text{MOOSE})}$$

$$(2)\ \ Y_M = \frac{Y_F(\text{MAINT}_{Y_1})}{N_{\text{COLL}}(\text{COLL} + \text{MOOSE})}$$

$$(3)\ \ Y_{TOT} = Y_F + Y_M$$

where COLL is the mean cost of a moose-vehicle collision, FENCE is the cost of the electric fence, MAINT_{Y_1} is the annual maintenance cost (including electricity and telephone fees), MOOSE is the mean monetary value of a live moose and N_{COLL} is the mean annual number of moose-vehicle collisions before fence installation. Y_F is the number of years required to make an electric fence profitable considering installation costs only, Y_M is the number of years required to make an electric fence profitable considering maintenance costs only and Y_{TOT} is the total number of years required to make an electric fence profitable.

3.6 Results

The electric fences were functioning properly during 35 of the 41 track surveys (85 %) that we carried out over the three summers. We found F175 without power three times in both 2004 and 2005 but F169 never malfunctioned. When the fence F175 was operational, 141 tracks were seen on the forest side *vs*. 22 tracks on the road side; when inoperative, 43 tracks were recorded on the forest side *vs*. 23 tracks on the road side (G = 12.60, df = 1, $P < 0.001$).

Number of moose tracks in the fenced and control sectors varied within and between summers (Figures 3.2 and 3.3). Tracks were relatively more abundant in June and July compared to August. Along F175, there were always fewer moose tracks on the road side of the fence than the forest side (Figure 3.2). Mean difference between numbers of moose tracks on the two sides of the fence was 9.56 in 2003 (n = 9, SE = 1.61, 95 % C.I. = 5.85 to 13.26), 3.22 in 2004 (n = 9, SE = 1.20, 95 % C.I. = 0.46 to 5.99) and 3.90 in 2005 (n = 10, SE = 1.30, 95 % C.I. = 0.95 to 6.85). Mean difference between number of moose tracks in the control and fenced sectors of F169 was 0.53 before fence erection (2003 and 2004: n = 19, SE = 2.16, 95 % C.I. = –4.02 to 5.07) and 12.46 after fence erection (2005: n = 11, SE = 3.10, 95 % C.I. = 5.54 to 19.37). Differences were therefore minimal in 2003 and 2004 but track numbers were much higher in the control compared to the fenced sector after fence installation (t = -3.55, df = 30, P = 0.001).

Tracks found inside electric fences were left by moose that crossed over the fence (33 %), used openings in the fence (*i.e.*, breaks in front of lakes or at intersections with secondary roads, 31 %) or went around fence ends (7 %). We could not determine the trajectory of moose for 29 % of tracks because tracks were lost on hard substrate or partially erased; no clues were found, however, to suggest that these moose have crossed the electric fence. We recorded 23 tracks in 3 years in the underpass of Highway 175 and 12 tracks in one year on the roadway crossing of Highway 169.

We recorded a mean of 1.5 moose tracks per survey (n = 26, SE = 0.31) on the road along F175 for three summers. We thus estimated the potential of F175 to reduce collision risk to be 76 %, by comparing the total number of moose tracks on the road side (45) with the total number on the forest side (184). Reduction in track numbers reached 84 % (22 tracks on the road side vs. 141 tracks on the forest side) when excluding malfunctioning data from F175. In the F169 sector, we recorded a mean of 3.4 moose tracks per survey (n = 9, SE = 0.65) in 2005, which was much lower than both the mean of 15.0 tracks per survey (n = 22, SE = 1.72) in the same sector before erection of the fence and the mean of 15.4 tracks per survey (n = 33, SE = 1.62) in the control sector over three summers. We thus estimated the potential of F169 to reduce collision risk to be 77 %. No moose-vehicle collision was reported in the fenced sectors following erection of the electric fences, whereas there had been 1.4 (n = 17, SE = 0.47) and 5.4 collisions per year (*n* = 76, SE = 0.68) on average along those sectors on Highways 175 and 169, respectively.

Electric fences could potentially influence only 9 individuals having home ranges of 25.7 – 67.2 km^2. Among the 9 affected moose, 2 crossed the fence, 5 approached the fence (<100 m) without crossing it and 2 individuals apparently remained at a distance (>500 m). Moose L42 and L51 each crossed F169 once in 2005 (Figure 3.4), with L42 passing near (or within) the wildlife-crossing structure in the southern section. Moose L51 gained access to the fenced corridor through an opening in front of a lake and then crossed the fence on the other side of the road. Typical examples of moose that were effectively blocked by the fence were L30 and L29 (Figure 3.4). L30 had been crossing the road once a year before erection of the fence. L29 only crossed the road south of the fenced sector while this individual had crossed the road 5 times in 2003, before erection of the fence. Only one collared moose lived near F175 but it never approached the fence. We observed only 2 highway crossings by moose in the sector where F169 was installed in 2005, compared to 18 and 19 crossings in 2003 and 2004, respectively. In contrast, moose continued to cross the road at a similar rate as before fence erection elsewhere in the area. Thirty-nine percent (7/18), 33 % (7/21) and 36 % (8/22) of moose crossed other stretches of highway in 2003, 2004 and 2005, respectively, for a total of 48, 45 and 43 crossings in 2003, 2004 and 2005, respectively.

We estimated the costs (in US$) of material and human resources related to installation and operation of an ElectroBraid electric fence and compared these costs to annual savings due to elimination of moose-vehicle collisions (Table 3.1). Electric fences on

Highways 175 (9,426 m) and 169 (18,181 m) cost *ca.* $ 210,000 and $ 407,000, respectively. A metal wired fence would have cost between $ 520,000 and $ 900,000 for the longer fence (Danielson and Hubbard 1998, Ministère des Transports du Québec 2001). Other annual expenses totalled $ 4,360 on Highway 175 and $ 8,420 on Highway 169. We thus estimated the time required to make the electric fences profitable to be 7 years on Highway 175 and 3 years on Highway 169, assuming complete cessation of moose-vehicle accidents, and 8 years on Highway 175 and 4 years on Highway 169, considering a reduction of 80 % in collision risk as in this study.

3.7 Discussion

The electric fence tested in this study was not an impenetrable barrier to moose. It was made of flexible cables that were easily scaled and so the effectiveness of electric fences relies on behavioral conditioning of the animals. If an animal receives a sufficiently unpleasant shock the first time it encounters an electric fence, then a drastic and long-term change in behavior can be observed (McKillop and Sibly 1988). If an animal learns to cross a fence while it is not electrified, however, future crossings by this individual are likely, even when power is restored (Poole et al. 2004). We therefore suggest that power failures be repaired rapidly, particularly during the first weeks following installation of a new electric fence. Power failure occurred 6 times in the course of our 3-year study of F175. A breaker that was extremely sensitive to variations in voltage caused the power failures. Even though we found that the number of tracks inside fences increased during power failures, we could not definitively demonstrate that moose accessed the fenced corridor by directly crossing the fence.

Presence of an electric fence significantly reduced the likelihood of encountering a moose on the road while not affecting moose numbers in control sectors. With the BACI design used at F169, we observed similar rates of moose tracks in fenced and control sectors before installation of the electric fence. Although the experimental design was better for Highway 169, we obtained comparable and convincing results in both sectors, which indicated that both electric fences acted as effective barriers to moose movements. For the F169 study site, we treated track surveys as independent replicates because tracks were systematically erased after observation and there was a mean interval of 7 days between surveys. Underwood (1991) has outlined the importance of using several control sites in BACI experiments whenever possible. Because of monetary and logistic constraints, however, we would not have been able to survey more than one control sector as well as the fenced sector in a given day, which is a pre-requisite for this type of analysis (Stewart-Oaten et al. 1986).

We observed a sharp decline in moose track abundance along electric fences at the end of summer. Such a decrease with time could be interpreted as behavioral conditioning of moose (McKillop and Sibly 1988). The seasonal pattern of moose track abundance was very similar in the fenced and control sectors, however, suggesting that behavioral conditioning was unlikely. Alternatively, we suggest that this seasonal decrease was due to moose spending more time feeding on aquatic forage that becomes more available as summer progresses (Fraser et al. 1980). Moose attendance at roadside salt pools also decreased in late summer in this region (see chapter II), resulting in reduced moose-vehicle collision risk (Dussault et al. 2006).

Some moose did cross the fence while the structure was electrified (16 tracks). In most instances, however, moose did not directly cross the fence but used openings that extended 720 m and 1,720 m along F175 and F169, respectively. The largest openings were located in front of lakes where roadways were too close to water to be fenced. Smaller openings also existed at the junction of secondary roads. This result indicates that it would be preferable to locate fence extremities in areas that are inaccessible to moose (*e.g.*, in front of steep cliffs, on bridges, *etc.*) or to install wildlife-crossing structures at fence ends.

Some individuals walked along the electric fence for over 1 km. This behavior illustrates the utility of wildlife crossings along fences (Foster and Humphrey 1995, Clevenger and Waltho 2000, Van Wieren and Worm 2001, Ng et al. 2004). In this study of moose tracks, we found evidence that moose used wildlife crossings almost weekly. We thus confirm the importance of including such passages when fences are erected.

Although we lacked direct observations, 5 individuals monitored with GPS telemetry very likely came in contact with the fence (<100 m). We found that only a few collared moose were affected by the fence (before / after fence data were available for 4 moose among a total of 47 GPS-collared moose captured in the study area). Moose seemed to avoid approaching major roads, as demonstrated by the low number of road crossings in unfenced sectors (Dussault et al., unpubl. data). The numerous locations obtained from GPS telemetry provided additional evidence that moose were usually reluctant to cross the electric fences.

The profitability estimates we obtained were optimistic because they were based on the assumption that collisions would cease completely in the fenced sectors. Cost-effectiveness, however, should not be the sole parameter used to evaluate a mitigation measure. Loss of human life, injuries, and stress caused by collisions have intangible values that must also be considered (Conover 1997). Electric fences have proved to be effective in protecting relatively small areas, such as crop fields, from wildlife damage (McKillop and Sibly 1988, Cowan and Rhodes 1992, McKillop et al. 1998, Poole et al. 2002, but see Geisser and Reyer 2004). This study, however, is among the first to report the effectiveness of electric fences as a measure to reduce collisions between vehicles and wildlife. We recorded no vehicle collisions in fenced sectors, even though these sectors were considered high-risk prior to fence erection.

3.8 Management Implications

Continuous electric fences must be installed along a given sector in order to prevent moose from reaching a road. We therefore propose that anti-ungulate structures (*e.g.*, deer-exclusion grates; Peterson et al. 2003) be used where openings in fences are inevitable (*e.g.*, at intersections with secondary roads). Road segments next to lakes should also be fenced with metallic wires or unpowered electric cables (that serve as a visual diversion). In addition, electric fences should be equipped with a failure detection system similar to the breaker used in our study. This device should facilitate maintenance but should not be relied upon entirely. Frequent physical checks are required in the field, particularly in spring in areas where snow accumulation could have damaged the fence during winter. Properly managed, electric fences should be considered an effective method to reduce moose-vehicle collisions. Electric fencing has the advantages of being less expensive and less obvious in terms of visual impact than conventional metal wired fences.

3.9 Acknowledgments

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Table 3.1. Estimate of costs (US$) of material and human resources related to installation and operation of an ElectroBraid electric fence and savings realized through elimination of moose-vehicle collisions along fenced sectors in the Laurentides Wildlife Reserve.

	Amount (US$)	Source
Costs		
Fence material[a]	12.90 m^{-1}	MTQ[b]
Electric gear[c]	4,360.00	MTQ
Ground preparation[d]	3.65 m^{-1}	MTQ
Drilling of holes[e]	43.00 each	MTQ
Installation	5.25 m^{-1}	MTQ
Maintenance	0.45 m^{-1}	MTQ
Fees[f]	10.00 $month^{-1}$	MTQ
Savings		
Mean monetary value of a moose[g]	7,954.00	M. Lacasse, MRNF[h], personal communication
Mean cost of a moose-vehicle collision[i]	18,935.00	M. Poulin, MTQ, unpublished report

[a] Includes cables, posts, clips and ground rods. [b] Ministère des Transports du Québec. [c] Includes breaker, transformer and insulated case. [d] Includes tree removal and ground levelling. [e] Drilling of holes was necessary to fix some posts in hard substrate and rock (fence F169 required 150 holes over 10 km). [f] Includes electricity and telephone bills. [g] Based on annual expenses of moose hunters. [h] Ministère des Ressources naturelles et de la Faune du Québec. [i] Includes costs of health-care services, based on moose-vehicle collisions that occurred during the period 2000-2004 (*n* = 310).

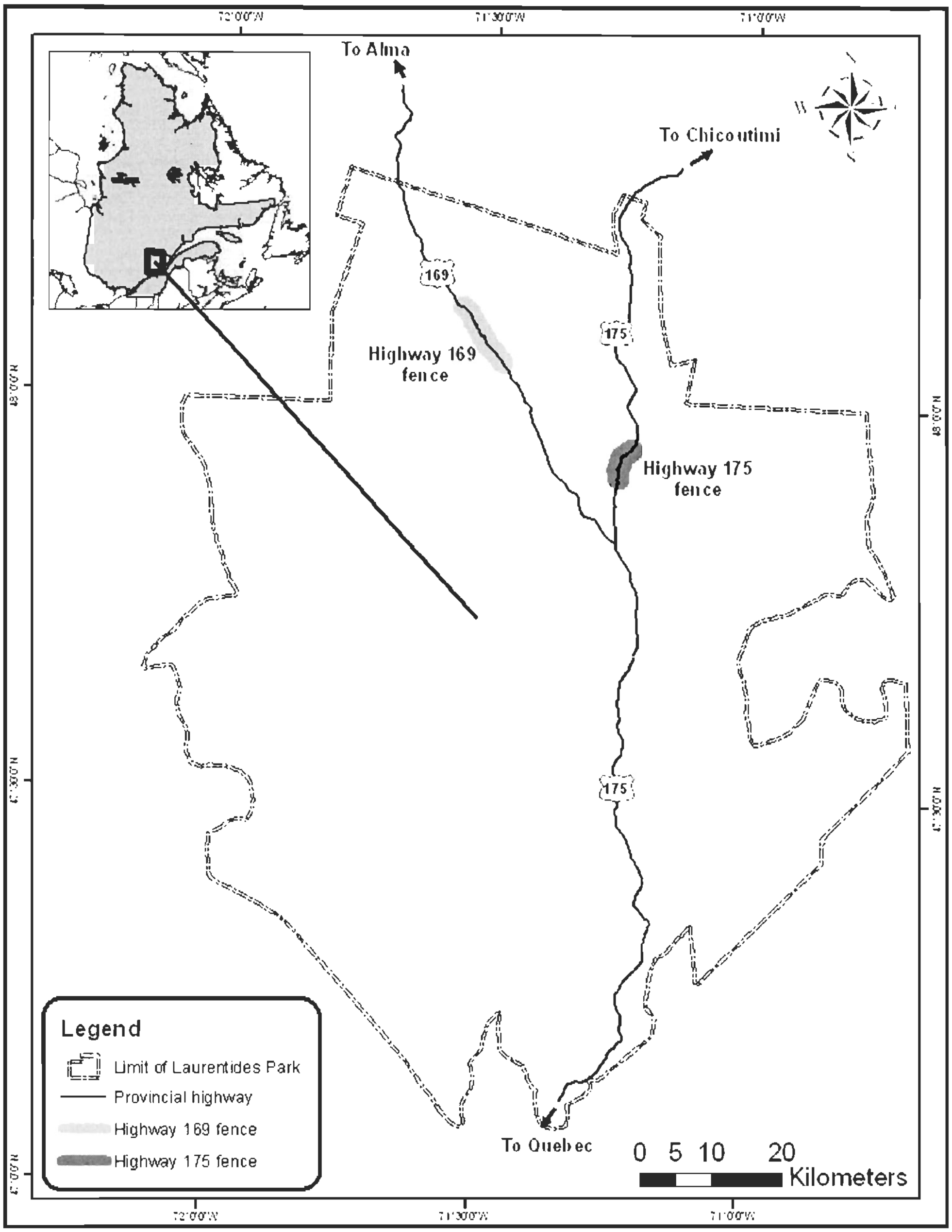

Figure 3.1. Map of the Laurentides Wildlife Reserve, Québec, showing provincial Highways 175 and 169 with locations of the fenced sectors.

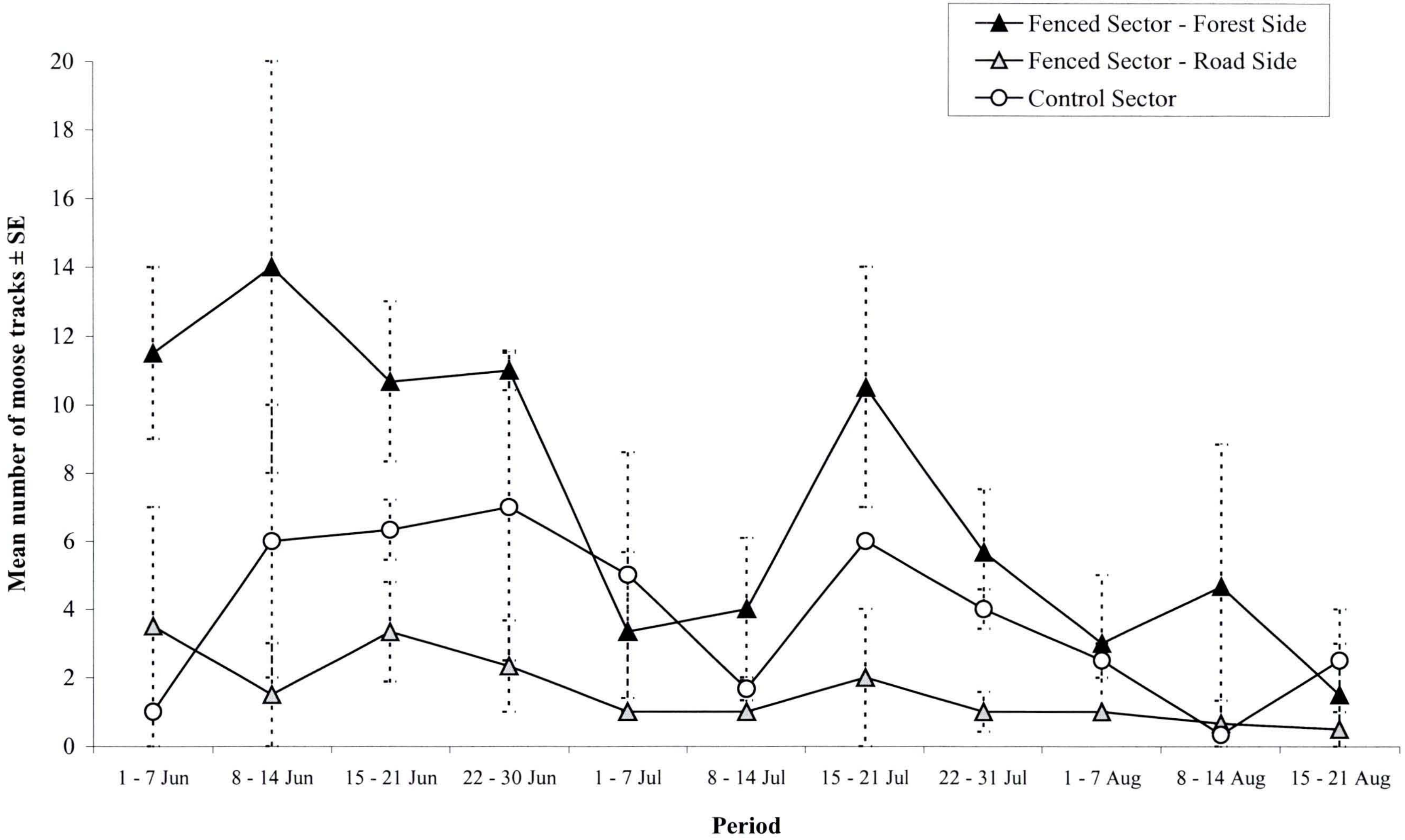

Figure 3.2. Mean annual number of moose tracks (+ SE) in fenced and control sectors of Highway 175 in the Laurentides Wildlife Reserve by weekly summer period from 2003 to 2005 (years are pooled). The fence was installed before the beginning of the study. Tracks in the fenced sector were recorded according to their position relative to the fence (*i.e.*, road side or forest side).

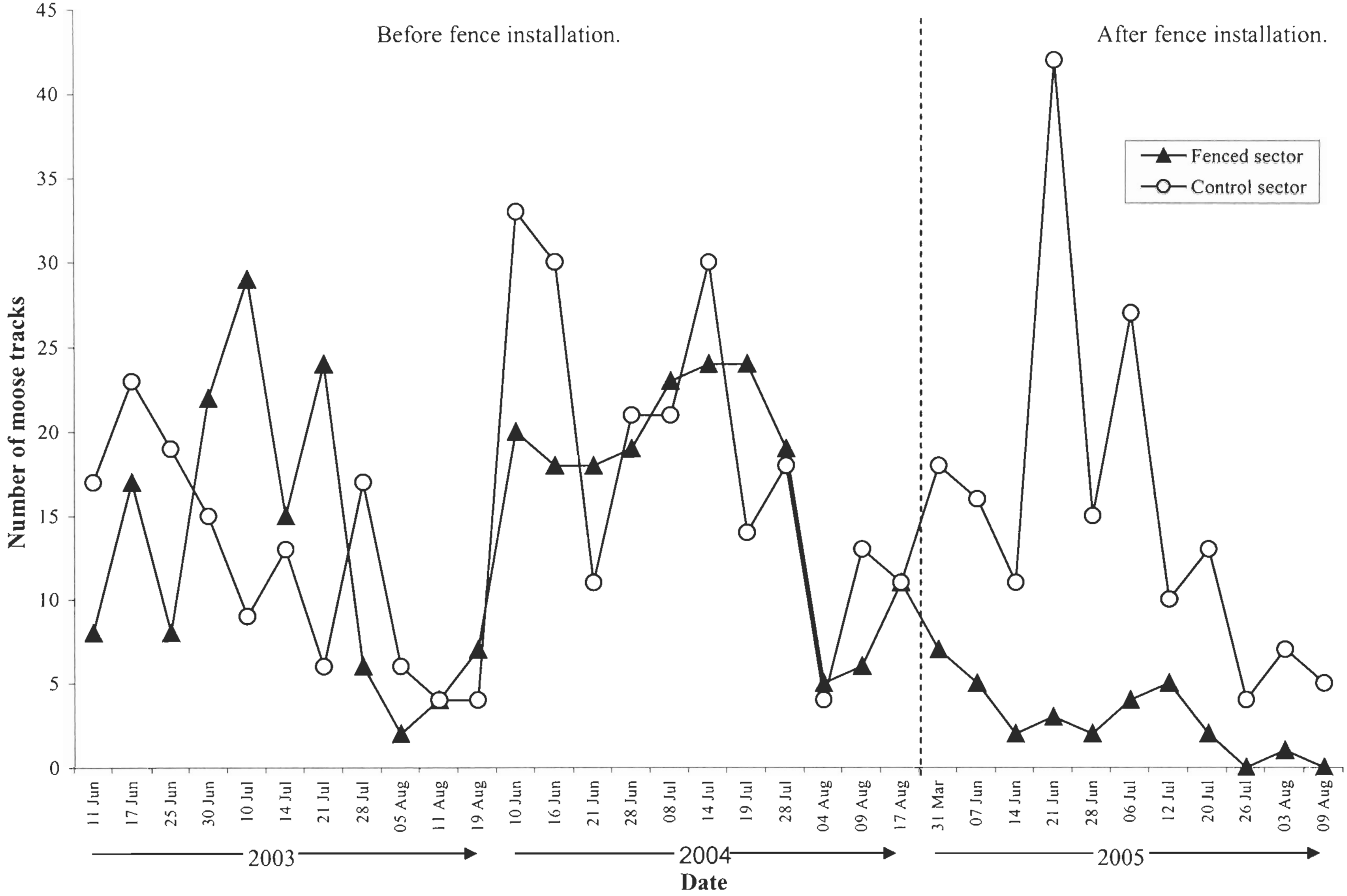

Figure 3.3. Number of moose tracks observed in fenced and control sectors of Highway 169 in the Laurentides Wildlife Reserve during summer from 2003 to 2005. The vertical dotted line indicates time of fence installation.

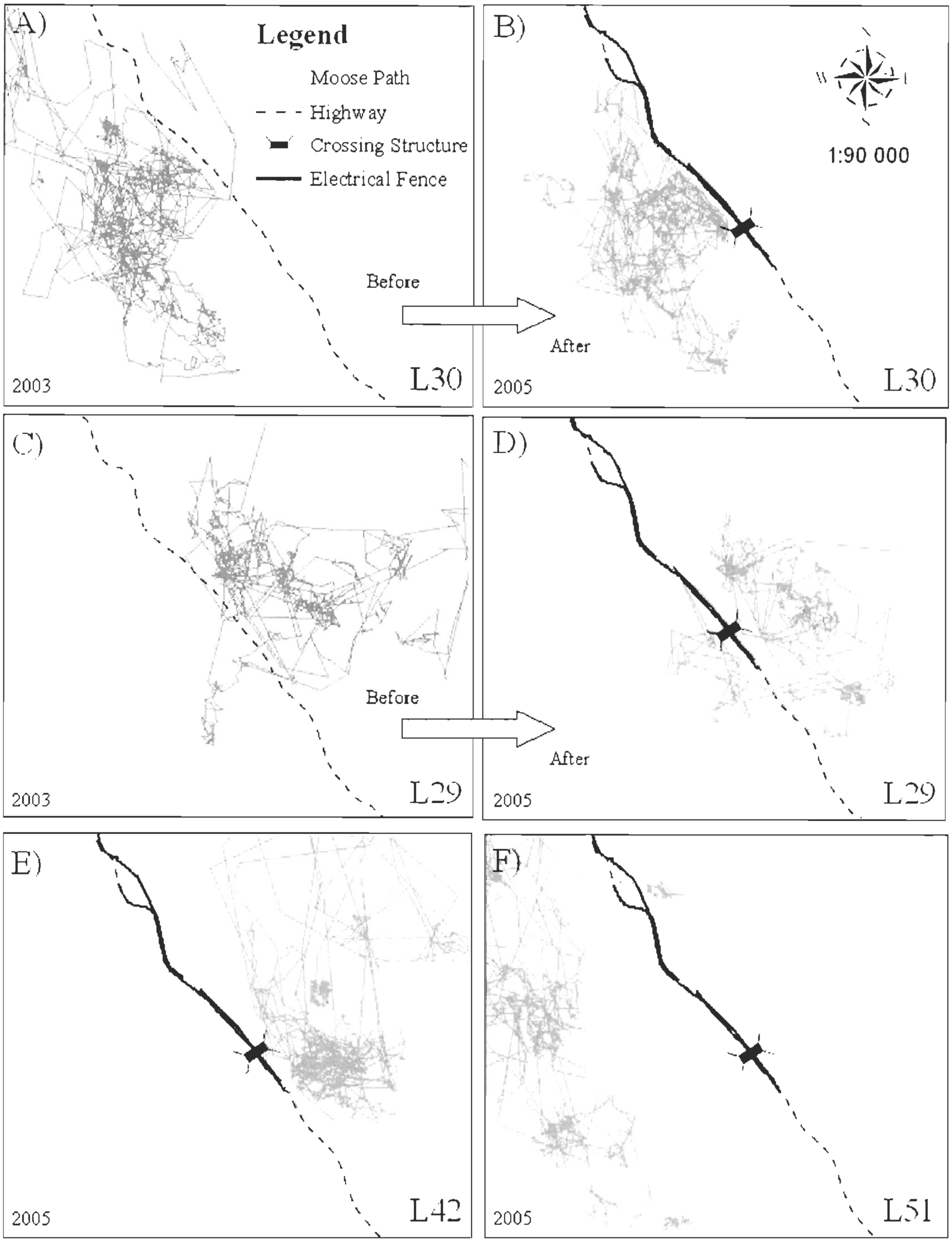

Figure 3.4. (See figure caption next page)

Figure 3.4. Annual movements of four radio-collared moose in the vicinity of the southern part of electric fence F169 in the Laurentides Wildlife Reserve. A) Moose L30 crossed the road once in 2003, before erection of the fence. B) Moose L30 was effectively blocked by the fence in 2005 since the home range was restricted to one side of the fence. C) Moose L29 crossed the road 5 times in 2003, before erection of the fence. D) Moose L29 approached the fence in 2005 and apparently did not cross it but crossed the road south of the fenced sector. E) Moose L42 crossed the fence in 2005 and likely used the wildlife-crossing structure. F) Moose L51 apparently approached the fenced corridor through an opening in front of a lake in 2005 and crossed the fence on the other side of the road.

CHAPITRE IV

CONCLUSION GÉNÉRALE

4.1 L'aménagement des mares salines en bordure des routes

De façon générale, l'effet de l'aménagement des mares salines en bordure des routes s'est manifesté principalement par une diminution du nombre de visites effectuées par les orignaux durant la nuit (*i.e.*, la période la plus critique pour les accidents routiers) et une réduction de la durée de ces visites. Il est encore plus important de souligner que les aménagements ont empêché tous les orignaux de boire l'eau salée des mares. Ces résultats suggèrent que l'aménagement des mares salines pourrait réduire l'intérêt des orignaux envers celles-ci, et ce, peut-être même davantage au cours des étés subséquents. En effet, cette étude a mesuré l'effet des aménagements seulement un an après leur réalisation. Or, un orignal doit évidemment retourner à une mare saline au moins une fois pour constater qu'elle a été détruite.

Nos résultats indiquent aussi qu'une autre méthode d'intervention complémentaire pourrait être envisagée. Puisque la fréquentation des mares salines augmente lorsque l'obstruction visuelle latérale vers la route augmente, il pourrait être efficace de retirer la végétation entre les mares salines et la route afin d'augmenter le dérangement causé par le trafic sur la route. Cette mesure pourrait aussi permettre d'augmenter la visibilité des automobilistes en bordure de la route. Un suivi à long terme des mares salines permettrait de mieux connaître la durabilité des aménagements et leur efficacité à long terme sur l'occurrence des collisions. Les aménagements devraient donc être entretenus afin d'assurer leur durée de vie. Néanmoins, nos résultats suggèrent que cette mesure d'atténuation pourrait réduire le risque d'accident dans les régions où des mares salines artificielles sont à la source de la problématique d'accidents routiers avec l'orignal.

4.2 La clôture électrique

Aussi bien les inventaires de pistes que le suivi par télémétrie GPS ont démontré que les clôtures électriques étaient efficaces à réduire le risque d'accident routier impliquant l'orignal, dans une région où les conditions météorologiques sont particulièrement difficiles. Aucun accident n'est survenu dans les secteurs clôturés au cours de l'étude, bien que ces secteurs étaient considérés à haut risque avant l'installation des clôtures électriques. Toutefois, nos résultats indiquent qu'afin d'obtenir un rendement optimal de la clôture électrique, il faut s'assurer de corriger les interruptions de courant rapidement et éviter de laisser des ouvertures le long de celle-ci. Dans le cas où de telles ouvertures sont inévitables, des structures anti-ongulés pourraient être utilisées pour empêcher les orignaux d'accéder au corridor clôturé (*e.g.*, grilles d'exclusion aux intersections avec les chemins forestiers; Peterson et al. 2003). De plus, l'utilisation d'un disjoncteur fonctionnel, tel qu'utilisé avec la clôture de la route 169, devrait être priorisée afin de simplifier l'entretien et de permettre de libérer rapidement les orignaux qui pourraient se prendre dans les câbles de la clôture électrique. En procédant de la sorte, nous croyons que la clôture électrique pourrait avoir un rendement comparable à celui de la clôture métallique conventionnelle, tout en étant moins dispendieuse et plus discrète. Elle devrait, à tout le moins, être considérée comme une mesure d'atténuation efficace des accidents routiers impliquant l'orignal.

L'impact d'une clôture électrique longue de plusieurs kilomètres pourrait être négatif sur le plan génétique si cette dernière empêchait totalement les déplacements entre les deux côtés de la route. La perméabilité des clôtures conventionnelles ou électriques est généralement améliorée par l'établissement de passages à faune qui permettent la connectivité (Clevenger et Waltho 2000). Des signes d'activité de l'orignal ont été observés dans le passage à faune de la route 175 à 15 reprises sur un total de 33 visites (45 %) au cours des trois étés. Quant au passage à faune de la route 169, des pistes d'orignal ont été observées lors de 7 des 11 visites (64 %) effectuées à l'été 2005. La littérature portant sur l'efficacité des passages à faune et sur les caractéristiques expliquant leur utilisation est abondante (Reed et al. 1975, Foster et Humphrey 1995, Clevenger et Waltho 2000, 2005, Van Wieren et Worm 2001, Little et al. 2002, Cain et al. 2003, Ng et al. 2004). Le dispositif employé dans cette étude ne permettait pas de quantifier l'efficacité des passages à faune, essentiellement à cause des limites de la méthode employée. Notre objectif était plutôt de démontrer leur utilisation par l'orignal.

4.3 Perspectives d'avenir

Il serait souhaitable de poursuivre le suivi des aménagements aux mares salines et des clôtures électriques afin de mieux juger de leur durabilité mais aussi d'évaluer leur efficacité à long terme. Il serait aussi intéressant de vérifier l'impact de ces mesures sur d'autres espèces de grande et de petite faune. De plus, pour conclure définitivement sur l'efficacité de ces méthodes dans un contexte de réduction des accidents routiers, il serait nécessaire de poursuivre le suivi des accidents routiers afin de voir si ceux-ci diminuent effectivement dans les sites expérimentaux. Un suivi à long terme serait à privilégier compte tenu de la grande variabilité interannuelle dans le nombre de collisions survenant le long des routes de la réserve.

Malgré les limites ci-haut mentionnées, cette étude sera d'un grand intérêt pour les intervenants qui recherchent des solutions à la problématique des accidents routiers avec la grande faune. En effet, les méthodes se sont avérées efficaces bien qu'ayant été testées dans un milieu très isolé avec des conditions météorologiques particulièrement difficiles.

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