The barrier effect of highway E4 on migratory moose (*Alces alces*) in the High Coast area, Sweden.

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Abstract

The new highway E4 along the Baltic coast of Sweden cuts through winter migration routes for moose (*Alces alces*). To counteract barrier effects of the fenced highway and increase traffic safety, two moose underpasses have been constructed in addition to conventional bridges and viaducts. As the road was opened for traffic, a follow-up study was initiated to evaluate the amplitude of the barrier effect and efficacy of the counteractive measures. Migratory movements were studied on individually marked moose; moose tracks were mapped on snow and counted on sand layer to reveal local movements along the road and through the underpasses. Changes in local moose density were indexed be pellet group counts and related to browsing damages to young forest stands and available forage. The majority (88%) of marked and recaptured moose had moved farther than the diameter of an average home range (5 km) and were thus classified as migrants. During winter, migrating moose were held up in their way to their former winter ranges near the coast and accumulated in productive areas west of the highway. Browsing damages consequently increased from 5% to over 40% during 1998 to 2000. Underpasses and viaducts were used only occasionally by moose (about 1.6 tracks per month) and there was no seasonal or directional difference in usage. This suggests that primarily resident moose were utilizing underpasses. In addition, snow tracking revealed that many moose were reluctant to enter the underpasses and instead preferred to cross the fenced road. We conclude that the counteractive measures have not been effective in reducing barrier effects on migratory moose. We discuss possible consequences to moose management and make recommendations for future infrastructure planning in the region.

Key-words: moose, monitoring, mitigation measure, fauna passage, effectiveness, barrier effect, EIA, Sweden

Introduction

Conflicts between moose (*Alces alces*) and road traffic in Sweden have mostly been addressed from a traffic safety perspective (e.g., Almkvist et al. 1980, Lavsund & Sandegren 1991, Seiler in press), while only little concern has been paid to barrier and isolation effects (e.g., Ball & Dahlgren 2002, Helldin & Seiler 2002). During the 1990's, Swedish police records amounted to over 4,000 moose-vehicle collisions (MVC) each year (Seiler in press), but the total number of accidents is likely twice a high (Seiler et al. in press). Various measures to mitigate moose-vehicle collisions have been tested in Sweden (Almkvist et al. 1980, Björnstig et al. 1986, Skölving 1985), but only exclusion fencing and roadside clearing have proven to work cost-efficiently (Niklasson & Johansson 1987; see also McDonald 1991, Clevenger et al. 2001). Exclusion fencing has become a standard in Swedish road management, and as of 2001, more than 5,000 km of highway have been fenced against large ungulates. The Swedish National Road Administration (SNRA) intends to significantly expand fencing as highways are upgraded, but recommends combining fences with designated wildlife passages to further increase traffic safety and counteract potential barrier effects on moose (A. Sjölund, SNRA, personal communication).

However, knowledge about the barrier effect of roads and fences on moose is limited. Small scale experiments suggested that road fencing may prevent up to 90% of moose movements (e.g., Skölving 1985, Nilsson 1987), while heavy traffic *per se* (above 10,000 vehicles per day) can impose a strong barrier as it repels animals from crossing (Müller & Berthoud 1997, Seiler 2003). Road fencing may cause local accumulations of moose (Kjell Ståhl, SNRA, personal comments) and can lead to increased browsing damages to young forests (e.g. Ball & Dahlgren 2002).

The barrier effect on moose of traffic and road fences is emphasized in areas north of 60°N where moose are partially migratory, moving tens of kilometres between upland summer areas and lowland winter habitats (e.g. Sweanor & Sandegren 1986). Migration seems to be triggered by environmental factors such as snow cover (Sandegren et al. 1985) and snow quality (Ball et al. 2001), and varies in amplitude between coastal/lowland and highland/inland populations. In coastal areas, near the city of Umeå, for example, moose move about 22 km between winter and summer habitats and about 55% of the population exhibits migratory behaviour (Ball et al. 2001). Further west in upland and mountainous regions, over 70% of the moose migrate and their movements usually exceed 35 km and may even go beyond 100 km (Sandegren & Ledström 1984, Sandegren et al. 1984, Sandegren & Bäck 1985; 1986).

Moose migration in northern Sweden is historically evidenced by pit-trap systems erected for more than 3,000 years and migration routes are often maintained for many generations (e.g., Sweanor 1987). Migratory behaviour seems to be culturally inherited from mother to offspring and is therefore largely resistant to changes in food distribution or the erection of movement barriers (e.g., Sweanor & Sandegren 1989, Andersen 1991, Ball et al. 2001). Traditional migration routes often follow the topography of the landscape, which in northern Sweden has a strong northwest-southeast orientation. Moose migrating towards the Baltic coast need to cross both the highway E4 and the main railway which parallel the northern coast over more than 1000 km. Migration usually blends migrant moose blend with resident moose within the winter ranges and results in local aggregations of moose that can cause severe browsing damages to forest and increase the risk for moose-vehicle collisions (Sweanor & Sandegren 1989).

Problems with migratory moose were anticipated as the E4 in the High Coast area (Figure 1) was about to be upgraded to motorway standard and partially rebuilt. Environmental impact assessment studies (EIA) pinpointed several locations along with the 32 km new (fenced) road section where traditional winter concentrations and migration routes of moose would be dissected (Schibbye 1992, Schibbye et al. 1995). To counteract barrier effects on moose, two underpasses exclusively designated to moose were constructed, one in an area where extensive migration has been observed. In addition, five viaducts with a span exceeding 200 m and several conventional road underpasses were believed to provide potential passage to wildlife.

However, doubts were raised, e.g., during the second IENE meeting held in 1997 in the High Coast area, as to whether these counteractions were sufficient to ensure continued moose migration. A follow-up study was proposed, which the SNRA finally agreed to finance. The goal of the study was to assess the amplitude of the barrier problem and evaluate the efficacy of the present mitigation measures during the first years after the construction of the new highway.

Study area and road

The new European Highway E4 was built between 1993 and 1997 as a two-lane highway with wildlife exclusion fences, no at-grate intersections, designed for traffic loads above 6,000 vehicles per average day at speed limits of 90-110 km/h. It was opened to traffic on December 1st, 1997. The new highway cuts through the High Coast Area from Överdal (62°43’ N, 17°45’ E) in the south, across the river Ångermanälven to the village of Gallsäter (62°56’ N, 18°06’ E) in the north at a length of 32 km (Figure 1).

The High Coast area belongs to the middle boreal zone of northern Sweden (Ahti et al. 1968). Land use is dominated by forestry (Scots pine, *Pinus sylvestris*, and spruce *Picea abies*), with agriculture scattered in lowlands, especially along the northern section of the road. A detailed description of the area and the natural as well as cultural background is given e.g., in EIA documents produced by Schibbye (1992) and Schibbye et al. (1995). Due to its specific topography and long cultural history, parts of the High Coast area are designated as areas of national interest to landscape conservation. This status obliges special environmental concern in industrial and infrastructure development such as to minimize the barrier effect on local transport and wildlife.

As part of the environmental adaptation of the new highway, 35 bridges (>2m in width) have been constructed, including five viaducts with a span of more than two hundred meters (e.g., Figure 2c, d). Most famous among these bridges is the 1,800 metres long suspension bridge across the Ångermanälven river (URL: http://www.hogakustenbron.nu/index.htm), one of the tallest constructions in Sweden so far. Because of this bridge and the new straighter alignment of the highway, the travel distance between Överdal and Gallsäter could be reduced from 72 to 32 km. The cost of the entire road project was about 210 million Euro, half of which was spend on the suspension bridge.

Another important environmental adaptation was the construction of two underpasses exclusively designated to moose. One underpass was placed in the southern section of the road, near the lake Furusjön (62°43’ N, 17°55’ E; Figure 2a), where migratory moose were assumed to pass through. The other moose underpass was built at the northern shore of the lake Storsjön (62°55’ N, 18°06’ E, Figure 2b) in an area where moose were considered mostly non-migratory. Both underpasses have similar dimensions of 4x5x26 meters (height x width x length); a design conventionally applied to bridges used for agricultural or forestry purposes.

Most of our work was focused at the southern section of the new E4, where moose migration was anticipated. Field inventories were conducted within a 7x6 km wide area dissected by the E4 between Överdal and Utansjö (62°46’ N, 17°55’ E) (Figure 1).

Methods

Moose migration

To study the length of movements between winter and summer habitats and the proportion of moose exhibiting migration, we marked 45 moose (including 21 cows, 13 bulls, 4 female and 7 male calves) with individual ear tags. Marking was done in the presumed winter habitats of moose near the new highway during February 1998. However, in the eastern part of the study area, moose density was much lower than expected and only six individuals could be captured and marked. During the consecutive four years, we collected 26 reports on marked moose that were shot during autumn hunt or killed in traffic accidents. Twenty-four individuals were killed during the summer period while they were presumed to be within their summer habitats, two moose were killed in collisions with vehicles during later winter 1998 and were thus not included in the analysis of migratory movements. Similar to earlier studies on moose migration (e.g., Sandegren et al. 1985, Sweanor & Sandegren 1989, Ball et al. 2001), we defined migratory movements if the distances between winter and summer locations were larger than the minimum diameter of an average moose home range irrespective of age or gender, i.e., 5 km (for a 19.8 km^2 home range; Sweanor & Sandegren 1989, Cederlund & Sand 1994). Note however, that migration must be understood as a continuous phenomenon, with 'migrants' and 'residents' being the end points of a continuum of movement distances (Ball et al. 2001).

Moose density

Due to the barrier effect of the fenced roads, we expected migratory moose to accumulate along the western side of the highway. To test this hypothesis, we used pellet group counts as index of local winter abundances in herbivores (Cederlund & Liberg 1995; Pehrson 1997; Harkonen & Heikkila 1999). We counted pellets fresh pellet groups of moose and roe deer (*Capreolus capreolus*) and individual pellets of hare (*Lepus timidus*) in 644 and 489 sampling plots, evenly distributed throughout the western and eastern part of the study area, respectively. The inventory was done shortly after the snow melt in May during 1998 to 2000, thus reflecting the amount of pellets produced during the preceding winter months.

Local accumulations in moose were calculated from the number of pellet groups per sampling plot and year, as kernel probability distributions (Worton 1989) using the software "Animal movements" developed by Hooge & Eichenlaub (1997). Estimates of the large scale trend in moose density during 1997 to 2002 were obtained from harvest statistics, as provided by the County Administrative Board, and from hunters' observations (number of moose observed per 100 man-hours) for the hunting districts Härnösand and Högsjö, as provided by the Swedish Association for Hunting and Wildlife Management.

Forage availability and browsing damages

An important consequence of increased moose density during winter are browsing damages to young forest, especially pine plantations (Lavsund 1987, Sweanor & Sandegren 1989). Moose density and site productivity appear as the dominant factors determining the occurrence of browsing damages (e.g. Danell et al. 1991, Andrén & Angelstam 1993, Hörnberg 1995), but landscape parameters, such as road barriers, can have additional influence (Ball & Dahlgren 2002).

Forage availability and site productivity was measured as tree species composition, tree cover, and top-shoot length in pine, spruce, and deciduous trees (mainly birch *Betula pendula*, aspen *Populus tremula*, and willow *Salix spp.*) at each sampling plot used for pellet counts.

To assess browsing damages, we selected pine afforestations with more than 20% pine at heights ranging between 0.5-3.0 meters, i.e. the main browsing height for moose (e.g., Lavsund 1987). Within these pine stands, we evaluated 1,000 to 1,650 trees for browsing damages per year and area. Results are presented as percent damaged trees. Browsing damages were measured according to the standard applied by the Swedish National Board of Forestry (i.e. 'Älgbetning 90, now called: 'ÄBIN'; URL: http://www.svo.se). In addition to 'ÄBIN', we also looked at old browsing damages, to assess the browsing pressure that had accumulated before the construction of the highway.

Moose movements along and across the road

The direct effect of the road barrier on moose movements was studied by snow-tracking along a 9 km long section of the highway (between Överdal and Utansjö, Figure 1). This section includes four bridges, one of which is the moose underpass 'Furusjön'. All bridges potentially provide save passage to moose underneath the highway. Snow-tracking was done eleven times during January to April of 1998 to 2001 (4x1998, 3x1999, 3x2000, 1x2001), representing a period of 90 days of undisturbed snow cover. All moose tracks along the road section were mapped, either they followed the fences or, eventually, crossed over the fence or through the underpasses.

Usage of underpasses

To evaluate the efficacy of the two underpasses ‘Furusjön’ and ‘Storsjön’ build exclusively for moose, we made regular track counts on sand and snow layers.

Sand (or snow) layers were checked for moose tracks once or twice every second week during the years 1998 to 2001, amounting 119 intervals representing 1040 days of accumulated tracks. We looked at differences in track frequency over time between the two underpasses, expecting that migratory activity around ‘Furusjön’ should be reflected in seasonal variation in numbers and directions of tracks. In addition, we compared these data with track counts made beneath a minor bridge across a small creek at Överdal, a 200 m long viaduct at Oringen, and a 435 m long viaduct at Skullersta (Figure 2). No moose tracks at all were observed beneath the bridge ‘Överdal’. In the following, we only present data from the remaining four passages.

Traffic safety

The reason for fencing the new highway was to reduce the risk for moose-vehicle collisions. We documented the change in collision numbers with data obtained from central accident statistics complied by the SNRA. Unfortunately, these statistics were discontinued after 1999.

Results

Moose migratory movements

Between 1998 and 2001, 24 of the 45 marked moose were reported dead while supposedly within their winter habitats. Distances between winter and summer locations approximated 11.0 km, yet with a wide range from 2 km (female yearling) to 46.3 km (male yearling during 31 months) (Table 1). Twenty-one (88%) of the 24 reported moose had moved farther than 5 km and ten farther than 10 km from their winter location and were therefore classified as migrants. Six of these 21 moose were yearlings and it is possible that their long distance movements also included dispersal from their natal home range. However, age class (adult or yearling), gender, and time passed between date of marking and date of reported death (during summer) had no effect on the distance moved (Table 2). Overall, males tended to move longer distances than females, but the difference was not significant (Unpaired t-test: DF=21, t =1.24, P=0.227). Movements were headed in all directions, on average however, moose moved with a west-northwest bearing of 278° (86° Std. Dev.) to inland habitats. Mean bearing was not affected by age or gender, but the three moose considered as residents had a mean bearing of 151° compared to 303° in migrants.

Moose density

During the first three winters after the construction of the highway, moose densities in the western part of the study area were significantly higher than in the eastern part (df=1, chi^2>13.91, p<0.0002). Pellet-group counts suggested winter densities of 17.3 individuals per 1000 hectares in the west, but only 6.8 per 1000 ha in the east. Overall, moose density was estimated at 12 individuals per 1000 ha, which matches the density estimated from annual moose harvest statistics from the region (10-12 moose per 1000 ha, Gunnar Ledström, Swedish Association for Hunting and Wildlife Management, personal comment). Inter-annual variation in moose density was large, but still smaller than the differences between the road sides (Figure 4). At regional scale, moose densities as indexed from hunters’ observations showed a slight but insignificant upward trend during 1997 to 2002 (Figure 5).

At local scale, within the partial study areas, accumulations of moose changed considerably from year to year probably reflecting small-scale variation in forage availability. However, moose accumulations were not in immediate vicinity of the new highway (Figure 6), as was expected provided the road would stop inland migratory moose on their way to winter habitats at the coast. It is possible, though, that these moose already had encountered the fenced road but chose to turn back into forest stands that were more productive than the immediate surrounding of the road.

In contrast to migratory moose, there was no consistent difference between the partial densities of hares and roe deer. Hare densities declined strongly (about 60%) in both areas during 1998 to 2000. Roe deer densities were generally low (about 2.5 deer per 1000 ha), but with no difference between west and east (df=1, $chi^2>2.32$, p>0.127).

Forage availability and browsing damages

Forage availability for moose fluctuated locally and annually, but was rather stable at broader scale. There was no difference in the cover of spruce and deciduous trees between the road sides; however, pine trees that provide the preferred winter forage to moose, were significantly more abundant in the western part of the study area (Table 3). Multiple regression analysis indicated that moose density, as indexed by pellet groups per sampling plot, correlated strongly with density and top-shoot length in pine (1998: DF=1130, F=28.41, p<0.0001; 1999: DF=1108, F=31.283, p<0.0001; 2000: DF=1099, F=39.563, p<0.0001).

The distribution of browsing damages to young pine trees reflected differences in moose density between the road sides. During all three years, significantly more pine trees were freshly damaged by moose in the western area than compared to the eastern area (Figure 7). In 1998, 17.4% and 20.4% of the pine trees studied in the western and the eastern area, respectively, showed damages that had accumulated already prior road construction. Three years later, however, more than 42% of all studied pine in the western area was damaged by moose, compared to 30% in the eastern area. Within the partial areas, local accumulations of damages coincided with the highest densities of moose as indicated by pellet group counts.

Moose movements along the road

During the four years after construction of the new highway, there was a remarkable decline in the number of moose tracks across the fenced highway or beneath the two underpasses and two viaducts (Figure 4). Crossing rates across the 9 km road section dropped from 19.2 recorded moose per month in 1998 to zero in 2001. However, due to the small number of inventories, no statistical test could be applied and conclusions must be drawn with caution. Annual variation in snow conditions may have distorted the picture. During 1998, for example, snow cover was especially deep and hard, which reduced the effective height of the fences to nearly one meter, and allowed moose to cross fences more easily than compared to the following winters. A summary of the situation in April 1998 is given in Figure 8.

Nevertheless, during all years, there were accumulations of moose tracks along with the western fence, especially between the underpass 'Furusjön' and the viaduct 'Oringen', while moose trails along the eastern side of the road were rare. Compared to the old and unfenced E4, only very few moose crossed over the new highway or through the underpasses and viaducts. For example, in 2000, 21 moose tracks crossed the old E4 near 'Oringen' during a period of 33 days, while only 3 crossed over the new highway and another 3 passed beneath the viaduct 'Oringen'.

Usage of underpasses and viaducts

We observed no significant seasonal variation in the number and direction of moose tracks through the underpasses and beneath the viaducts that would suggest increased moose mobility during the period of migration (Figure 9). The underpass at the lake Furusjön, where moose migration was expected, was not used more frequently than the underpass at the lake Storsjön, where moose were considered non-migratory. Although the overall number of tracks was rather low, significantly more moose went through these two 'moose underpasses' (1.6 tracks per average month) than beneath the viaducts 'Oringen' and 'Skullersta' (0.6 and 1.0 tracks per average month, respectively) (Table 5). However, in the course of the four study years, moose tracks became more frequent at 'Oringen' ($F_{1,117}=7.32$, p<0.008, adj. $R^2=0.051$) and 'Storsjön' ($F_{1,112}=6.61$ p<0.011, adj. $R^2=0.047$), but not at 'Furusjön' and 'Skullersta' (Figure 10).

Repeatedly, snow tracks illustrated how moose that approached an underpasses or viaduct hesitated to move through and instead turned back or decided to cross over the fence near the underpasses. In addition to moose, occasional tracks of roe deer, hare, bear (*Ursus arctos*), and lynx (*Lynx lynx*) were observed beneath the viaducts.

Traffic safety

During 1993 to 1997 (before the construction of the new road), an average of 3.6 vehicle collisions with moose and 1.8 collisions with roe deer was reported each year on the 9 km section between Överdal and Utansjö. After the opening of the highway in December 1997, moose collision numbers on the new road dropped to 2 and 1 in 1998 and 1999, respectively, while no moose-vehicle collisions were reported on the old E4. No accidents with roe-deer were reported in 1998 and 1999. Collision statistics were discontinued after 1999.

Discussion

Migration and barrier effect

The migratory patterns we observed in moose in the High Coast area were similar to those described in other studies in northern Sweden: Winter migration in coastal areas is less pronounced and less directed than in the mountainous inland (Sandegren et al. 1984, Ball et al. 2001). In our study, 41% of all marked and recaptured moose had moved farther than 10 km between winter and summer habitats and 88% matched the definition of migrant moose (e.g., Sandegren et al. 1985, Sweanor & Sandegren 1989). Average migration distances were less than observed in radio-tracked moose populations near Umeå (22 km; Ball et al. 2001), but because our data is based on only two locations (marked and killed), it provides but a minimum estimate of the true distance moved. Individual moose headed in all directions, but distance and mean bearing was not related to age or gender. Still, the farthest movements had an average west-northwest bearing, as has the structure and topography of the landscape. In that, our study approves the presumptions made on moose migration in the EIA document of the new E4 (Schibbye et al. 1995).

Our data suggests that in December 1997, when the highway was opened for traffic and exclusion fences were at place, migrating moose encountered the new barrier and were held up in their way to their former winter habitats near the eastern cost. Consequently, moose accumulated in habitats west of the highway and caused increased browsing damages to young pine stands. The pattern was repeated during the following years. Local moose concentrations, however, varied among the years, reflecting local differences in available pine forage. As observed by others, moose browsing is associated with moose density (e.g., Andrén & Angelstam 1993) and site productivity (e.g., Danell et al. 1991). The observed differences in browsing damages between road sides may therefore partially result from a generally higher pine productivity measured in western habitats. However, the lack of difference between road sides in browsing damages that have accumulated prior to the construction of the E4, suggests that the observed patterns mainly reflect the barrier effect of the new highway.

Also snow-tracking data revealed a strong barrier effect on. Moose trails were primarily observed along the western fence and, compared to the old E4, only few moose crossed the new highway. In addition, crossing rates declined substantially from 1998 to 2001, suggesting a possible increase in the overall barrier effect. Similar changes in the moose-road conflict have been observed elsewhere: problems with moose forcing fences are mainly associated with new fences (Kjell Ståhl, SNRA, personal communication) and moose-vehicle collisions tend to be most frequent during the first years after that a new road is opened for traffic (A. Seiler, unpublished data). This pattern probably indicates that moose learn to accept the fence as a movement barrier and adapt their home ranges accordingly, or that those moose that used to cross the road corridor during migration or during daily movements were already hunted. Experiments suggested that fencing may reduce moose movements with about 90% (Skölving 1985, Nilsson 1987). On the other hand, telemetry studies revealed that moose can establish and maintain home ranges on both sides of a fenced road (Kjell Wallin, unpublished data). How moose respond to road fencing probably varies between individuals and populations. More research is needed to understand the pattern and predict the overall effect.

Usage of underpasses

Moose rarely crossed beneath viaducts or through the two designated moose underpasses. On average, only about one moose track was recorded every third week. The number of tracks beneath the four bridges recorded during snow tracking was only slightly larger than the number of moose tracks that crossed over the fenced highway. No seasonal, directional, or consistent annual variation in the usage of viaducts/underpasses was recorded that would suggest an effect of migration or accommodation. There was no difference in usage between the two underpasses built for migratory and resident moose, respectively.

Various authors suggest that large herbivores such as moose are highly reluctant to use narrow underpasses (Olbrich 1984; Bekker 1991; Clevenger & Waltho 2000). We repeatedly observed that moose hesitated to move through an underpass and instead chose to turn back or cross the road elsewhere over the fence. One of the three moose-vehicle collisions reported after the opening of the new highway until 1999 occurred in vicinity to the moose underpass 'Furusjön' in January 1998. These observations strongly suggest that the design of the moose underpasses and of the conventional viaducts was suboptimal (compare also Iuell et al. 2003). Their overall effect on moose movements was clearly insufficient to counteract winter accumulations west of the road.

Conclusions

Our study suggests that the new fenced highway exerts a strong barrier effect on moose in the High Coast area. In addition, the barrier effect seems to increase as moose probably adapt to the new situation. However, without better knowledge of moose movements and density prior to the construction of the highway, conclusions about the overall effect of the new highway must be drawn with caution. Pre-impact studies are crucial to the evaluation of follow-up studies and should be a natural part of the environmental monitoring work of the transport sector.

Nevertheless, our data suggests that the barrier effect caused moose to accumulate along the western side of the highway which resulted in increased browsing damages to pine stands. Counteractive measures, i.e. moose underpasses and viaducts, were used regularly but rarely and appear insufficient to migratory moose. Some moose movement across the road or through viaducts and underpasses certainly continues and will probably prevent long-term isolation effects such as genetic divergence between inland and coastal moose populations. Still, coastal populations may depart demographically and thus require a different management than inland populations.

If further infrastructure is added to this area, such as the planned railway Ådalsbanan (URL: www.banverket.se), the barrier effect on migratory moose will certainly increase and more effectively separate coastal from inland populations. Demographic as well as genetic problem may occur in areas where coastal populations are small and isolated (as due to natural movement barriers). To evaluate this risk, more knowledge is needed on moose movements across landscape and infrastructure barriers and about the efficacy of counteractive measures.

Based on our study, and especially with respect to a possible change in moose behaviour over time, we recommend:

to adapt arrangement of hunting districts to include the new highway as a border between management units,

to continue monitoring of moose density and moose movements across the road and through underpasses,

to experiment with different design of the underpasses and viaducts at the E4 to improve their acceptance by moose (this may include protection screens above the underpasses, planting of preferred forage near the passages or supplemental feeding to attract moose).

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Figures

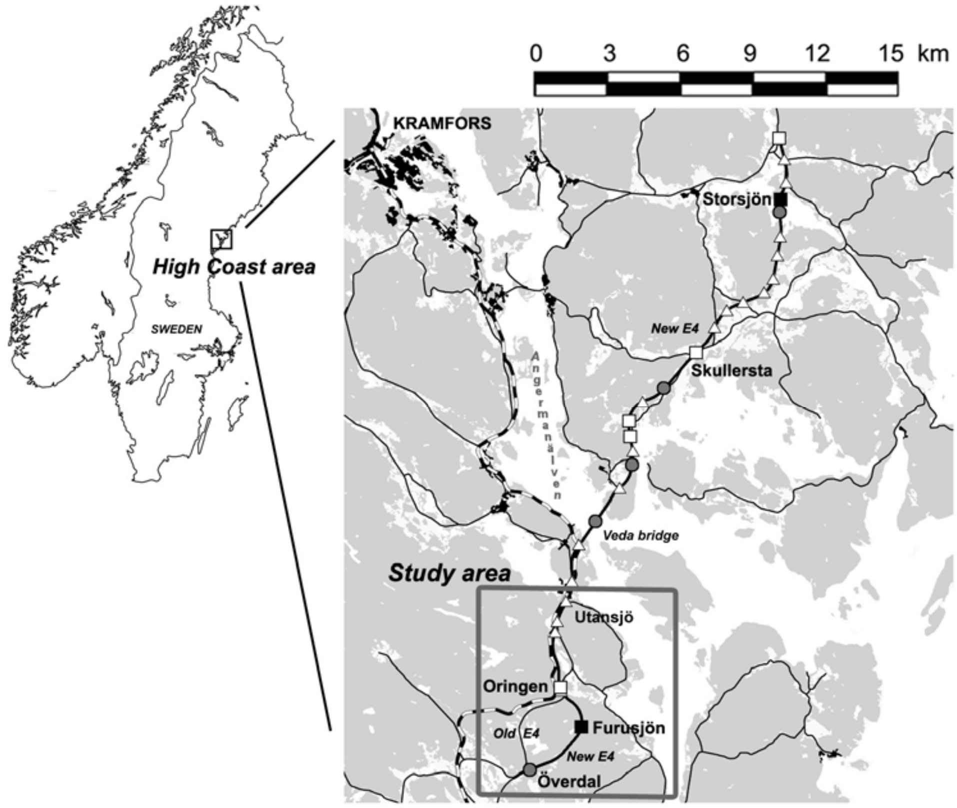

Figure 1. Location of study area and highway E4 in the High Coast Area in northern Sweden. The new highway covers 32 km with a total of 35 bridges. White triangles indicate conventional bridges built over minor roads, grey circles denote bridges over water (including river banks or sea shores), white squares indicate viaducts with a span wider than 200 m, and black squares identify two underpasses exclusively designated to moose. Field inventories and snow tracking was done within the study area between Överdal and Utansjö (large square).

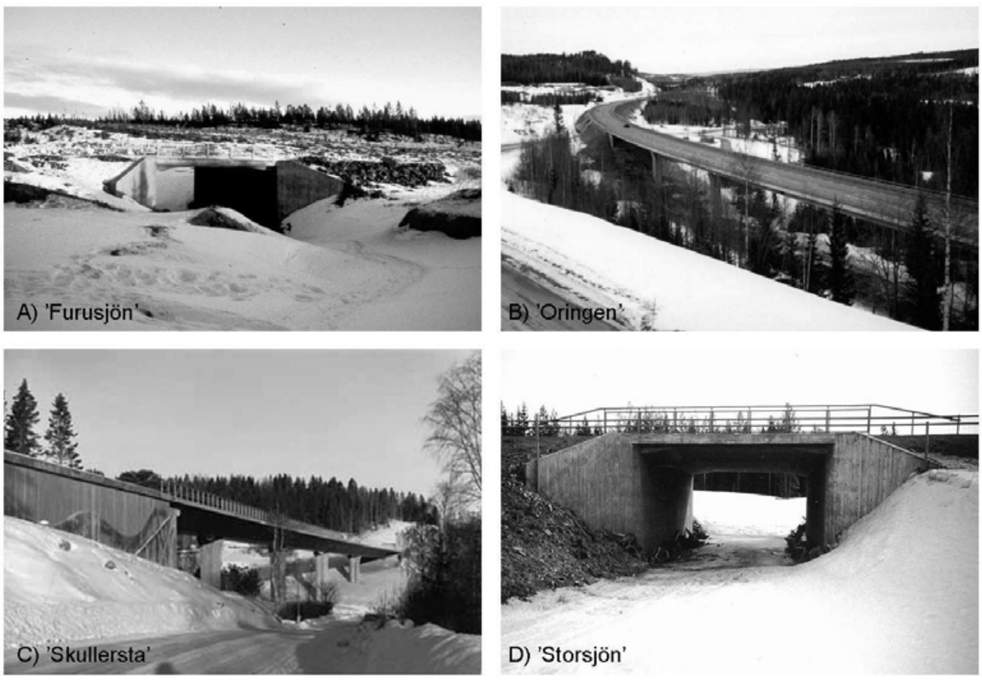

Figure 2. Moose underpasses (A, C) and viaducts (B, D) where moose tracks were counted during 1998 to 2001.

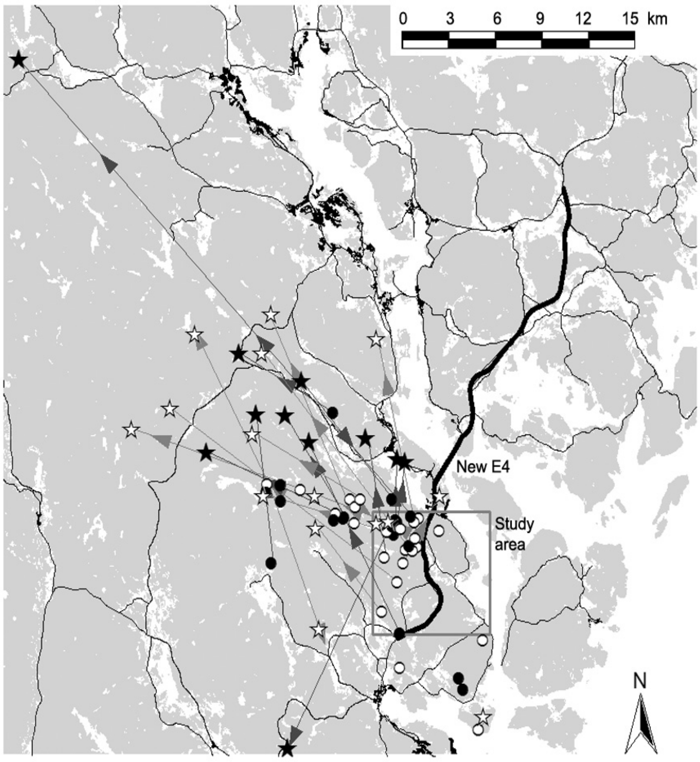

Figure 3. Distance and direction of moose movements between winter locations (circles), where 45 moose were captured and marked in 1998 and summer locations (stars), where 24 moose were reported dead until 2001. Open circles and stars denote females, black signs denote male moose.

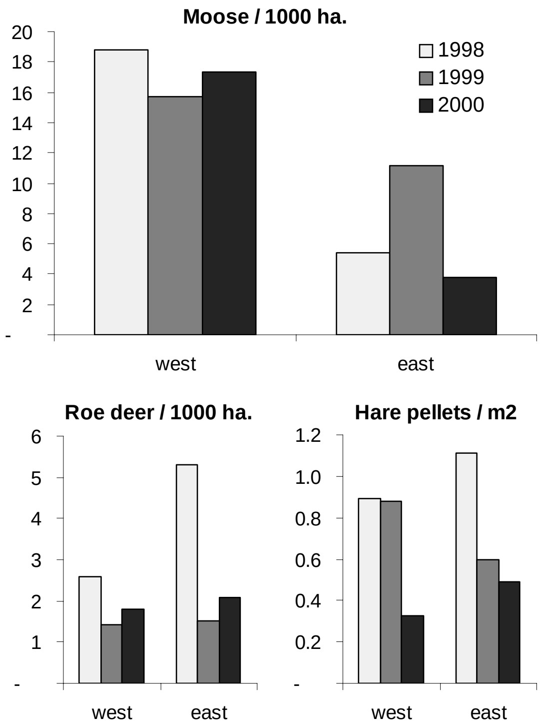

Figure 4. Differences in winter density of moose, roe deer, and hare between the western and eastern side of the new highway. Densities have been estimated from pellet and pellet-group counts in the study area between Överdal and Utansjö during 1998 to 2000.

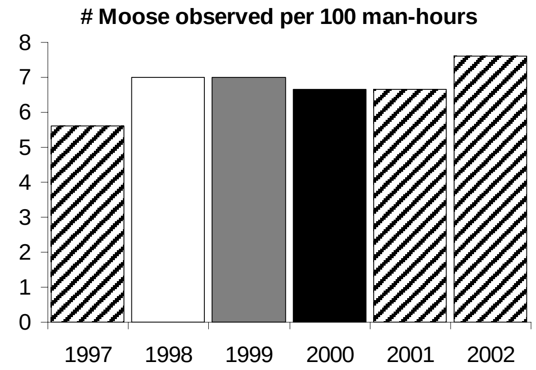

Figure 5. Changes in regional moose density as indexed from hunters' observations in the hunting districts Härnösand and Kramfors.

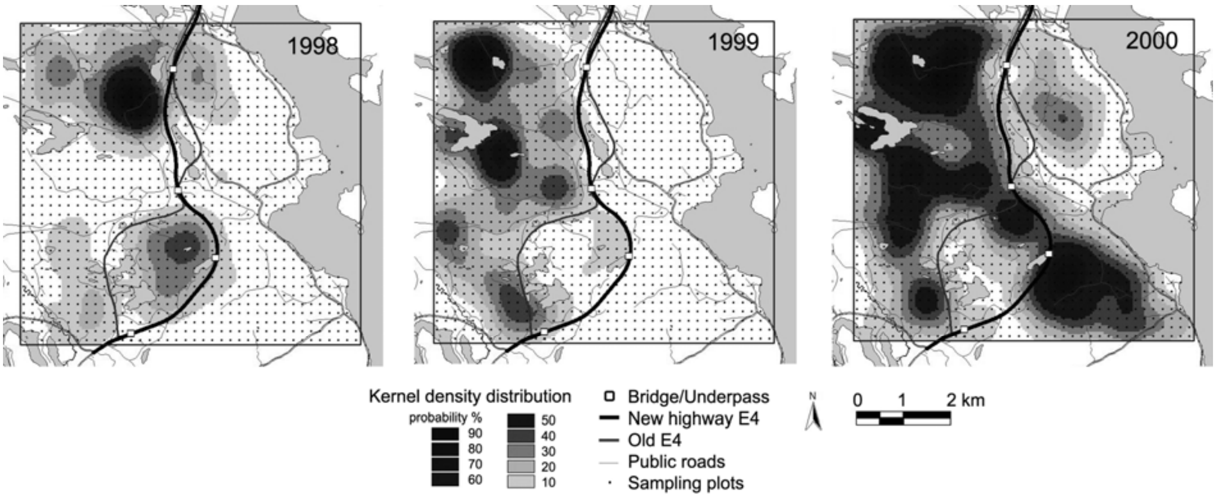

Figure 6. Fixed kernel distribution of moose densities in 1998 to 2000 calculated from pellet group counts in 1133 sampling plots distributed evenly across the study area.

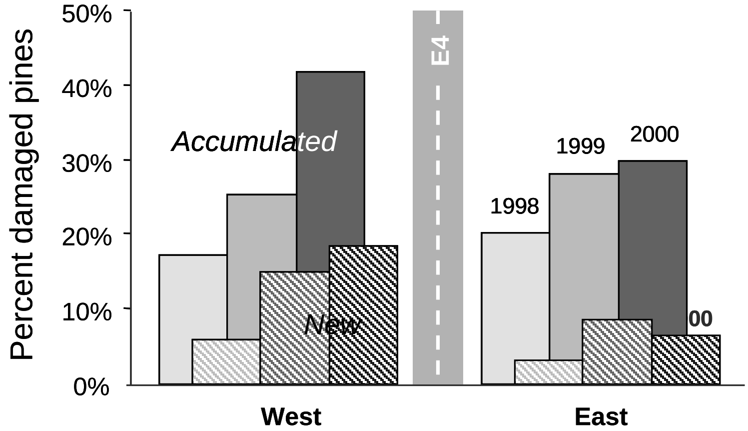

Figure 7. Accumulated and fresh browsing damages to young pine trees by moose east and west of the new highway during the first three years after the construction of the new highway E4.

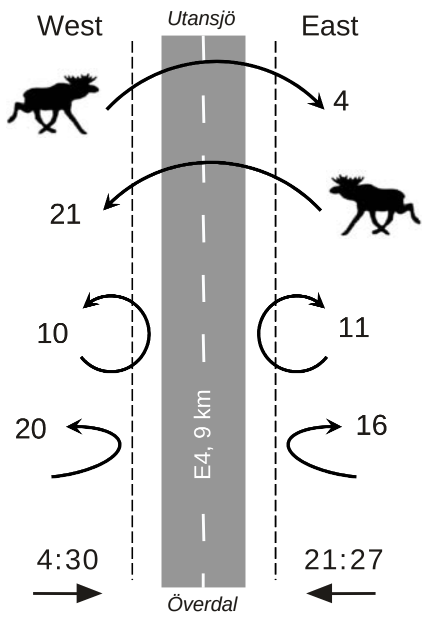

Figure 8. Moose movements along the 9 km section of the new highway E4 during 39 days in first winter after construction and fencing of the road. Snow tracking was done during April, i.e., during a season where migrant moose usually return to their summer home ranges further upland (west).

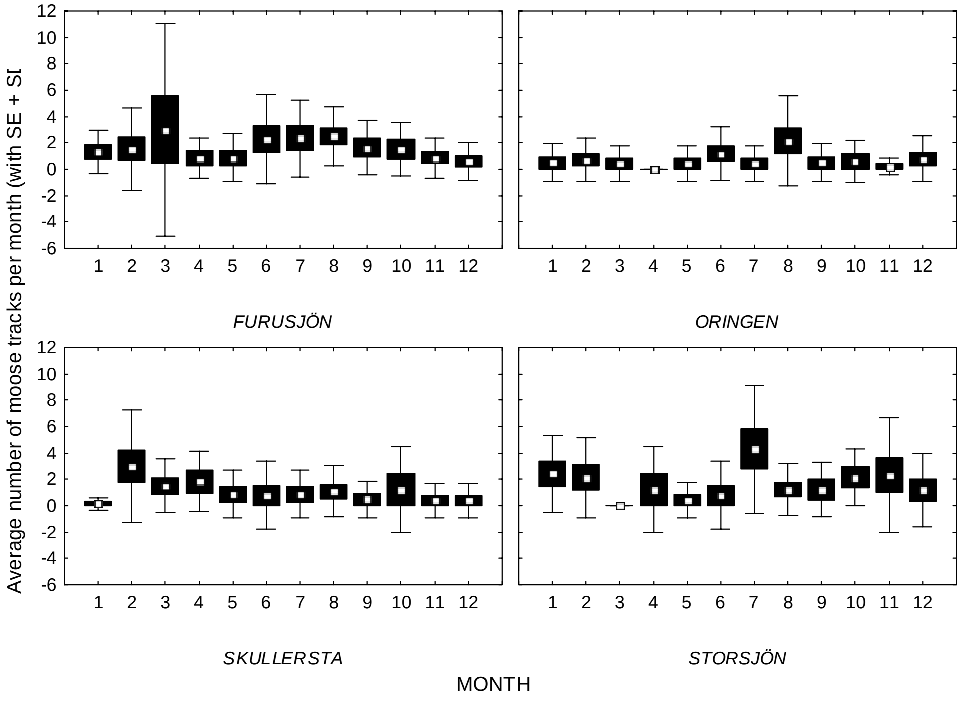

Figure 9. Mean number of moose tracks per month during 1998 to 2001 beneath two viaducts and two underpasses at the E4 (see figure 1). The data summarises a total of 119 tracking intervals representing 1040 days of accumulated tracks. Box plots represent mean values with standard deviation and 95% confidence intervals.

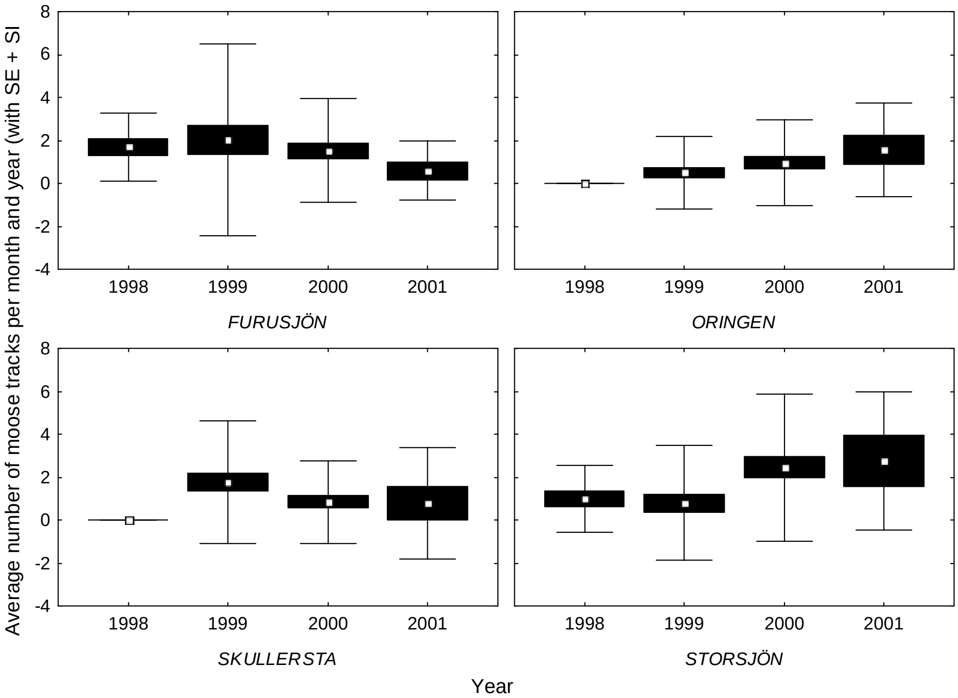

Figure 10. Change in the mean number of moose tracks per month during 1998 to 2001 beneath two viaducts and two underpasses at the E4 (see figure 1). The data summarises a total of 119 tracking intervals representing 1040 days of accumulated tracks. Box plots represent mean values with standard deviation and 95% confidence intervals.

Tables

Table 1 Minimum distances between locations where moose were marked in winter 1998 and where they were reported dead during the consecutive summers of 1999 to 2001. Among 24 reported deaths, two were due to traffic; the remainder was due to regular moose hunt.

	Moose category				of all 45 marked
	adults		yearlings		
Distance (km)	bull	cow	bull	cow	
Count	5	12	4	3	24
Mean	10.5	8.6	20.7	8.5	11.0
Std. Dev.	3.2	4.5	18.0	5.7	8.7
Std. Error	1.4	1.3	9.0	3.3	1.8
Minimum	7.0	2.2	6.9	2.0	2.0
Maximum	14.5	17.6	46.3	12.2	46.3
Count > 5 km	5	10	4	2	21 of 24
Count > 10 km	2	3	3	2	10 of 24
Bearing (°)					
Mean	311.0	246.0	310.6	305.8	277.8
Std. Dev.	59.1	106.4	16.3	19.6	84.5

Table 2 ANOVA table for the effect of moose category (gender and age class) and the time (months) passed between marking and reported death on the minimum distance travelled between summer and winter locations. One outlier (male calf, 31 months, distance 46.3 km) was removed from the analysis.

Distance (km)	DF	SS	F-Value	P-Value
Category	3	47.31	0.77	0.53
Months	1	24.92	1.22	0.29
Category * Months	3	110.70	1.80	0.19
Residual	15	307.20		

Table 3. Forage availability measured as percent cover in tree species averaged over three years and 1,926 and 1,420 10m^2-sample plots east and west, respectively, of the new highway. Differences between road sides were tested with unpaired two-tailed t-test with DF=4 (3 years and 2 areas).

% Cover	Pine		Spruce		Deciduous	
	west	east	west	east	west	east
Mean	3.14	1.84	9.17	8.21	5.95	6.00
Std. Dev.	0.17	0.19	5.39	5.10	4.23	4.24
Unpaired t	8.96		0.23		0.01	
P-Value	*0.0009*		*0.8333*		*0.9894*	

Table 4. Summarized results from eleven snow-track inventories along the 9 km long section of the new highway. This section includes four underpasses of which one was especially designated to moose.

			# moose tracks		tracks / 30 days	
winter	N	summed days	through underpass	across road	through underpass	across road
1998	4	39	24	25	18.5	19.2
1999	3	14	15	2	32.1	4.3
2000	3	33	3	3	2.7	2.7
2001	1	4	0	0	0.0	0.0
SUM		*90*	*42*	*30*	*14.0*	*10.0*

Table 5. Analysis of variance in the number of moose tracks per 30 days through four passages during 1998 to 2001.

ANOVA	DF	SS	MS	F	p
Intercept	*1*	*454.6*	*454.6*		
PASSAGE	3	52.3	17.4	2.62	0.050
YEAR	3	32.2	10.7	1.61	0.185
PASSAGE*YEAR	9	132.7	14.7	2.22	0.020
Error	455	3,022	6.6		
Intercept	*1*	*688.8*	*688.8*		
PASSAGE	3	75.2	25.1	3.69	0.012
MONTH	11	86.1	7.8	1.15	0.320
PASSAGE*MONTH	33	225.2	6.8	1.00	0.466
Error	423	2,876	6.8		