EXPLORING WAYS OF REDUCING MOOSE-VEHICLE COLLISIONS THROUGH THE USE OF AN AGENT-BASED MODELLING COMPUTER SIMULATION

Introduction

Humans have been constructing road networks for a long time but only recently they have considered that the effect of roads on the distribution and abundance of wildlife is an important issue (Forman et al. 2003). Roads fragment the habitat of many wildlife species. This leads to biodiversity loss and in the case of larger land mammals, to numerous wildlife-vehicle collisions (WVC) that result in human injury and death, wildlife mortality, and property damage (Forman et al. 2003). It is estimated that, globally, there are several million vehicle collisions with moose (*Alces alces*), elk (*Cervus canadensis*), caribou (*Rangifer tarandus*) and other members of the cervidae family each year (Groot Bruinderink and Hazebroek, 1996; Romin and Bissonette, 1996; Conover, 1997).

Some existing roads are now being retrofitted and new roads designed with wildlife overpasses and underpasses, fencing and other mitigation measures in order to reduce wildlife-vehicle collisions. Some of these measures will also reduce habitat fragmentation by providing suitable habitat corridors for migrating species and meta-populations. The placement of these mitigation measures cannot be done solely based on the WVC's most frequent locations but should also be based on the ecology and the focal species' behaviour. Various modelling and analysis methods are employed by road ecologists to identify the important environmental variables that determine the wildlife behaviour in road crossings and contribute to the temporal and spatial distribution of WVC. The road network's long-term existence and the mitigation measures require that proper planning, analysis and design processes and post-implementation review are performed (Forman et al. 2003).

Road Ecology

When a road divides a landscape and thus, within that landscape, some wildlife habitats, there are a number of effects. These effects include the creation of meta-populations from a single contiguous population of a species, the edge effect, stream and wetland changes, chemical runoff such as road salt and other pollution, easier access for invasive species, the barrier effect, road avoidance and road kill (Forman and Alexander, 1998). All of these effects extend different distances into the surrounding landscape depending on their nature and the topography and wind currents creating a "road effect zone" that forms a convoluted buffer around the road (Forman and Deblinger, 2000). It has been estimated that in the United States, about twenty percent of the contiguous land is ecologically affected by the road network (Forman, 2000). Each of these effects shall briefly be examined.

MVC and Roadside Salt Pools

Over 200 MVC occurred in Quebec every year between 1990 and 2002, there are an average of fifty to seventy MVC in the Laurentides Wildlife Reserve (LWR), located north of Quebec City, every year (Dussault et al, 2006) . The majority of MVC occurs between the months of May and October and mainly between dusk and dawn even though traffic volumes are lower. Statistically, the most dangerous time is on a Friday in late June after dark (Dussault et al, 2006).

One causal factor influencing MVC is the presence of roadside salt pools in the spring and summer months. About 100 tons of road salt / km is used in the LWR during winter and in the spring snow melt, the runoff takes the road salt to the ditches and depressions beside the road. Sodium is an essential nutrient in the moose's diet for a number of reasons (Jolicoeur and Crête, 1994) and they can obtain it by browsing on aquatic plants or making a quick trip to the roadside (perhaps crossing the road to get to the salt pools on the other side of road). The concentration of sodium is two or three times higher in the salt pool compared to the aquatic plant's environment (Leblond et al. 2007b). As observed by Miller and Litvaitis (1992), moose in Northern New Hampshire, U.S.A., elongated their summer home ranges to encompass roadside salt pools; this is also the case for the LWR moose where GPS telemetry data reveal a clear difference between the winter and summer home ranges.

It has been estimated that MVC increase by 80% in the proximity of roadside salt pools (Dussault et al. 2006). With the modification of route 175 from a two lane highway to a four lane divided highway, the Quebec Ministry of Transport is planning to eliminate the roadside salt pools as a MVC mitigation measure. They also plan on experimenting with the placement of compensatory salt pools located further from the road (approximately 300m to 1700m) in the general vicinity of the eliminated roadside salt pools (Leblanc et al. 2005). The elimination is done by first draining the salt pools and then filling the depressions with rock to a height of around 30 cm so that the moose that return to the salt pool will not be able to reach remaining salt at the pool's bottom. A recent study has shown that this can be a successful strategy (Leblond et al. 2007b).

Research Objective and Hypotheses

ABM does not appear to have yet been applied, however, to the problem of WVC. Some benefits of using it could include before and after exploratory studies of changes in mitigation measures and landscape structure and composition, "what if" simulations on a longer time scale than normally used in other studies and a dynamic approach that simulates the wildlife's actions not only at the road-habitat interface but through their habitat. Using agent-based modelling, it will be explored whether salt pools removal and salt pool displacement would reduce moose-vehicle collisions (MVC) using moose road crossing as a proxy measure (Grosman et al. accepted). Therefore, with respect to road crossings, this study's null hypothesis is that salt pools removal and salt pool displacement would have no effect on the number of road crossings; the alternate hypothesis is that it would lead to a reduction in road crossings. With respect to total distance travelled by the moose, the null hypothesis would be that salt pools removal and salt pool displacement would have no effect on the total distance travelled; the alternate hypothesis would be that it would lead to a change in total distance travelled because the moose would not need to stretch their summer home ranges to reach the roadside salt pools but may spend more time searching for aquatic plant locations.

Methodology

The model's physical study area is the northern portion of the Laurentides Wildlife Reserve (LWR) situated between Quebec City and Chicoutimi in the Province of Quebec, Canada (Figure 1). The LWR is a 7,861 km^2 forested area (Dussault et al. 2006) that has two provincial roads, routes 175 and 169 that cross its territory. The Parc national de la Jacques-Cartier (PNJC) is located in the southern portion. Hunting is prohibited in PNJC but is permitted on a controlled basis in the LWR.

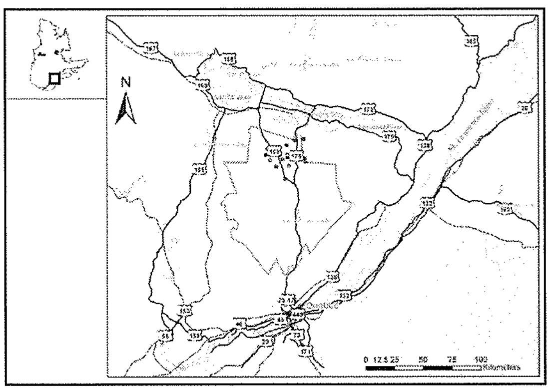

Figure 1. Physical Study Area with the LWR boundary in green. source: ESRI Data & Maps Media Kit. (2006) and Dussault (2007).

Electronic GIS data sources were supplied by researchers from the Québec Ministère des Ressources naturelles et de la Faune (MRNF) and Université du Québec à Rimouski (UQAR) (Dussault, 2007). These data sources contained the following ESRI shapefiles: Moose Movement locations in both the LWR's northern portion and the PNJC, Forest Stands, Roads, Water Bodies and Streams, Topography, Digital elevation model, and Salt pool locations.

A 24 km by 46 km area centered on Route 175 above the junction with route 169 was selected from the Forest Stand data to serve as the GIS landscape for the model, corresponding to approximately 10,000 polygons. Twelve moose whose home ranges were almost wholly within 12 km of route 175 were selected as agents. Route 175's road segments were merged into one line and a 45m buffer (Sansregret and Auger, 2002) was applied to it to create the road buffer polygon representing both the two-lane highway and its vegetative borders.

Model Parameters

Since the model was designed to explore the effects of salt pool removal, the time duration was chosen to be the spring and summer months when the moose are reported to be the most active visitors at salt pools (Leblond et al. 2007b). As well, the model was run on a 2 hour time step to match the GPS telemetry storage interval used by the MRNF and UQAR researchers (Dussault et al. 2007). Thus the model was step up to run from May 1st to August 31st on a two hour time steps or Repast J "ticks", resulting in a total of 1,476 total steps or "ticks". The start date and time parameters can be modified before the start of the model run by the model user.

The model moose location shape file and the Forest Stand shape file names are parameters that can be changed by the model user prior to model execution. This was necessary for the different calibration runs.

A moose's daily activity can be divided into four parts: foraging for food, ruminating, resting, and travelling. A moose's 24 hour day was initially equally partitioned prior to model calibration, that is, 6 hours to each activity based on Renecker and Schwartz (1998). After calibration, these four activities were assigned the following durations: food: 6 hours, ruminating: 6 hours, resting: 8 hours, and travelling: 4 hours. This is further explained in the Calibration section below.

The distance a model moose moved while foraging in the two-hour time step was determined to be 160m by taking the average of the mean distance travelled by month for the spring and summer months for the twelve real moose that corresponded to the model moose. One can see the significant decrease in forage distance in the winter months due presumably to the deep snow cover of the study area (Dussault et al. 2006). If one considers the 160m distance to be the hypotenuse of a right-angled triangle then the distances along the x and y axes would both be equal to 112m, according to the Pythagorean theorem, i.e. $(112^2+ 112^2)^{0.5} = 160$, approximately. So the forage distance was set to 112m in the model.

Habitat use rules

The moose's habitat use rules to determine which forest stand patch they will move to in the next time step, were based on the five most significant parameters determined from the current scientific literature on moose in the LWR (Dussault et al. 2005; 2006; 2007). These five parameters were determined to be food quality, cover quality (protection from predators), minimal slope, proximity to water bodies and streams and proximity to roadside salt pools. Moose require 3 to 8 kg of food daily depending on their size to maintain a positive energy balance and can spend about 6 to 9.5 hours a day in the summer foraging (Renecker and Schwartz, 1998; Dussault et al. 2005). Moose seek protection from predators such as wolves (*Canis lupus*) and black bears (*Ursus americanus*) by selecting habitat with lower visibility due to increased forest density. Mature conifer stands typically offer the best cover (Dussault et al. 2005).These two parameters were coded for each forest stand polygon based on the habitat type in the Forest Stand data received from MRNF and UQAR as mentioned above. Moose in general when travelling tend to seek flat terrain; they can travel along streams and also along hill ridges but tend not to move up and down slopes in order to conserve energy (Dussault et al. 2006). These two parameters were coded for each forest stand polygon based on the habitat type in the Forest Stand data received from MRNF and UQAR as mentioned above. The Forest Stand data contained a field that classified slope and this was reclassified as a numerical value by the model for the purposes of scoring the neighbours of a forest stand polygon. Both proximity to water bodies and proximity to salt pools were chosen because of the animal's essential nutritional need for sodium in its diet. These two parameters were added as fields to the Forest Stand shape file and then each Forest Stand polygon was classified based on its proximity to its closest water body or roadside salt pool. Each parameter was given a weight reflecting its relative importance for habitat use, while ensuring that the weights' sum equalled 1.00.

The final set of parameters is the Habitat Quality ranks with values initially set as follows: Score of 5 = 0.60 chance of selection, Score of 4 = 0.25, Score of 3 = 0.125, Score of 2 = 0.08, and Score of 1 = 0.01. Rather than have the moose agent always select the neighbouring polygon with the highest weighted score, these rankings are used to assign a likelihood that any particular score from 0 to 5 should be selected.

Moose Movement Rules

If the moose is foraging then it must move to a new point within its current forest stand polygon. The new point is constructed from its current location by taking a new x-coordinate and y-coordinate calculated by multiplying the forage distance parameter (initially set to 112m) by a number randomly selected between -1 and +1 and then adding to these to the current location's x and y coordinates. If the new point is outside the current forest stand polygon, then the calculation is redone until a new point with the current forest stand polygon is obtained. If the moose is resting or ruminate, then the moose does not move from its current position.

If the moose is travelling, a stochastic approach is used to choose the highest valued neighbouring polygon rather than always selecting the highest scored neighbouring polygon in a completely deterministic manner.

Model Calibration

A comparison of the distance of the 12 real moose GPS locations from the roadside salt pools versus random points on the road showed no significant statistical differences (t-test: one-sided p-values $\geq$ 0.10). Therefore, the Model calibration was done using the real twelve moose's habitat use and the total distance travelled (

Table 1) instead of using the salt pool visits and visits to random locations on the road. Ten runs were executed with various sets of moose daily activity budgets and the model parameter weights. It was found that the run #8 fit the Habitat use best and fit the Total Distance travelled second-to-best. These parameter weights and daily activity budget were chosen for the scenario runs.

	(in hours)				Parameter Weights				
run#	foraging	travelling	resting	ruminating	Cover	Food	ProxWB	ProxSP	Slope
1	48	16	0	0	0.2	0.3	0.1	0.35	0.05
2	48	***4***	0	0	0.2	0.3	0.1	0.35	0.05
3	***24***	4	0	0	0.2	0.3	0.1	0.35	0.05
4	***36***	4	0	0	0.2	0.3	0.1	0.35	0.05
5	36	4	0	0	***0.225***	***0.325***	0.1	***0.3***	0.05
6	***6***	***6***	***6***	***6***	***0.2***	***0.3***	0.1	***0.35***	0.05
7	6	***4***	***8***	6	0.2	0.3	0.1	0.35	0.05
8	6	4	8	6	***0.1***	***0.4***	0.1	0.35	0.05
9	6	4	8	6	0.1	***0.45***	0.1	***0.3***	0.05
10	6	***2***	***10***	6	0.1	***0.4***	0.1	***0.35***	0.05

Table 1 Parameters for the 10 calibration runs. Run#8 was selected as best fitting the Habitat use and Distance Total travelled statistics of the corresponding 12 real moose.

Scenarios

Now that the model has been calibrated, we want to test various policy scenarios involving different configurations of roadside salt pools and compensatory salt pools to see if any lead to a reduction in moose road crossings.

The 36 roadside salt pools are not distributed uniformly on route 175; they have more of a clustered distribution. So they randomly divided up into six sets of six; the eighteen compensatory salt pools were divided up into three sets of six based on which roadside salt pools they were compensating for. Four of the eighteen compensatory salt pools are actual data points from the MRNF/UQAR data (Dussault, 2007) and the other fourteen were added by the author.

The following five scenarios were designed to test the model:

1. Current situation (CS), no Salt Pools Removed, no Compensation Salt Pools
2. 100% Salt Pool Removal, No Comp. Salt Pools
3. 100% Salt Pool Removal, 100% Comp. Salt Pools
4. 66.67% Salt Pool Removal, No Comp. Salt Pools
5. 66.67% Salt Pool Removal, 66.67% Comp.Salt Pools.

Each scenario was run 100 times. The Forest Stand data for each scenario was created with the appropriate values for the Proximity to Salt Pools field depending on that scenario's set of salt pools, using ArcMap's ModelBuilder. For scenario #2 only, since there were no salt pools in the GIS landscape, and moose must obtain the sodium that is an essential nutrient in their diet, the moose should revert to the sodium-rich aquatic environment (Leblond et al. 2007b). Accordingly, the Proximity to Salt Pool parameter weight was reduced to zero and the Proximity to Water Bodies parameter weight was correspondingly increased to 0.45; for the other four scenarios, all weights were kept to the results of the model calibration. The data logs for each scenario were combined and summarized to determine the number of moose-road crossings while travelling, the total distance travelled by the model moose, and their habitat use. Student t-tests were performed on the 100 runs of scenario #2 to #5 against the 100 runs of scenario #1, to test if roadside salt pool removal and displacement led to a statistically significant reduction in moose crossings and secondly, to a statistically significant reduction in total distance travelled.

Results

Road Crossings

In scenario#1, CS, the moose crossed route 175, a mean of 45 times. In the other scenarios where roadside salt pools were removed with and/or without compensatory salt pools, the number of road crossings by moose was reduced from about 16% to 49% (Table 2).

Scenarios	1	2	3	4	5
100 runs	C.S.	100% elimination of salt pools	100% elimination of salt pools with comp. S. P.	2/3 elimination of salt pools	2/3 elimination of salt pools with comp. S. P.
means	45.58	23.14	37.55	38.27	38.06
std deviation	22.79	13.18	19.03	16.52	17.04
std error	2.28	1.32	1.90	1.65	1.70
reduction		49.24%	17.62%	16.05%	16.50%
1-sided p-values		<<0.001	0.004	0.005	0.004

Table 2 Number of road crossings by model moose while travelling.

As stated in the Introduction, with respect to road crossings, the null hypothesis was that salt pools removal and salt pool displacement would have no effect on the number of road crossings;

the alternate hypothesis was that it would lead to a reduction in road crossings. In each test, it was found that there was a statistically significant reduction in road crossings, compared to the CS scenario.

Only 3 of the 12 real moose, however, crossed the road for a total of 53 times: two did so 2 times each, and the other 49 times, this moose's home range is bisected by route 175 (Figure 7). This was determined using Hawth's Analysis Tools for ArcGIS (Beyer, 2004).

Total Distance Travelled by the set of moose

In scenario#1, CS, the 12 moose travelled a total of 2,724 km from May 1st to August 31st. In the other scenarios where roadside salt pools were removed with and without compensatory salt pools, the total distance travelled varied from a reduction of about 1% to an increase of 9% (Table 3).

Total Distance Travelled					
Scenario	1	2	3	4	5
100 runs	C.S.	no Salt Pools	no Salt Pools 100% with Comp. S.P.	66.67% Salt Pools removed	66.67% Salt Pools removed with Comp. S.P.
mean (m)	2,724,149	2,972,175	2,724,698	2,692,953	2,755,586
standard deviation (m)	307,667	291,852	247,334	261,522	304,079
standard error (m)	30,767	29,185	24,733	26,152	30,408
reduction		-9.10%	-0.02%	1.15%	-1.15%
two-sided p-values		<<0.01	0.99	0.44	0.47

Table 3 Total distance (m) travelled by moose.

As stated in the Introduction, with respect to total distance travelled by moose, the null hypothesis was that salt pools removal and salt pool displacement would have no effect on the total distance; the alternate hypothesis was that it would lead to a change in total distance because either the moose would no longer elongate their summer home ranges to reach the roadside salt pools or search more distance for aquatic plant locations. Two-sided Student t-tests were performed comparing the means of each of scenarios #2 - #5 to the CS scenario. In three of the four tests, it was found that there was no statistically significant difference ($\alpha=0.05$). Only scenario #2 differed significantly (2-sided p-value <<0.01) from the CS scenario. In comparison, the corresponding set of 12 real moose travelled 2,018 km over the same time period. This is 26% less than the CS scenario.

Habitat use

The model moose selection of habitat did not vary between scenarios, which all represented quite well the actual moose's habitat use (Figure 2). The relative habitat type rankings appear to be consistent between the scenarios and the actual set of moose.

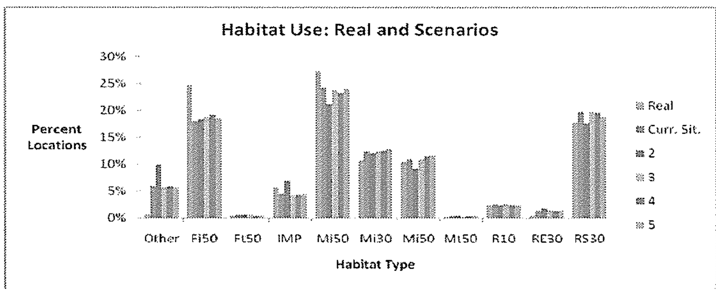

Figure 2. Habitat use by Moose, Actual and Scenarios. Source: Dussault, (2007).

Discussion and Conclusion

The model results showed that the removal and displacement of roadside salt pools does lead to a statistically significant reduction in road crossings by moose in the model. This would correspond to less MVC depending on the road crossing dates and times. One can conclude that roadside salt pool removal and/or displacement will have a positive impact on MVC reduction by reducing moose visits to roadside salt pools (Leblond, 2007b).

The greatest reduction of road crossings occurred in the second scenario when all the salt pools were removed and no compensatory ones were created. For this scenario only, since there were no salt pools (roadside or compensatory), the proximity to salt pools parameter weight was to reduced to zero, Consequently, the proximity to water bodies parameter weight was increased to 0.45, as the aquatic plants that are found there became the moose's primary source of sodium. This weighting scheme reflects the moose's essential requirement of sodium in spring and summer (Leblond, 2007b). The absence of any salt pools near route 175 led to the 44% reduction of road crossing compared to the CS scenario. Small reductions in moose crossings occurred in the other three scenarios that had salt pools.. The scenario with no road salt pools but 18 compensatory ones had a greater reduction in road crossings than the scenarios with 33.3% of salt pools remaining. This can be attributed to the placement of the compensatory salt pools at a distance of 300m to 1700m from route 175; the attraction of salt pools starts to decay at 100m and reaches a value of zero at a distance greater than 1,000m.

The model moose's habitat use agreed with that of the real moose, particularly in the habitat rankings if not in exact percentages. Therefore, the habitat use rules that were based on the weighted average of the five parameters of food, cover, slope, proximity to salt pools and proximity to water bodies with the stochastic variability appear to give reasonable results and generally agree with the habitat use of Dussault et al. (2005).

The total distance travelled by the moose, however, was consistently greater than that of the real moose. As discussed below, the moose movement rules need to be redesigned to better fit the GIS data. The scenario with no salt pools did have a statististically significant increase in distance travelled and this may be attributed to the model moose searching for the water bodies (Leblond, 2007b).

Potential for Future Improvements

The model could be improved in the following areas: more individual-based behaviour, sensitivity analysis and calibration of parameters, home range enforcement, foraging based on recognized ecological patch dynamics, spatial memory of roadside salt pools, the consideration of the road effect on moose movement, the calculation of the MVC probabilities, the addition of other mitigation measures and changes to the road footprint (i.e. the expansion to a four-lane divided highway), traffic volumes and the forest stand composition (for more details, see Grosman et al., accepted).

Conclusion

This use of model for studying WVC and MVC appears to be a worthwhile effort. This model showed a clear reduction in moose road crossings that correlated to salt pool removal and displacement, agreeing with (Leblond, 2007b). As well, habitat use results generally agreed with Dussault, et al. (2005). A model can cover the wildlife's entire habitat and not just the road habitat interface. As well as being dynamic and thus being able to simulate wildlife behaviour over longer time periods than this study did, a model can be used to test hypotheses about different aspects of wildlife-human environmental interaction such as hunting and outdoor recreation.

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