Mattias Olsson

The use of highway crossings to maintain landscape connectivity for moose and roe deer
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DISSERTATION

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The use of highway crossings to maintain landscape connectivity for moose and roe deer

Publications

This thesis is based on the following manuscripts which are referred to by their Roman numerals.


IV. Olsson P.O.M. and P. Widén. The use of highway crossing structures by moose (*Alces alces*) and roe deer (*Capreolus capreolus*). Manuscript

Paper II is reproduced with permission from the publisher (Nordic Council of Wildlife Research).
Introduction

The ecological impacts of roads are considered to be as severe as many other major environmental issues, such as modern forestry, agriculture, invasive species and global warming. It is however difficult to compare and quantify its effects in relation to the others, because infrastructure relates to many of these other environmental issues. The infrastructure affects the landscape connectivity, the degree to which a landscape facilitates or impedes the movement of individuals (Taylor et al. 1993).

Today, there are more than 600 million passenger cars worldwide, more than 12 times the number in the late 1940s (Smith 1999). Since 1950 the public road system in Sweden has increased nearly fivefold and today entails approximately 415 000 km (Table 1) (Eriksson and Skoog 1996) and the land area used by roads and road verges is more than 5000 km², which corresponds to approximately 1.2 % of the total land area of Sweden (Eriksson and Skoog 1996). In comparison, the railroad system in Sweden is approximately 10 000 km and occupies an area of about 100 km² (Eriksson and Skoog 1996).

Table 1. Road length and number of vehicles in selected countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Road length (km)</th>
<th>Vehicles</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>870 000</td>
<td>13 000 000</td>
<td>Straker 1998, Austr. transp. stat. 2006</td>
</tr>
<tr>
<td>China</td>
<td>1 400 000 (expressways)</td>
<td>18 020 000</td>
<td>Spellerberg 2002, Turner 2006</td>
</tr>
<tr>
<td>Germany</td>
<td>644 400</td>
<td>45 000 000</td>
<td>European road statistics 2006</td>
</tr>
<tr>
<td>Great Britain</td>
<td>372 000</td>
<td>27 800 000</td>
<td>European road statistics 2006</td>
</tr>
<tr>
<td>India</td>
<td>2 030 000</td>
<td></td>
<td>Spellerberg 2002</td>
</tr>
<tr>
<td>South Africa</td>
<td>534 000</td>
<td>6 990 000</td>
<td>Turner 2006</td>
</tr>
<tr>
<td>Sweden</td>
<td>415 000</td>
<td>4 000 000</td>
<td>SNRA statistics</td>
</tr>
<tr>
<td>USA</td>
<td>6 200 000</td>
<td>200 000 000</td>
<td>Hamilton and Harrison 1991</td>
</tr>
</tbody>
</table>

The impacts of infrastructure have gained much attention during the last decades as the wildlife-traffic interactions have increased, and with that an increased use of different measures to mitigate those negative effects. This thesis focuses on highway impacts on moose (Alces alces) and roe deer (Capreolus capreolus), and the use of wildlife crossings and conventional road passages to increase the connectivity for those species.
The effect of infrastructure on wild animals

Roads and traffic are considered to have four major impacts on wildlife populations: (1) habitat loss due to the area that roads occupy; (2) avoidance by wildlife due to disturbances, (3) mortality due to collisions with vehicles; and (4) barriers that fragment habitats and limit recourse accessibility, individual movements, and gene flow (Mader 1984, Putman 1997, Forman and Alexander 1998, Spellerberg 1998, Jaeger et al. 2005, Riley et al. 2006). The effects of roads on species are related to species-specific characteristics such as habitat requirements, diet, reproduction rates and movement patterns. Species with slow reproduction rate, large home ranges or highly specialized habitat demands are considered to suffer most from road development.

This introduction focuses on large mammals but the theories can also be applied to other animals. Road effects on mammals can be studied and described at different levels, from individual- to population levels, and from local- to landscape scales.

Loss of habitats

The construction of roads uses large areas of land and road encroachment leads to a loss of natural habitats. The total area occupied by infrastructure in Sweden is approximately 1.2 % (Eriksson and Skoog 1996), which can be compared to the total area of national parks in Sweden which was estimated to be 1.5 % (699 863 ha) of the Swedish land area in 2005 (SCB 2005).

Traffic mortality

The effect of traffic mortality may vary greatly among different species and among different populations within the same species. The mortality may either be compensatory or additive depending on how the mortality strikes the population. Among the species that are directly threatened (locally or globally) as a consequence of traffic mortality include the Florida panther (*Felis concolor coyri*) (Maehr et al. 1991), the badger (*Meles meles*) in Netherlands (Zee et al. 1992) and the Iberian lynx (*Felis pardina*) (Ferreras et al. 1992).

High ungulate densities and increased traffic volume on Swedish highways have resulted in an increased number of ungulate-vehicle accidents (Figure 1). During the 1990s, Swedish police recorded approximately 4500 moose-vehicle and 22 600 roe deer- vehicle collisions annually (Seiler 2004, SNRA database), which accounted for approximately 60% of the total number of traffic accidents (Land and Nilsson 2002, Seiler 2004). However, the total number of ungulate-vehicle collisions may be twice as high because many go
unreported (Seiler et al. 2004). A questionnaire among Swedish drivers indicated that traffic accidents in 1992 may have killed between 7000 - 13 500 moose and 43 500 – 59 000 roe deer (95% C.I) (Seiler et al. 2004).

Disturbance

Increased noise levels and human activity along roads may disturb sensitive species. Avoidance caused by highway disturbance has been documented for black bear (*Ursus americanus*) (Broady and Pelton 1989), gray wolf (*Canis lupus*) (Thurber et al. 1994) and bobcat (*Felis rufus*) (Lovallo and Andersson 1996). Avian communities may also be disrupted, both in forested and grassland habitats (Reijinen et al. 1995 and 1996, Brotons and Herando 2001). Increased accessibility often also increases hunting (and poaching) in areas that previously were inaccessible (McLellan and Shackleton 1988).

Barrier effect

The barrier effect on wild animals results from a combination of disturbance and avoidance effects, physical hindrances, and traffic mortality, all of which reduce the movements across infrastructure (Seiler and Folkeson 2006). Large mammals are generally not completely hindered by roads, as long
as the road is unfenced and the traffic volume is low (Müller and Berthoud 1997). Müller and Berthoud (1997) distinguished three levels of barrier effects of unfenced roads depending on speed limits and traffic volumes: 1) Roads with less than 1000 vehicles a day may be rather permeable to most wildlife species. Many individuals cross the road successfully and the number of casualties is limited. 2) Roads with between 4000 and 10,000 vehicles per day impose a strong barrier. Noise and movements from the traffic will repel many individuals, and many of those that try to cross will get hit. 3) Highways with traffic levels above 10,000 vehicles/day are considered as impermeable to most species.

Barriers may reduce the ecological connectivity within the landscape and thus alter different ecological processes that maintain local populations. For example, reduced access to vital habitats can have effects on small isolated populations. Mountain goats (Oreamnos americanus) in Glacier National Park, Montana, regularly have to cross U.S. Highway 2 in order to reach mineral rich areas (Singer and Doherty 1985). In the absence of wildlife crossings along the highway, the population would have been hindered to reach vital recourses.

**Fragmentation**

A new road divides previously connected landscapes into small fragments. It also alters the biotope mosaic within the landscape, resulting in a reduction of core areas and an increase of edge habitats (Spellerberg 2002). Thus, habitat fragmentation results in an increase in the number of habitat patches, an increase in edge habitats, and a species-specific degree of isolation of populations. This phenomenon may disrupt historic spatial and temporal patterns in the ecology of many wildlife species.

The effects of fragmented landscapes are species-specific and depend mainly on two factors, fragment size and barrier effects. Reduced gene flow, altered demographics and habitat degradation may increase vulnerability to stochastic environmental and demographic events in small populations (Forman and Alexander 1998, Jaeger and Fahrig 2004). In extreme cases animals can be isolated in areas that are too small to sustain viable populations, leading to local extinctions (Fahrig and Merriam 1994). The density of roads (km/km²) is an often used measure to quantify fragmentation caused by roads. A few studies have described critical thresholds in road density that affect the occurrence of wildlife. Populations of wolves (Canis lupus) and mountain lions (Felis concolor) were not sustainable when road densities exceeded 0.6 km/km² (Mladenoff et al. 1999).
Genetic effects of isolation due to roads

Several studies have demonstrated the importance of gene flow in maintaining genetic diversity (Reh and Seitz 1990, Keller and Largiardér 2003, Riley et al. 2006). An altered genetic composition between subpopulations on either side of the road may occur when a barrier persists over many generations. Mills and Allendorf (1996) suggested that a minimum of 1 to 10 migrants per generation into isolated populations would be an appropriate general rule of thumb for genetic purposes. Thus, ungulates may break exclusion fences (Almqvist et al. 1980) and use wildlife crossings and conventional road under- and overpasses (Paper IV) at a rate that would prevent genetic differentiation in small populations isolated by roads.

Human perspective of ungulate–vehicle interactions

Traffic safety and economical concerns

Moose (Alces alces) and roe deer (Capreolus capreolus) populations began to increase considerably in Sweden during the 1960’s (Cederlund and Liberg 1995, Lavsund et al. 2003). The increase of both species were attributed to habitat improvements created by modern forestry techniques, changes in sex- and age-specific harvest regulations, and a functional lack of native predators such as wolves (Canis lupus), lynx (Lynx lynx) and brown bears (Ursus arctos) (Cederlund and Markegren 1987, Cederlund and Liberg 1995, Lavsund et al. 2003).

Moose has been the focal species for traffic safety concerns in Sweden due to its large size and dramatic increase in numbers since the 1960s. The number of collisions between moose and vehicles rapidly increased during the 1970s (Figure 1), and with that also the number of injured and killed people (Figure 2). The rapid increase was in part due to the major growth in moose numbers, but also to the fact that the traffic increased considerably during the same period. An increased number of ungulate-vehicle collisions prompted changes in highway construction policies and an increased use of exclusion fences.
Figure 2. Reported number of human injuries and fatalities from moose-vehicle accidents on Swedish roads 1970-2005 (SNRA, database).

Fences are evidently effective, but do not give complete protection, particularly if no alternative possibility to cross the road is offered (Ratcliffe 1974, Bekker and Caners 1995, Foster and Humphrey 1995). Studies indicate that fencing can reduce the rate of accidents with moose by up to 80% and with roe deer by up to 55% (Almqvist et al. 1980). Roadside clearing has proven effective in reducing moose and roe deer accidents by removing palatable vegetation along roadsides. It also increases the visibility of approaching mammals along road verges, and thus an increased time for drivers to react (Rea 2003).

Wildlife-vehicle collisions and their importance for traffic safety differ by species composition within the country. For example, only 0.3% of the total number of traffic accidents in the Netherlands resulted in human loss or personal injury was due to wildlife-vehicle collisions (Borer and Fry 2003). In contrast, 11% of the light, 5% of the severe injuries and 4% of the human loss in Swedish traffic accidents were due to moose-vehicle accidents in 1997, and 60% of the total police reported road accidents involved ungulates (Seiler and Folkeson 2006). Traffic safety and economics are often the driving forces that promote mitigation efforts (Romin and Bissonnette 1996). SNRA estimates an average cost of 7400 to 20 000 € per moose-vehicle accident and 1400 to 2800 € per roe deer-vehicle accident, depending on speed and severity of human injury (Seiler and Folkeson 2006). With these estimations the direct cost of
Moose-vehicle collisions probably exceed 100 million € each year in Sweden (Lundin and Sjölund 2005). Annual ungulate-vehicle accidents in Europe are calculated to cause over 300 human fatalities and 30,000 injuries at a cost of more than 1 billion € (Groot-Bruinderink and Hazebroek 1996).

**Mitigations against ungulate-vehicle accidents**

Remedial measures have the explicit goal of limiting the negative effects of roads on animals and to reduce the number of wildlife-vehicle accidents. A wide range of different mitigation efforts have been tested and evaluated throughout the years. The aim to increase traffic safety, protection of large and valuable game species and conservation of endangered species are the primary motivating forces behind most of the measures used (Foster and Humphrey 1995, Romin and Bissonette 1996). While roads and traffic themselves restrict movements of many animal species, fences that keep animals off the road are widely used and increase barrier effects even more. Mitigation measures can be divided into non-structural and structural approaches.

**Non-structural approaches**

Most of the non-structural methods are focused on altering animal behavior, making the animals aware of the road. The methods are often in need of a long term management strategy and need to be maintained over many years.

**Olfactory repellents, sound-scarers and reflectors**

No long term effects were found in the studies that evaluated olfactory repellents, sound-scarers or reflectors. The scents (foam repellents) of humans, predators or other unpleasant odours are spread along the roadsides with the intention of raising animal awareness, and keeping them away from the road. The olfactory repellents are suggested to provide a temporary barrier but have not yet been adequately evaluated on a large scale (Almqvist et al. 1980). A number of commercial companies are now offering sound-scarers, which emit a high frequency whistle, claimed to deter deer from entering roads. However, in a study in Utah (Romin and Dalton 1992), mule deer showed no behavioural response to such equipped vehicles. Reflectors were evaluated in Sweden in 1975-1978 and no effect on traffic accidents with moose or roe deer could be found for the 80 road segments that were investigated (Ekström 1980).
Population control

A controversial method to reduce wildlife-vehicle accidents is population control of the fauna in the vicinity of roads. The observed relationship between collisions and harvest statistics of moose and roe deer suggests that population control influences the number of accidents involving these species (Seiler 2004). Thus, a large scale population reduction should influence the number of accidents. However, it would be difficult to find support of such an effort, both from a biological and ethical point-of-view, even though the species are widespread and abundant. Two states in USA, Illinois and Michigan, used deer harvest to decrease deer–vehicle accident, but only Michigan reported success using the strategy (Romin and Bissonette 1996).

A local population reduction around roads is more easily achieved but the results may not be the desired (Almqvist et al. 1980). Animals that disperse into managed areas might have a lower perception against roads, and thus, may get hit at a higher proportion than the former local population. Hence, the activity and movement patterns of local populations might influence traffic accidents to a higher degree than local densities. The effect can be compared to construction of a new road where the accidents seem to be highest during the first couple of years when the local fauna is not used to the new traffic situation (Almqvist et al. 1980, Jones 2000). This phenomenon has also been observed by hunters that remove carcasses from ungulate-vehicle accidents on new roads in Sweden. It appears that after a few years, a high proportion of local ungulates have either been killed in traffic accidents or shot during hunting, or have modified their movements with regard to the new road.

Roadside clearing and re-distribution efforts

Both roadside clearing and habitat modification have proven effective at reducing ungulate-vehicle accidents. Roadside clearing increases the visibility of approaching animals and gives the driver more time to react (Waring et al. 1991, Rea 2003). The removing of palatable vegetation also reduces the time that animals spend in the vicinity of the road, and thereby decreases potential interactions (Nielsen et al. 2003, Rea 2003). Jaren et al. (1991) found that removal of vegetation in a 20-30 m strip on each side of a railway caused a 56 % reduction in moose-train collisions along managed segments.

Feeding stations allocated at strategic places along roads might have a potential effect on the collision risks during critical times (Boutin 1990, Storaas et al. 1999). Andreassen et al. (2005) found a general 46 % reduction in the number of moose-train collisions on sections mitigated through scent marking,
forest clearing (20-60 m strip) and supplemental feeding. The effect of scent-marking was questionable but forest clearing and supplemental feeding seem to be reliable ways to reduce moose-train collisions. In Norway, placement of feeding stations redistributed migrating moose on a local scale, and the results indicated that moose-vehicle collisions decreased during the two year study (Nystedt 2005). Providing salt licks in the area adjacent to roads may also reduce the attractiveness of roads to deer (Feldhammer et al. 1986).

**Public information**

In Sweden, moose is the focal species of most public information campaigns, which generally take place in the fall when the risk of collision is highest. The effects of these campaigns are argued but they may decrease the injuries and fatalities that are associated with secondary accidents (Allen and McCullough 1976).

**Structural approaches**

**Exclusion fences**

One of the most common methods to prevent wildlife-vehicle accidents is the use of exclusion fences (Falk et al. 1978). Increased vehicle collisions with moose and roe deer since the 1970’s prompted changes in highway construction policies in Sweden (Lavsund and Sandegren 1991). As a result, various methods intended to reduce ungulate-vehicle collisions on Swedish roads have been tested (Almquist et al. 1980). However, only exclusion fencing and roadside clearing were found to be cost-effective (Niklasson and Johansson 1987). Exclusion fences, 2.2 m high, are present along approximately 34% (5000 km) of highways and national roads in Sweden (Seiler 2004, O. Eriksson SNRA pers. comm.).

The effectiveness of fencing in reducing wildlife-vehicle accidents and interactions between wildlife and vehicles has been documented in several studies. Feldhammer et al. (1986) documented fewer deer on the road in areas where 2.7 m fencing was installed compared to areas with 2.2 meter fencing. Reed et al. (1982) documented a decline of deer-vehicle accident by of 78.5% after installation of a 2.4 m high exclusion fence at six highway sections in Colorado. Seiler (2005) observed that the presence of fences significantly reduced the probability of moose-vehicle accidents per km road. Together with traffic volume and vehicle speed, fencing appeared to be the dominant road factor determining collision risk with moose.

However, an important issue evaluated by Falk et al. (1978) is the maintenance of the fence to insure proper function. Gaps greater than 23 cm
were common where the fence crossed streams, ravines and rock formations and allowed deer to crawl under the fence. Deer were also observed to jump over fences at locations were fallen trees laid over the fence (Falk et al. 1978). There is also evidence that deer continually test the fences, making a proper maintenance program necessary (Ward 1982). Also, fences that are too short may not have the desired function but simply shift the problems toward the fence ends (Ward 1982, Clevenger et al. 2001). The problems with proper maintenance were also documented by SNRA in a study along Highway 6 (E6) in southwestern Sweden (M. Lindqvist pers. comm.). Altogether, 30 km of fence was examined to insure proper function. The examination revealed 15 fence gaps associated with fallen trees, human violence, and improper connection to bridges and to the ground.

Few studies have addressed the construction of exclusion fence and wildlife crossings in monetary terms. Reed et al. (1982) estimated that there is a deer-vehicle accident rate, below which the cost-benefit will not be favored. In Colorado, 2.4 m high fencing along one side of the road, both sides of the road and both sides of the road with one underpass, was found to be cost effective if 8, 16, or 24 deer-vehicle accidents occurred per year along a 1.61 km stretch of highway, respectively (Reed et al. 1982).

Wildlife crossings

The construction of wildlife crossings along fenced roads can provide both safe road conditions for humans and mitigate barrier effects on wildlife (Andrews 1990, Bekker and Canters 1995, Rodriguez et al. 1996 and 1997, Clevenger and Waltho 2000). Wildlife crossing structures have been constructed in many parts of the world in an effort to mitigate the negative effects of highways and exclusion fences on wildlife (Andrews 1990, Bekker and Canters 1995, Spellerberg 2002, Rodriguez et al. 1996 and 1997, Clevenger and Waltho 2000 and 2005, Lundin and Sjölund 2005). Wildlife crossings in combination with exclusion fences reduced road kills and enhanced resource accessibility in the United States and Canada (Foster and Humphrey 1995, Clevenger et al. 2003). Furthermore, several studies have documented that conventional road bridges and tunnels provide crossing opportunities for wildlife (Yanes et al. 1995, Rodriguez et al. 1996 and 1997, Clevenger and Waltho 2000). These structures have increased the permeability of the road at the same time as they have reduced traffic mortality for a wide range of species (Yanes et al. 1995, Ng et al. 2003, Clevenger and Waltho, 2005). Seiler (2005) found that the risk of moose-vehicle collisions in Sweden decreased where conventional tunnels or bridges separated the intersected roads. However,
Hubbard et al. (2000) observed increased white-tailed deer-vehicle accident likelihood where bridges were associated with deer travel corridors.

In Sweden, underpass structures for small mammals are more common than passages designed for moose and other large mammals (SNRA annual reports, O. Eriksson SNRA pers. comm.). From 1997 to 2005, 34 structures were built to facilitate movements across highways by large ungulates (Table 2), but this number is somewhat unreliable due to limited documentation (A. Sjölund, O. Eriksson and M. Lindqvist (SNRA) pers. comm.). However, a preliminary list of minimum criteria for any wildlife crossing has been proposed. So far, most of the wildlife crossings for ungulates are adapted conventional road underpasses and few are designed as overpasses. The development of highway crossing structures for wildlife is regarded by SNRA as an experimental initiative, where efforts are made to evaluate a wide range of highway crossing designs relative to their use by ungulates and other wildlife species (Paper IV). Previous studies have evaluated the importance of structure design and size for ungulates (Olbrich 1984, Rodriguez et al. 1996, Clevenger and Waltho 2000 and 2005), but few studies involved moose which is the target species for most large ungulate mitigations in Sweden.

Table 2. The number of crossing structures built for wild animals in Sweden, from 1997 to 2005.

<table>
<thead>
<tr>
<th>Year</th>
<th>-97</th>
<th>-98</th>
<th>-99</th>
<th>-00</th>
<th>-01</th>
<th>-02</th>
<th>-03</th>
<th>-04</th>
<th>-05</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC(^1) for ungulates(^2)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>16</td>
<td>8</td>
<td>34</td>
</tr>
<tr>
<td>WC for mammals(^3)</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>15</td>
<td>17</td>
<td>18</td>
<td>74</td>
</tr>
<tr>
<td>Passages for amphibians</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Fish passages</td>
<td>16</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>10</td>
<td>63</td>
<td>14</td>
<td>136</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>21</td>
<td>35</td>
<td>28</td>
<td>251</td>
</tr>
</tbody>
</table>

Cross-walks

The development of underpasses and overpasses is expensive and may not be justified in all new road constructions, especially if mean daily traffic volume is less than 5000 vehicles (Iuell 2005). An alternative may then be cross-walks (fence gaps). A 20 – 100 m gap in the fences on both sides of the road allows movements of ungulates across the road area (Iuell 2005, Lundin and Sjölund 2005). The use of automatic alarms to notify motorists of crossing
animals can be used to increase traffic safety. Cross-walks have the advantage that they can be installed after completion of any roadway where crossing locations are deemed necessary (Lehert and Bissonette 1997). In a Norwegian study, about 5% (5 of 97) of the crossing moose were hit by vehicles and, it was questionable if the measure increased the traffic safety (Kastdalen 1996).

**Warning signs, animal detection and warning systems**

Ungulate warning signs are the most common approach to reduce accidents at known crossing points at unfenced roads. It is however doubtful that they have an effect on driving awareness and accident frequency in the long run, since drivers tend to habituate to them (Almqvist et al. 1980, Sullivan and Messmer 2003). Almqvist et al. (1980) reported that only between 37 – 50% of the drivers that just passed a moose sign paid attention to it. It is also difficult to judge which road sections that should be posted with signs since accident rates tend to differ widely between years (Almqvist et al. 1980).

**Objectives and General Methods**

This thesis focuses on highway impacts on ungulates, and to what extent wildlife crossings and conventional road passages are used. The focus is on moose, but roe deer is also monitored in two manuscripts. I used both an ungulate behavior approach and a wildlife crossing use approach to document use and effects of wildlife crossings.

<table>
<thead>
<tr>
<th>Problem/Goal</th>
<th>Solution?</th>
<th>Research methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce traffic accidents</td>
<td>Effective wildlife crossings in combination with exclusion fences</td>
<td>Track count studies in wildlife crossings and conventional road passages</td>
</tr>
<tr>
<td>Reduce barrier effects</td>
<td></td>
<td>Camera surveillance of a wildlife crossing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Studies of GPS collared moose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring of ungulate-vehicle accidents</td>
</tr>
</tbody>
</table>

*Figure 3. The general description of methods used within this thesis.*
The main methods involved track count studies, use of camera surveillance and monitoring of GPS-collared moose (Figure 3). The different manuscripts span from a detailed analysis of a single overpass to more general track count studies at several highway crossings.

Ungulate behavior approach

Paper I describes the habitat selection and space use of moose in southwestern Sweden. In southwestern Sweden, human population growth and concomitant infrastructure and development pressures in or near coastal areas increasingly threaten to fragment and isolate local moose populations. We monitored 22 adult moose fitted with global positioning system radio collars and characterized their space and habitat use patterns and response to highway E6 reconstruction.

The objective of the study in paper II was to evaluate moose response to exclusion fencing and wildlife passages. Specifically, we studied pre- and post-movements of GPS-collared moose in relation to a non-fenced road that was transformed to a fenced highway with three wildlife crossings designed for moose.

Wildlife crossing structure approach

In paper III we evaluate ungulate use of a wildlife overpass in southwestern Sweden that was designed specifically for moose and roe deer (Figure 5 and 6). We used infrared cameras (Figure 4) and GPS-collared moose to examine crossing frequencies and behaviour in relation to time of day and highway traffic volume.

Figure 4. Moose at the overpass “Grytingen”, in southwestern Sweden 2002.
Paper IV focuses on wildlife crossings and conventional road passages and how structure design, disturbances and location affected ungulate use (Figure 7). The primary aims of the study were to evaluate different structures and to determine if underpass structures that were not specially designed as wildlife crossings were used by wildlife. Furthermore, we aimed to identify important variables as structural underpass design, human disturbances and landscape factors that ungulates responded to, in order to anticipate future development of wildlife underpasses.

Study areas

The study in papers I, II and III was conducted in coastal southwestern Sweden between the cities of Uddevalla and Munkedal (Figure 5). We defined the 320 km$^2$ study area by generating a minimum convex polygon (Mohr 1947) around all moose telemetry locations and modified it to exclude ocean using the Animal Movement Extension (Hooge and Eichenlaub 2000) in ArcView 3.3 (ESRI, Redlands, CA). A 15 km section of European Highway 6 (E6) spanned the study area and also conveniently delineated the approximate boundary between boreonemoral and nemoral ecoregions (Abrahamsen et al. 1977). The 320 km$^2$ study area east and west of E6 differed in their land use composition. The area east of the highway was within the boreonemoral zone and the area west within the nemoral zone. However, local forestry practices west of the highway have altered forest composition so that there is little difference in forest composition between the two sides of the highway. By area, coniferous forests dominated the landscape east of the highway (61%) with low amounts of deciduous forests (9%), farmlands (7%), mires (6%), water (4%), glades (2%) and human development (1%). The landscape west of the highway was dominated by a mosaic of coniferous forests (32%), farmlands (31%), glades (12%) and deciduous forests (11%) with a low amount of human development (3%), water (0.8%) and mires (0.2%). The percentage of clear-cut and young forest was equal (10 %) for both sides of E6. Norway spruce (Picea abies) and Scots pine (Pinus sylvestris) dominated forested habitats, with patches of deciduous species such as common alder (Alnus glutinosa), pendunculate oak (Quercus robur), birch (Betula sp.) and rowan (Sorbus aucuparia). Agricultural lands were comprised of crops that primarily included wheat (Triticum aestivum), barley (Avena sativa), oats (Hordelymus vulgare), and rye (Secale cereal), as well as hay and pastureland. The pastureland was dominated by a mosaic of grasses that included perennial rye (Poa pretensis), quackgrass (Elytrigia repens), orchardgrass (Dactylis glomerata), and timothy (Phleum pretense).
Reconstruction of European road 6 (E6)

The highway E6 from Gothenburg to Uddevalla has in the past 30 years been subject to extensive development into a fenced highway. During the study, E6 in the study area was modified from a two-lane unfenced road to a fenced four-lane highway with three wildlife crossings, two overpasses and one underpass designed for moose and roe deer (Figure 5). There were two stages of road development within the study area that potentially could have altered the behavior of ungulates; construction phase and the period after construction.

Reconstruction periods of the highway E6 were as follows: (1) the period before construction (speed limit 90 km/hr), from February 2002–September 2002 (the road in the southern portion [6 km] of the study area was a fenced highway with two wildlife crossings, one overpass, and one
(2) The period during highway construction (speed limit 70 km/hr), from October 2002–May 2004 when six kilometers of the highway through the study area was under road construction. (3) The period after highway construction (speed limit 110 km/hr), from June 2004–December 2005. The highway in the study area was fenced in June 2004 and ungulates could only cross the highway at three wildlife crossings, five conventional under- and overpasses and at an unfenced section north of the study area.

**Wildlife crossings within the study area**

Three wildlife crossings were located within the study area, two overpasses and one underpass. The southernmost overpass was hour-glass-shaped, 80m long, 17m wide at the center, and 29m wide at the entrances (Figure 6).

![Figure 6. The highway overpass “Grytingen” in southwestern Sweden, which was studied in paper III, photographed from east in 2002. Photo: Mattias Olsson.](image)

The second overpass had smaller dimensions, 67 m long and 13 m wide at the center, and 20 m wide at the entrances. The sides of each overpass were equipped with 2-m high shields to reduce reflections from headlights and noise. The distance to forest cover was < 50 meter from each entrance on both overpasses. Both overpasses were covered with sand and combined with gravel roads with low traffic use (0.4 and 1.6 vehicles/hr, respectively). The underpass
(35 m long, 4.7 m high and 13 m wide) was combined with a paved road (400 ± 84 vehicles/day) (SNRA, traffic volume database) and located between the two overpasses (Figure 5). Two wildlife crossings designed for smaller mammals as badgers (*Meles meles*), foxes (*Vulpes vulpes*) and hares (*Lepus spp.*) were also present in the study area. A paved road with a traffic volume of 800 (± 168) vehicles/day (SNRA, traffic volume database) was situated parallel to the highway, and passed less than 30 m from the eastern side of each overpass (Figure 6).

Study area paper IV

The study in paper IV was conducted in southwestern Sweden along four major highways; E6, E20, rv44 and rv40. All roads were fenced and had two lanes in each direction. E6 (18 passages) stretched along the coastline from Trelleborg in the south to Svinesund at the Norwegian border. Rv44 (n=3), rv40 (n=11) and E20 (n=2) were all oriented in an east-west direction. The 34 monitored crossing structures were of different design and size; 21 were conventional road tunnel or bridges (Figure 7), eight were wildlife crossings designed for moose and roe deer, three were viaducts and two were ecoducts. All selected crossing structures for this study were of relative large size, making them at least theoretically possible for large animals such as moose and roe deer to use. Not all passages were open for vehicles, but humans on foot, on bicycles or horse-back used all of them, more or less frequently.

Figure 7. A conventional road underpass monitored in the track count study, paper IV. Photo: Mattias Olsson
Summary of results
Moose space use (paper I)

The home range sizes (minimum convex polygon method) of 22 adult moose, 13 females and 9 males were analyzed to determine sex, season and sex x season interaction effects. There was a significant sex x season interaction effect on moose home range size. Home range size of cows did not differ among seasons; however, bulls had larger home ranges during fall than all other seasons. Mean home range size of bulls during fall and spring was larger than cows during all seasons.

We analyzed 16 adult moose (10 F, 6 M) with at least one complete year of telemetry data to determine differences between sexes in composite home ranges. Males (52.2 km$^2 \pm 10.9$ km$^2$) had larger mean composite home ranges than females (15.6 km$^2 \pm 2.6$ km$^2$).

Moose habitat use and highway reconstruction effects (paper I)

Animals are believed to select habitats at different hierarchical levels (Johnson 1980). We performed a Euclidean based approach to test for moose habitat use at second order (landscape) and third order (within home range) selection. The advantage of a distant-based approach over a classification-based one, is that the relation to linear structures such as roads can be analyzed (Conner et al. 2003).

Season and the sex x season interaction did not affect second order habitat selection, and consequently, we pooled data across seasons within the composite home range of each individual and examined sex effects on second order habitat selection. We found no differences between males and females, but moose selected habitats when choosing a home range. Moose selected mature coniferous forest and mires, but no preference between these habitats was found.

Season was found to affect third order habitat selection, but the sex x season interaction did not, and consequently, we pooled sexes within season. Moose generally preferred clear-cuts and early successional forest, mature coniferous forest, and glades, but avoided agricultural areas and open water. During spring, moose preferred mature coniferous forest over glades and early successional forest and avoided agriculture. During summer, moose preferred early successional forest over deciduous forest and avoided open water. During fall, moose preferred early successional forest over urban areas and avoided mires and agriculture. During winter, moose preferred early successional forest over other habitats but avoided mires and agriculture.
We found few movements across E6 as two of the three highway sections were finished and fenced, even though three wildlife crossings were present (Paper II). We therefore analyzed the effects of E6 road construction on habitat use and the distance of moose locations to E6 by comparing paired seasonal location data across two of three consecutive road construction phases. We performed seasonal pair-wise comparisons of the distances of 7 moose (10 seasons x 2 construction phases) to E6 during pre-construction and construction road phases. Moose were found at expected distances to E6 before (2.65 km ± 0.48 km) and during construction (2.77 km ± 0.68 km). We performed seasonal pair-wise comparisons of the distances of 10 moose (20 seasons x 2 construction phases) to E6 during construction and post-construction road phases. Moose were found at closer distances to E6 during construction (1.82 km ± 0.21 km) than post-construction (2.19 km ± 0.16 km). Even though moose moved away from the highway as it was upgraded and fenced, no effect could be found for habitat use on selected habitat classes as mature coniferous forest, clear-cuts, early successional forest and glades.

**Effect of fencing and highway crossings on moose movements (paper II)**

We studied movements of 24 GPS-collared moose before, during and after a existing two-lane road (highway E6) was reconstructed to a fenced four-lane highway with three wildlife crossings designed for moose. Movements across highway E6 were analyzed using three datasets: 1) Before-After construction, 2) Before-During construction, and 3) During-After construction.

We recorded 135 highway crossings during a total of 8830 moose-days. Of these, 47 occurred before construction began, 76 during construction, and 12 occurred after the highway was fenced. All highway crossings after fencing occurred on the two overpasses designed for moose. Males crossed the highway more frequently than females, accounting for 95% of the total number of crossings during the entire study. Males also crossed the wildlife overpasses more often than females, accounting for 60% of the total number of crossings. We observed no seasonal effects among crossing frequencies, although there was an indication that wintertime movements across the highway were less frequent than crossings during spring, summer, and fall.
Figure 8. Mean number of highway E6 crossings per moose–day near Uddevalla, Sweden, 2002–2005. Three datasets were used: 1) Before-After construction, 2) Before-During construction, and 3) During-After construction.

The average number of crossings over the highway per moose-day decreased by 89%, from an average of 0.036 crossings per day before fencing to 0.0038 after fencing (Figure 8, dataset one). In the second dataset, we monitored 7 moose (5 females and 2 males) before and during the construction phase. Two males routinely crossed the unfenced road during this period. A total of 97 (47 crossings before construction and 50 during construction) crossings were recorded during a total of 2862 moose-days. The average number of highway crossings per moose-day decreased by 36% from an average of 0.044 before construction to 0.028 during construction (Figure 8, dataset two).

In the third dataset, we monitored 12 moose (7 females and 5 males) during and after construction. Of those, six moose routinely crossed the highway during the construction phase and two after the highway was fenced. A total of 38 highway crossings were recorded during a total of 5093 moose-days. 26 crossings occurred before and 12 after the highway were fenced. The average number of highway crossings per moose-day decreased by 67%, from an average of 0.012 before fencing to 0.0041 after fencing (Figure 8, dataset three). The results indicated that overpasses were preferred even though an underpass was situated between the two overpasses.

**Detailed use of a highway overpass (paper III)**

We used infrared remote cameras, track surveys, aerial inventory of moose and GPS telemetry to monitor the use of a highway overpass by moose and roe deer in southwestern Sweden. Specifically, studies included crossing frequencies and behaviour in relation to time of day and highway traffic.
volume, number of moose individuals using the overpass annually and an estimation of the “highway overpass zone”. The highway overpass monitored during this study was completed in June 2000. The structure was hourglass-shaped, 80 m long, 17 m wide at the center, and 29 m wide at the entrances. The sides were covered with 2 m high gray tempered glass-shields intended to reduce disturbances from highway E6. We used two methods to monitor overpass use by ungulates: 1) track counts in sand beds and 2) digital infrared cameras. We monitored GPS-collared moose to quantify the influence of daily movement patterns on the time of day that moose used the overpass.

a. Crossing frequencies

Roe deer crossings increased throughout the six-year study, but moose crossings did not. Crossing frequencies did not differ among the seasons for roe deer, but did for moose. Moose used the overpass less during winter than during summer. Most (84%) (Figure 9a) moose crossings occurred during 21:00 to 04:59 h even though this period only comprised 1/3 of the day. Roe deer used the overpass primarily (76%) between 22:00 and 05:59 (Figure 9b). Most moose (64%) and roe deer (75%) crossings occurred during hours when traffic volume was <200 vehicles/hour.

![Figure 9](image-url)  
*Figure 9. Number of overpass crossings (bars) by moose (a) and roe deer (b) plotted against mean hourly traffic volume by hour (dotted line).*

b. Effects of natural movement patterns and highway traffic volumes on crossing frequencies

We used multiple linear regressions to test for movement rate and traffic volume effects on moose crossing frequencies during operational times of the camera (17:00 to 07:59 hrs). The number of moose crossings was negatively correlated with mean traffic volume ($P<0.05$). The number of moose crossings was positively correlated with hourly movement rate for moose, but was not significant at the $P=0.05$ level. Thus, most overpass crossings by moose did not
occur at times of peak moose movement, but rather when traffic volume on E6 was low.

c. Sex and age class effects on crossing frequency

Adult female (n=154) and fawn (n=145) roe deer used the overpass most, whereas adult males (n=61) used it least. Adult male (n=45) and female (n=38) moose used the overpass more than calves (n=3). We found an overall difference in overpass crossing frequency for moose due to sex/age class when compared to the expected results from an aerial inventory. Adult males and solitary females used the overpass more than expected, whereas cows with calves used it less than expected.

d. Behavior and traffic volume

We were able to document both crossing behavior and concurrent traffic volume for 83 and 177 moose and roe deer crossings events, respectively. Moose walked across the overpass, shifted between walking and trotting, and trotted-galloped on 33 (40%), 32 (38%), and 18 (22%) occasions, respectively. Roe deer behaved similarly whereby they walked, shifted between walking and trotting, and trotted-galloped on 81 (46%), 45 (25%), and 51 (29%) occasions, respectively. Both moose and roe deer walked at low traffic volumes and shifted to trotting as the traffic volume increased.

e. Estimated number of individual moose using the overpass

Of 131 moose crossings documented by camera during the period when GPS-collared moose were present in the area (February 2002 - December 2005), 44 (33%) were made by 4 collared individuals. Those 4 individuals correspond to 20% of the number of moose that were collared more than three seasons (n=20). Our estimations suggest that approximately 5-7 individual moose used the overpass annually. This estimate corresponds to 14.9-18.4 % of the total number of moose in a 57.1 km² zone surrounding the overpass.

f. Reduction of ungulate-vehicle accidents

The number of moose- and roe deer-vehicle accidents reported to the police on E6 within the study area decreased after fencing and the construction of highway crossings. There was a 70 % reduction in roe deer-vehicle collisions during the first 29 months post-fencing compared to the same amount of time pre-fencing. On average, 2.7 moose (total n=35) and 5.3 roe deer (total n=67) accidents were reported annually along the entire 15 km segment of unfenced road from 1990 – 2001 (153 months). During the 20-month construction period of the middle 6 km segment, 1.8 moose (total n=3) and 4.8 roe deer (total n=8) collisions were reported annually. No moose and four (1.5/year) roe
deer collisions were reported since the middle 6 km segment of E6 was completely fenced in June 2004 (31 months).

**Use of different crossing structures (paper IV)**

Ungulate use of different crossing structures is dependent on various variables related to size of structure, location and human disturbances. We conducted a sand plate track count study of 34 structures that were of relatively large sizes, making them at least theoretically possible for animals such as moose and roe deer to use. The crossing rate was calculated for each passage using the ratio between the number of tracks found in the passage and the number of operative days. All structures were categorized into one of three groups; (1) Conventional road crossings: Over- (n=4) and underpasses (n=17) without adaptation for ungulates. (2) Wildlife crossings for ungulates: Over- (n=2) and underpasses (n=6) designed for moose and roe deer. (3) Viaducts (n=3) and ecoducts (n=2): Large (between 45 and 140 m wide) structures with vegetation.

![Figure 10. The relative use of wildlife crossings, viaducts and ecoducts by moose and roe deer. Use of conventional road crossings was indexed to one.](image)

Both moose and roe deer used viaducts and ecoducts to a greater extent than smaller structures. The viaducts and ecoducts were all used to the greatest extent by roe deer compared to other structures and all had crossing rates exceeded one crossing per day. The mean number of moose tracks across wildlife crossings was more than three times as many as those across conventional road crossings (Figure 10). Roe deer did not follow the same
pattern and wildlife crossings and conventional road crossings were used to about the same extent.

**Use of underpasses in relation to size, disturbance and landscape features (paper IV)**

A total of 23 underpasses (17 conventional underpasses and 6 wildlife underpasses) were monitored to identify structure preference in relation to various variables. The sand beds were placed in the middle of the crossing structure in a 100 cm wide and five cm thick band across the whole width of the passage. Depending on topographic characters of the surroundings, one to three reference beds with equal dimensions as the sand bed at the passage were placed within 100 meters from the entrance on each side of the passage. Each underpass was characterized according to 12 independent variables describing different attributes. The variables were related to dimensions of the passages (height, width, length and relative openness), human disturbances (traffic/hr, humans/hr, and distance to nearest house) and landscape features (distance to forest, distance to nearest other passage, proportion of forest within 1 000 m radius from passage, proportion clear-cut within 1 000 m radius from passage and number of clear-cut patches within 1 000 m radius from passage).

High rates of human use decreased the preference for roe deer. Also, roe deer used underpasses that were situated close to forest edges to a higher degree than those situated further away. None of the structural variables significantly reflected roe deer use although a positive response was found to higher, wider and shorter passages.

The structural variable that had most influence on moose preference was relative openness; moose used larger structures to a higher degree than small. Contrary to roe deer, moose used underpasses located at long distances from forest edges to a higher degree than those situated near edges. Moose used underpasses to a higher degree when located in areas with lower proportions of forest in the surroundings. Human disturbances (humans/hr or traffic/hr) had low influence on any of the high ranked explanatory models for moose.
Conclusions and management implications

Time should always be a factor to consider when constructing wildlife crossings. The corridors used for the major infrastructure have a long life span, often more than 100 years, and thus mitigations should be planned to limit impacts for a changing landscape and fauna. One example in Sweden is the wild boar (*Sus scrofa*) that has been absent since the 1700s, but now increases and expands at a high rate. The number of wild boars shot during hunt has on average increased with 29.2 % per year since 1990 until 2005, as calculated from the Swedish association for hunting and wildlife management harvest statistics (Svenska Jägareförbundets viltövervakning), and the population is still expanding (Lemel 1999). It is important that this animal is taken into consideration in the plans for new and upgraded roads in Sweden, even though it might not be present at the time of road construction.

The upgrading of a non-fenced road to a fenced highway with three wildlife crossings decreased the moose movements across the highway by 67 % (Paper II). If we estimate that a fenced highway without crossing opportunities would decrease the number of passages by 90 % (Skölving 1985, Nilsson 1987), then the two overpasses might have reduced the barrier by about 23 %. If we also assume that the two overpasses were equally effective for moose, then each overpass reduced the barrier by 11.5 %. However, more research is needed to be able to predict the effect of different crossing structures. All crossings after construction were documented at the two highway overpasses and no at the underpass, which indicated that moose selected overpasses even though an underpass (width 13 m, height 4.7 m) were situated less than 3 km from each overpass.

An issue that has been debated is what the optimal distance between wildlife crossings should be, both with respect to construction costs and effect for wildlife. For non-migrating moose, the effect zone around each passage is theoretically equal to an area based on the average diameter that encompasses a moose home range (Figure 11). An approach to calculate the optimal distances between wildlife crossings or other crossing opportunities for moose is to use this zone. It might not be necessary to build moose passages closer to each other within each zone; however landscape features and known crossing points must be taken into consideration, and be judged with special emphasis. For moose, we calculated that zone to be 57.1 km² (a radius of 4.26 km), based on the diameter of the average annual home range size of both males and females.
Thus, the distance between wildlife crossings for non-migrating moose could with this approach be about 8.5 km.

Conventional road underpassages can serve as a complement to wildlife crossings for both moose and roe deer if emphasis is taken to each species demands. For moose, structural variables of underpasses were of great importance, and based on the results in paper IV, I would recommend a minimum size of 10x5 m (width x height), and as short as possible (a minimum relative openness of 1.85 and up for passages with a length of 27 m). However, these results may only imply to a non-migrating moose population. For migrants, the crossing structure may have to be larger since these moose do not have the time to adjust their movements and behavior to new constructions, rather wildlife crossings must appear safe at first encounter. Observations of this problem have been reported for partially migrating moose in north-eastern Sweden (Seiler et al. 2003). Roe deer were not sensitive to size down to a
relative openness of 0.7; however human use had a strong negative influence. I suggest that (1) it is important to limit human access to conventional passages (where possible) and wildlife crossings. (2) Passages should be constructed in a variety of biotopes along a highway and (3) moose should be the focal species for ungulate passages in Fennoscandia.

I would encourage a greater cooperation among the road administration, municipalities (or other regional division) and land owner in the vicinity of wildlife crossings. The municipalities should treat areas surrounding wildlife crossings as any other important conservation areas for preservation of nature and resources in the landscape. A connectivity plan could preferably be established within the land use plan that limits activities (development, mining etc.) that could decrease the accessibility and use of the wildlife crossing for any species. Our results indicates that no matter how well designed wildlife crossings may be, use will be limited if human activity is not managed around them. To my knowledge, no such actions have been taken in Sweden yet, but by doing so, wildlife crossings could be secured for future wildlife, and wildlife management.

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The use of highway crossings to maintain landscape connectivity for moose and roe deer

Increasingly wildlife managers and land managers are challenged to maintain the viability and connectivity among large mammal populations. Thus, it is important that effective wildlife crossings and conventional road crossings are identified and optimized with respect to construction cost, facilitation of ungulate movements, and ability to reduce wildlife-vehicle collisions. Previous studies have evaluated the importance of structure design and size for many ungulate species, but few studies involved moose (*Alces alces*) which is the target species for most large ungulate mitigations in Sweden.

We used infrared remote cameras, track count surveys, and GPS telemetry to monitor the use of wildlife crossings and conventional road passages by moose and roe deer (*Capreolus capreolus*). Given the continued changes that will occur in Sweden due to human development and infrastructure, we suggest that the construction of wildlife crossings along fenced roads are an important tool for traffic safety and to maintain meta-population dynamics across otherwise isolated areas.