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Procedures for the Design of Roads in Harmony with Wildlife

Preliminary Maintenance Report
Part A: Ecological functions of roads

Deliverable F
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CEDR Call 2013: Roads and Wildlife – Cost efficient Road Management
Harmony
Procedures for the Design of Roads in Harmony with Wildlife

Maintenance report
Ecological functions of roads

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Executive summary

This report presents a review of literature about the relationship between roads and wildlife. It focuses on the ecological functions roads can offer wildlife and which factors underlie the use of road components by wildlife. This information will be used in a later stage to develop a cost-efficient maintenance strategy that improves the value of road components for wildlife.

Roads and their components can fulfil the following functions for wildlife:
- Food sources
- Breeding sites
- Resting sites
- Hibernation sites
- Commuting routes for daily or seasonal travel
- Routes for dispersal

Considering the factors that underlie the use of road components it appears that animals prefer to use or live near roads when the road system offers something extra compared to the surrounding landscape. The extras can be:
- availability of a resource (food, breeding site, minerals e.g. sodium and calcium);
- quality of a resource;
- ease of access to an available resource ;
- permanency of a resource;
- avoidance of threats in the surrounding landscape (e.g. predators, disturbance)

Traffic volume and verge widths of individual roads also play a role in their use by wildlife. As well as general use, species richness is also affected by these factors. The wider and more diverse (in natural cover) the road verge the more species inhabit the verge and also the density of species increases. Increasing traffic diminishes the benefits of a wide verge and at very high traffic intensities the benefits of a wide verge do not outweigh the impact of the traffic anymore.

For all animals, if the road is to have a positive effect, the benefits of living near roads have to outweigh the detrimental effects. Such effects are collisions with cars, disturbance by noise and light or poisoning by heavy metals. In contrast to general opinion, creating favourable habitat near roads does not necessarily lead to an ecological trap. At least for butterflies it was noted that at the population level species benefit of an attractive habitat in road verges compared to the surrounding landscape, even though more butterflies were killed by traffic than in unattractive road verges.

Besides the usual road components this review also analysed literature about mitigation measures (over- and underpasses for wildlife to cross roads). It was noted that the effectiveness of crossing structures depends on species-specific requirements for the physical construction, but most importantly on their location. The passageways must be easy to find, which means preferably on an existing commuting route. Existing guiding structures must be kept intact or when newly constructed they must leave the animals no alternatives to cross the road at other places. If the latter is not possible, more crossing structures are needed.

Animal species differ in their vulnerability to the detrimental effects of roads. Also, populations of a species can differ in their vulnerability, resulting in different attitudes towards roads between populations. Therefore, it is not possible to present species-specific guidelines for road management that apply to the whole of Europe; also because legislation about road safety differs between countries. For a wildlife friendly maintenance strategy, the

local situation must be assessed beforehand to decide for which species mitigation measures are useful, and where and how to implement them. It should be clear that measures near the road add something to the conservation of species. Improving the conditions along roads should not be an excuse to neglect possibilities for improvement farther away from roads y

1 Introduction

The Harmony project brings together a consortium of ecologists and engineers to develop sustainable solutions to road transport challenges that are in harmony with wildlife. One of the solutions studied is the maintenance of roads and their components (bridges, culverts, verges, fences etc.) and the effect it has on wildlife conservation.

In general, where animals meet road networks conflicts arise. Wildlife-vehicle collisions result in road kill, car damage and sometimes human casualties. But roads also have detrimental effects that are not so clearly visible. Roads can form a barrier, fragmenting an animal's habitat. In addition the detrimental effects of the infrastructure are not restricted to the immediate area but extend into the surrounding landscape. The effects can be nearby (e.g. pollution of vegetation or water with heavy metals and de-icing salt) or reach far into the surrounding landscape (e.g. noise, light and nitrogen emitted by traffic).

To prevent or diminish the negative effects of roads on wildlife many solutions have been developed and implemented e.g. fences to prevent road kill, under- and overpasses to cross roads, special armature for streetlights to light only the road and not the surrounding landscape, etc. The effectiveness of these measures depends on the design, the location and the maintenance. But actually, the presence of a road is not always bad for nature. In many countries the verges of roads form refuges for rare plants that are pushed away from their original habitats by encroaching agriculture and urbanisation. Also, some species of animals find favourable habitats in the verges of roads. Other road components, like bridges, road side ditches and culverts are used by wildlife too. Even without specific measures the road network offers resources or habitat to wildlife.

This report will describe the ecological functions roads can have for wildlife. It will not describe specific requirements of individual species as there are many handbooks that cover such requirements. It seeks to find general ecological principles that apply throughout Europe. Knowledge about the factors that determine why an animal uses components of the road network is necessary to design a network that has minimal detrimental effects on animal populations and to develop a maintenance strategy that maintains the objective of the designers or improves the natural value of an existing road network.

Another deliverable of the Harmony project (Deliverable G: Final Maintenance Report) addresses the issue of maintenance in further detail. Part A of this deliverable describes a strategy for developing a cost-effective maintenance plan and Part B provides a handbook which describes maintenance methods and addresses some key points for the effective maintenance of each road component.

The focus in this report is on motorways and expressways, because these fall under the responsibilities of the National Road Authorities (the members of CEDR). From the literature it is however not always clear what type of road is studied. So probably in the review there are also examples described from smaller roads.

2 Ecological functions of the road and its components

The road network is a system consisting of many parts. All these parts can fulfil some kind of function for animals. Figure 2.1 shows the different components of a road system.

The ecological functions the road system can fulfil are:

- Food sources
- Breeding sites
- Resting sites
- Hibernation sites
- Commuting routes for daily or seasonal travel
- Routes for dispersal

Table 2.1 gives an overview of the ecological functions the road components can fulfil for different species groups. The overview is the result of a literature study and personal experiences.

Table 2.1 Ecological functions of roads for different species groups. i = insects, s = spiders, c = crustaceans, iv = other invertebrates, f = fishes, a = amphibians, r = reptiles, m = mammals, excluding bats, bt = bats, bd = birds, all = all groups, ex. = excluding

Subsystem of road	foraging	commuting	breeding	resting	hibernating	migration/dispersal
carriageway / hard shoulder	bd	m				i, s, c, m
road verge / soft shoulder	i, s, c, iv, r, m, bd	i, s, c, iv, r, m	i, s, c, iv, r, m	i, s, c, iv, r, m	i, s, c, iv, r, m	i, s, c, r, m
median strip	i	i	i	i		i
resting site / parking place / fuel station	i, m, bd		i, m, bd	i, m, bd	i	
underpass (dry)	r	all, ex. bd & f	bt	r, bt	bt	all, ex. f
- tunnel	r	all, ex. f		r, bt		all, ex. f
- bridge		all, ex. f	bt	r, bt		all, ex. f
underpass (wet)		all	bt, bd	i, bt	i, bt	all
- culvert/tunnel		all	bt, bd	i, bt	i, bt	all
- siphon						f
- ditch / canal / river/ stream crossing road = bridge		all	bt, bd		i, bt	all
overpass (dry) = bridge		all, ex. f	bt, bd	bt	bt	all, ex. f
- bridge over (rail)road, river or canal		all, ex. f	bt, bd	bt	bt	
overpass (wet) = aqueduct		f				
roadside ditch	all	all	all	all		all
pond	i, a, f, bd		i, a, f	bd		
sound barrier / screen / fence = guiding structure	bt, bd	all, ex. f		bd		all, ex. f
lantern / street lamp	i, s, bt, bd			bd		
sign posts	bd			bd		
gantry		bt				

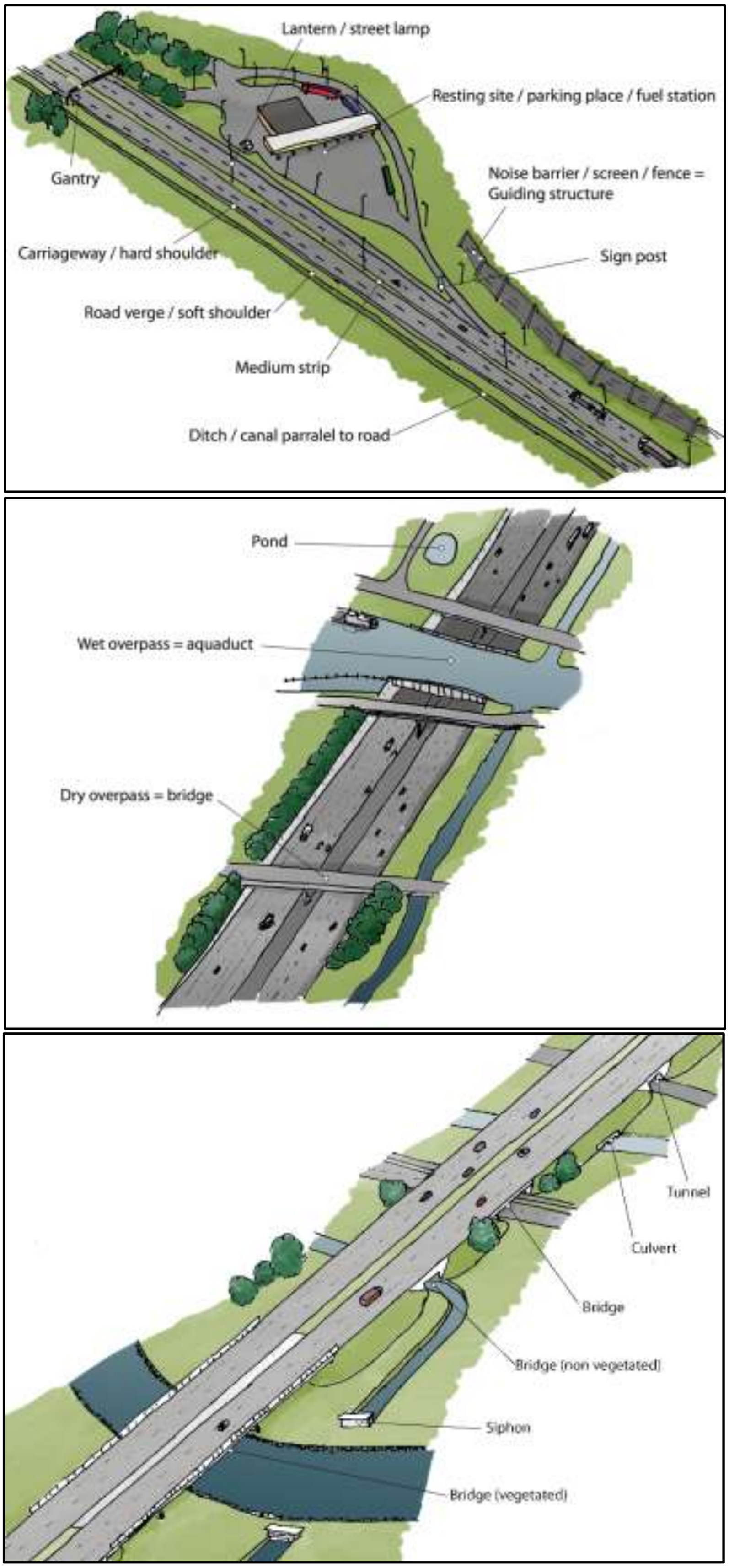

Figure 2-1 The road network and its components.

3 Factors affecting the use of road components

There are many reasons for animals to avoid roads. They can die or suffer injury in animal-vehicle collisions; get poisoned by heavy metals or de-icing salt; and get disturbed by noise and light. The impact of roads can reach beyond the immediate area. Berthinussen & Altringham (2012b) found that the total bat activity (the number of species and the activity of Common pipistrelle (*Pipistrellus pipistrellus*); the most abundant species in their study area) was positively correlated with distance from a major road in Cumbria (UK), irrespective of differences in landscape. Total activity increased more than threefold between 0 and 1600 m from the road. Similarly, Eigenbrod *et al*. (2009) found that all anurans living in ponds along a highway in eastern Ontario, Canada, had reduced abundances near to the highway. The extent of the effect differed between the species from 200 m to more than 1000 m. For grassland birds in the Netherlands, Reijnen *et al*. (1996) found road-effect zones (significant reductions in population density) varied from 40–2800 m in width, depending both on the species and the traffic volumes on the roads. The effects may be direct (e.g. mortality, noise disturbance) or indirect (e.g. less invertebrate food for forest birds because there is less food (decaying leaves) for invertebrate soil fauna near to the forest road; Haskell 2001)

So what explains why animals get near to roads at all, and in some cases spend their whole life there? The reason lies mainly in differences in resource variables along a road compared with the surrounding landscape (see Figure 3.1). If the difference is such that the detrimental effects of living near a road can be overcome, animals may prefer to live near roads or visit the road or its neighbourhood temporarily. The following overview will go into the details. It will also become clear that, considering the attractiveness of road verges, the width of the verge plays an important role.

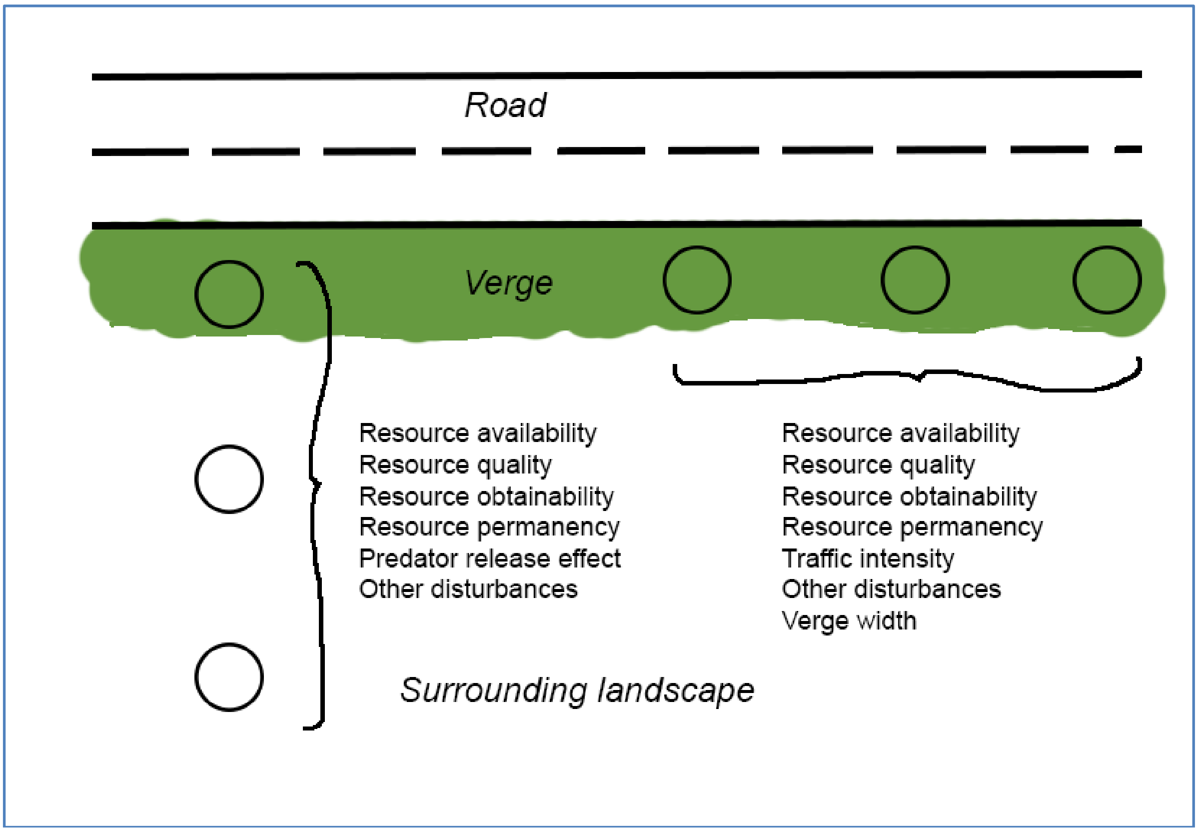

Figure 3-1 Factors affecting the use of roads by wildlife. The presence or density of wildlife near a road (e.g. in the verge) depends on differences in resource availability, quality etc. in the verge compared to the surrounding landscape (left part of the figure). Differences in the same parameters, plus traffic intensity and verge width, affect the presence or density of wildlife in different stretches along a road (right part of the figure)

3.1 Roads versus the surrounding landscape

3.1.1 Resource availability

Certain animal resources may be found near a road that are not available elsewhere in the region or are only available in low quantities. The resource can be food, water, minerals, resting sites, breeding sites, mates or warmth (Larson *et al*. 2000, Dean & Milton 2003, Smith & Dodd 2003, Antworth *et al*. 2005, Andrews *et al*. 2006, Stryjecki 2006, Fahrig & Rytwinski 2009, Peeters *et al*. 2012, Creemers & van Delft 2009, Camacho 2013, Gvozdenović & Iković 2014, Heske 2015, Planillo *et al*. 2015, Andrews *et al*. 2015, own observations).

The effect can be relatively significant, such as Hanley & Wilkins (2015) found in SW England. Along 30 hedgerows, bordered either side by roads and arable fields (cultivated with wheat, barley, oilseed rape, or beans), they found bumblebee abundance to be over twice that observed on adjacent crop-facing margins. Both the total number of flowering plant species and the floral abundance of three of the five most visited plants, as indicators of food availability, were also higher on roadsides.

In some cases a combination of resources is needed to create favourable conditions for a species to live near a road. For example obligate myrmecophilic butterfly species, such as the Scarce large blue (*Phengaris teleius*) and the Dusky large blue (*P. nausithous*), have narrow habitat requirements. Living as a caterpillar in the nests of the ant species *Myrmica scabrinodis* and *M. rubra*, respectively, they can only survive on sites with both host ants and the host plant Great burnet (*Sanguisorba officinalis*). Due to a more intensive use of pastures the Great burnet and the ants are missing in pastures in the Netherlands. On some road verges, as well as in some nature reserves, the host plant density is high and both ant species are present. These are the few places where the two butterfly species are found nowadays (Wynhoff *et al*. 2011).

For the two aforementioned butterfly species the conditions in road verges are always better than farther away from the road, at least in a highly cultivated country as the Netherlands. For other animal species road verges are only attractive during certain periods. Laurian *et al*. (2008) for instance found a temporary deficiency of sodium as a driving force for Moose (*Alces alces*) to visit roads. Sodium has many fundamental physiological functions in animals but is rare in boreal ecosystems where Moose thrive. In Québec (Canada), sodium is readily available in aquatic vegetation and in pools with de-icing salt that form along highways. Moose appeared to visit the pools when the need was greatest and the aquatic vegetation had not fully developed, even though the pools were near to habitually avoided highways and required long-distance movements. A comparable effect was found by Groot-Bruinderink *et al*. (2009) with Wild boar (*Sus scrofa*) and Roe deer (*Capreolus capreolus*) in the Netherlands. In years with a high quantity of beech and oak nuts (so-called 'mast years') the animals stayed in the neighbourhood of this food source. In years with a low quantity they travelled longer distances with a higher chance to cross roads. The likelihood to be hit by a car was highest for Wild boar because they find alternative food in the verges of roads. For Roe deer it was lowest, and not significant, because for this species alternative food sources are available in the neighbourhood of the beech and oak trees.

A temporary deficiency of food may also be an explanation for the contrary results of Moose road kill in Sweden. For Moose attractive browsing and resting areas are distributed patchy and occur in both large and small patches, giving a mosaic-like pattern mainly driven by forestry activities. The spatial pattern of attractive areas for browsing and resting change over time as vegetation in new areas enters the right successional stage (Kastdalen & Thøger-Andresen 2014). Thus tree removal along railways (and roads) might lead to increased traffic victims because the animals come to the fresh vegetation (Seiler *et al*. 2011). However, Eriksson (2014) did not find a relation between tree removal and collisions between trains and Moose in Sweden. An explanation could be that the animals didn't have to visit the patches with fresh food, because there was enough in the surrounding landscape. A small effect of clearance on accidents was found for the summer season when food availability is low.

3.1.2 Resource quality

It is not always just the availability of a resource but its quality can also explain the preference of a species to live near a road. In the open landscape of Israel the likelihood of Pistachio trees (*Pistacia atlantica* and *P. palaestina*) to be parasitized by galls of aphid Fordini species is higher in roadsides than away from roads. Moreover, in the semi-dry regions, eight aphid species induced more galls[1] in plants growing along roads than away from roads. The annual growth of the two host plants was significantly more vigorous in

[1] Galls are abnormal growths that can arise in all parts of a plant resulting from the work of immature insects and other organisms.

roadsides than away from roads, which may have made them more attractive for gall-inducing aphids (Martinez & Wool 2006).

3.1.3 Resource access

Many species of different taxa are known to scavenge on road kill or forage for prey in the verges (Dean & Milton 2003, Smith & Dodd 2003, Antworth *et al*. 2005, Fahrig & Rytwinski 2009, Heske 2015, Andrews *et al*. 2015, Planillo *et al*. 2015).

Food availability or quality alone is not always enough to make a road verge attractive for an animal. Raptors and White storks (*Ciconia ciconia*) can be seen in freshly mowed verges. When all the tall vegetation is gone, small mammals are more visible to hunters and easier to catch. In Spain, vultures and Black kites (*Milvus migrans*) frequent roads to feed on road kill. For vultures the explanation is that carcasses of larger animals are rare nowadays. In Europe, large carnivores that are able to kill large prey which they only partly eat are rare. For an obligate scavenger like the Griffon vulture (*Gyps fulvus*) road kill hotspots are the only locations in Spain where they can find food (Planillo *et al*. 2015). On the other hand, a generalist raptor such as the Black kite can find food everywhere. However, in the study of Planillo *et al*. (2015) Black kites were the only raptor species that was not negatively affected by high traffic volumes, and also showed a strong selection for road kill hotspots. Showing a preference for roads irrespective of the disturbance intensity was explained by roads and motorways being easy to spot. For a generalist predator used to human disturbance, they can provide food in a more predictable way than random movements through the landscape.

The preference for verges by certain bird species may be explained by other factors which make it easier to hunt for prey. In an intensive arable plain in western France, Meunier *et al*. (2000) found that some raptor species used motorway verges (Buzzards *Buteo buteo*) and also secondary road verges (Kestrels *Falco tinnunculus*) in preference to cultivated fields for hunting. However, their abundance along roads was not directly related to the relative abundance of small mammals. The supply of perching sites, allowing a less energy-demanding hunting behaviour than flight-hunting, and the width of the verges, appeared important factors in the attractiveness of roadsides for these species.

3.1.4 Resource permanency

Road verges offer relatively undisturbed habitats especially in highly urbanised areas or in areas with extensive agricultural fields, i.e. undisturbed by mowing, ploughing, trampling, etc. This may attract species that are sensitive to this kind of disturbance. For example Delaplane and Mayer (2000) mention permanency as a factor for ground-nesting bees to build their nest in road verges, where the soil is undisturbed compared to nearby agricultural fields (Figure 3-2). Undisturbed verges also help Common voles (*Microtus agrestis*) and Hamsters (*Cricetus cricetus*) to overcome bad periods in their more favoured habitat. Both mammals are present in arable fields in high abundances when seeds are available. After harvesting the population collapses, but a remnant population remains in the road verges. Food resources in the verge may be less, but the conditions are more stable than in the arable field. When conditions in the arable field improve, voles and Hamsters can recolonize it from the verges.

Permanency, next to the proximity to water and foraging sites, and predator avoidance, is also mentioned by Smith & Stevenson (2013) as an explanation why bats often choose concrete bridges as roosts. Probably the same applies for swallows. For birds that normally breed on cliffs bridges are good substitutes in areas without mountains. Of course the benefits have to outweigh the noise and vibrations of passing traffic.

Figure 3-2 Sand heaps created by Hairy-legged Mining Bees (*Dasypoda hirtipes*) that dug their nests in a sandy road verge (Photograph Liesbeth Leusink).

3.1.5 Predator release effect

Sometimes, the abundance of a species in road verges is higher than farther away from the road, though a clear difference in habitat between the two locations is not apparent. A driving force other than food, shelter or breeding sites may be in operation. Results of a study by Ruiz-Capillas *et al*. (2013) in Spain revealed different activity patterns of both mammalian predators and prey near motorways that are independent of structural differences in microhabitat. Both the Red fox and small mammals were found to use the zone close to the motorways more frequently, whereas lagomorphs and mustelids were less active there. On the one hand these results suggest that the Red fox acts as 'top predator' and mustelids follow a 'safety match' strategy avoiding the area close to the motorway where the fox is more active. On the other hand, abundances of prey species are negatively associated with the activity of their most frequent predators; mice and voles are prey of mustelids and rabbits and hares are prey of Red fox (the predator release effect, Fahrig & Rytwinski 2009). However, Planillo & Malo (2013) found the lowest rabbit abundance next to the motorway and the highest abundance at an intermediate distance, while hunting and carnivore pressures were highest farthest from the infrastructure. They argue that some sort of road avoidance or other process must underlie the observed abundance pattern, possibly in combination with a predator release effect.

3.1.6 Other factors

The cause of a preference for roadsides as breeding habitat is not always clear. Polak *et al*. (2013) noted a higher number of Great tits (*Parus major*) and Song thrushes (*Turdus philomelos*) near a busy road in Poland than farther away from the road, while for all other bird species it was the other way round. They could not find an explanation for this finding. Actually, nests of Great tits near the road had an elevated mortality among nestlings, probably because the parent birds had been killed in collisions with vehicles. Halfwerk *et al*. (2011), working with Great tits in the Netherlands, also found an effect of traffic on reproductive success. They found a negative effect of traffic noise on reproductive success with females laying smaller clutches and pairs fledging fewer young in noisier areas.

From an evolutionary point of view breeding near a road seems to be disadvantageous for Great tits and Song thrushes in the study of Polak *et al*. (2013). For now it is unclear which factors make them breed here anyway and in higher numbers than farther away from the road.

3.2 Differences along roads

3.2.1 Resource availability

Differences in the availability of resources (food, shelter, breeding sites) are also good predictors for differences in the presence or abundance of species parallel to roads. For example, in a dry agricultural landscape in central Spain, road stretches with road kills of European polecats (*Mustela putorius)* were characterised by greater numbers of Rabbit (*Oryctolagus cuniculus*) burrows in road verges and by higher traffic flow and speed than road stretches without Rabbit burrows (Barrientos & Bolonio 2009).

In an open agricultural landscape in southwestern Poland disproportionately high mortality among birds was recorded near trees, and hedgerows parallel to the road and near built-up areas, while it was much lower in open farmland. The trees and hedgerows attracted birds that made their nests in them, foraged in them, used them as a retreat when a threat appears while foraging on the ground or hunted for insects that aggregated at the lee side of them (Orłowski 2008).

The presence of (planted) hedgerows and hedges also had an effect on spider communities in France and small mammals in the UK. In highway verges in an intensive agricultural landscape west of Paris, France, the presence of (planted) hedgerows resulted in a different spider community compared to sites without hedgerows. Spider communities in non-planted sites were complementary to that of planted sites (Le Viol *et al*. 2008). In north Cambridgeshire, UK, Bank vole *(Myodes glareolus*) and Field vole (*Microtus agrestis*) numbers showed a significant positive correlation with the dimensions of hedges and the width of the tall grass area, respectively. Wood mice (*Apodemus sylvaticus*) were also more numerous on verges with large hedges but the relationship between mouse abundance and verge structure was complex. The number of mice in 1994 was positively and significantly correlated with hedge features and with the width of the short grass sightline, whereas in autumn 1996, they were only significantly correlated with total verge width (positive association) and ditch width (negative association) (Bellamy *et al*. 2001).

For flower visiting insects the presence of flowers is obviously important. Working in Kansas Hopwood (2008) found bees to be twice as abundant on roadsides supporting native prairie plants compared with those dominated by non-native grass and flowers; roadsides with native plants also supported about 35 percent more bee species. Higher floral species richness, higher floral abundance, and higher percentage of bare ground were the factors that led to the greater bee abundance and bee species richness.

For butterflies in road verges in semi-natural grasslands in Finland Saarinen *et al*. (2005) found that high nectar abundance was the most important factor increasing the numbers of meadow butterflies in road verges, while meadow moths were mostly favoured by shelter provided by tall vegetation. Of all habitat variables explored by Ries *et al*. (2001) in roadsides in Iowa, US, the species richness of plants in flower showed the strongest effect on mean richness and abundance of both disturbance-tolerant and habitat-sensitive butterfly species. Interestingly, relative numbers indicated that mortality risk was more than twice as high on grassy roadsides (with less flowering plants). Tracking studies by Ries *et al*. (2001) showed that butterflies were less likely to exit flower-rich prairie roadsides, indicating that their mortality rates may be lower along these verges. This was confirmed in a study by Skórka *et al*. (2013), who found that the proportion of individuals killed on roads in farmland in Poland was negatively linked with the abundance of butterflies in road verges, the richness of the plant species and the share of grassland in the surrounding landscape. These results suggest that a so-called 'ecological trap' (i.e. animals are attracted to a dangerous place) did not exist for these butterflies.

Figure 3-3 The more flowering plants in the verge, the higher the abundance and species richness of butterflies. At the same time the relative numbers of road killed butterflies decreases (Photograph Floris Brekelmans).

3.2.2 Resource access

Not only do high objects in verges benefit single avian species (see section 3.1.3), their presence also appears to have an influence on avian species richness. In a sample of 100 right-of-ways (ROW) or verges the best competing model to explain avian species richness included the synergistic effects of verge width, traffic intensity and the availability of perch sites (McCleery *et al*. 2015). Species richness was higher in verges with perches. Perches being signposts, fences, trees, utility poles, etc.. Birds used the perches for singing, courtship flights, hunting and scanning the surroundings (for mates, food or danger).

3.2.3 Verge width and traffic

For birds, small mammals and butterflies it was shown that the width of the verge has an effect on species presence, abundance or species richness (Bellamy *et al*. 2001, Saarinen *et al*. 2005, de Redon *et al*. 2015, McCleery *et al*. 2015). In west-central Illinois, USA, species richness of small mammals along six different road types increased significantly with verge width and vegetation height. Species richness decreased significantly with vegetation thickness and biomass (McCleery *et al*. 2015). In the same study, avian species richness was found to increase with verge width and to decrease with traffic intensity. Increasing traffic (vehicles/day) reduced the positive effect of verge width considerably. Along roads with high traffic intensity (>7000 vehicles/day) the avian species richness in wide verges (>30 m) was only half as much as in narrow verges (<10 m), while along roads with low traffic intensity (1 vehicle/day) it was 8:1. Along roads with medium traffic intensity (1427 vehicles/day) it was 5:1 (McCleery *et al*. 2015).

Traffic volumes (average number of vehicles per day) did also affect the abundance, species richness and diversity of the raptor bird community in Central Spain (Planillo *et al*. 2015). These parameters were highest at medium traffic volumes and decreased at highest traffic volumes. Among the species there were exceptions. The abundance of Booted eagles (*Hieraaetus pennatus*) was driven by the abundance of prey, not by any variable related to traffic.

Figure 3-4 A highway in the Netherlands with a broad verge and median stripe (Photograph Dennis Wansink).

Traffic volume and roadside width do not affect the abundance and species richness of bees in Kansas, USA (Hopwood 2008). However, the widths of the roadsides in this study were 18 m or more, while in the studies mentioned earlier the smallest widths were less than 5 m. De Redon *et al*. (2015) found lower abundances of Millet's shrew (*Sorex coronatus*) in road verges than in highway verges. The authors argued that the broader highway verge provided more food for this species, enabling the animals to spend more time here; possibly their whole life cycle. The narrower road verges were probably only used by animals dispersing from nearby woods. Shrews need lots of food (invertebrates) and move intensively through their relatively large home range to find it. Therefore, Hopwood (2008) may not have found an effect because the smallest verge width in her study provided all the resources needed by all bee species. In general larger patches of habitat are considered to have higher conservation potential, because they have larger core areas, are less likely to be influenced by external impacts (edge effects) and are more heterogeneous in vegetation structure, thus providing suitable habitat for more species.

4 Road crossings

A common reason why animals come into contact with roads is because they want to cross over to habitat on the opposite side for various reasons e.g. (temporarily available) food, mates, hibernation or breeding sites; or young have to leave their birthplace (dispersal). Ideally, animals would not have to cross the road at grade; availing of under- or overpasses. In considering the various factors that determine the use of under- and overpasses or the location where animals cross at road level, some trends become apparent.

4.1.1 Under- and overpasses

Under- and overpasses must have dimensions appropriate for the animal to pass through or over. For example, badgers use tunnels that are hardly wider than themselves, but the sizes of underpasses for bats are much bigger than their body sizes. Thus, for example, the minimum cross sectional area of culverts for Daubenton's bats (*Myotis daubentonii*) is 7 m^2, for Pond bat (*Myotis dasycneme*) 18 m^2 and for Common pipistrelle (*Pipistrellus pipistrellus*) 47 m^2 (Boonman 2011), which is significantly more than their body sizes. In fact, the smallest of the three (Common pipistrelle) had the largest minimum cross sectional area. It has been noted by Abbott *et al*. (2012) that the use of underpasses by bats depends on their flight capability and sensory perception. Clutter-adapted species such as Lesser horseshoe bat (*Rhinolophus hipposideros*), Natterer's bat (*Myotis nattereri*) and Brown long-eared bat (*Plecotus auritus*) flew through narrow drainage pipes, while edge-space species, the Common pipistrelle and Soprano pipistrelle (*Pipistrellus pygmaeus*) for instance, used the larger tunnel. The open-adapted Leisler's bat (*Nyctalus leisleri*) didn't use any underpass but flew over the road. Both the clutter-adapted and the edge-space species showed a preference to fly through an underpass over flying over the road (Abbott *et al*. 2012).

Effects of size and form of underpasses were also found for fish. On first sight no obstructions seem to be present in culverts and siphons to be used by fish. However, in narrow culverts and in siphons the stream velocity is often too high for fish to overcome. Culverts and tunnels with the same width as the stream they connect do not create this problem. Culverts and siphons with adaptations to diminish the stream velocity or that create standing water where the animals can rest solve this problem (Benton *et al*. 2008, Ottburg pers. com.).

Figure 4-1 A wildlife overpass in Hungary (Photograph Dennis Wansink).

Some species do not seem to have specific requirements regarding the shape and dimensions of under- and overpasses. Emond *et al*. (2011) compared the use of 139 tunnels by badgers with the physical aspects of the tunnels. It appeared that none of the physical aspects explained the frequency of use. When corrected for badger density and distance to the nearest badger set, the landscape structure was the decisive factor to predict badger use (see also Bach & Müller-Stiess 2005 for bats). In half open landscapes, with c. 50% (25-75%) wooded banks, hedgerows and c. 50% grassland, arable land, ditches etc., the frequency of use was highest, while in urban landscapes it was lowest. In other words, preferred foraging sites and guiding structures near a tunnel will enhance its use more than its physical aspects. Grilo *et al*. (2008) also found that the form and size of underpasses in Portugal was not the decisive factor determining their use by the most common carnivores (Red fox *Vulpes vulpes*, Stone marten *Martes foina*, Badger *Meles meles*, Genet *Genetta genetta* and Mongoose *Herpestes ichneumon*). In terms of individual species usage patterns, Red foxes used drainage tunnels less frequently in open areas with little cover, martens avoided tunnels with vegetation cover over the entrance, while Otters (*Lutra lutra*) crossed more frequently where tunnels fed into streams and rivers and when river banks had more vegetation. Low disturbance by humans was also a key feature.

Figure 4-2 A badger tunnel made of a drainage pipe used by Badgers (*Meles meles*) to cross a highway in the Netherlands (Photograph Floris Brekelmans).

Kintsch & Cramer (2005) and Jacobson (2015) argue that different guilds of species can be recognised in relation to the use of under- and overpasses based on their ability to minimize mortality risk. For example, many small animals readily accept small, enclosed culverts as passageways because the darkness and cover simulates conditions they seek in other situations to avoid detection by predators. Contrarily, Pronghorn (*Antilocapra americana*) seek open passages and plenty of manoeuvring room because of their adaptation to seeing their predators from afar and running away; thus any hint of enclosure is perceived as dangerous to them. It has been noted, however, that animals do not always follow the rules of their guild. The minimum width of fauna overpasses for Roe deer (*Capreolus capreolus*) is set at 15 m (Wansink *et al*. 2013), but in the Netherlands animals are seen on narrower bridges with high screens (creating a tunnel appearance) and have actually been seen sleeping there (pers. com. J. Brandjes). A possible explanation could be that Roe deer in the Netherlands are less cautious, because of the absence of large predators, low hunting pressure and high human density in the country.

4.1.2 Road level crossing location

The many studies carried out on the characteristics of locations where animals cross roads directly and where blackspots of road kill occur, have shown that an animal's movement through the landscape determines where they will cross the road. When commuting, most animals follow linear structures (forest edges, hedge and tree rows, ditches, fences, footpaths etc.). Where these structures meet roads, animals will cross the road (Huijser 2000, Lesiński 2008).

According to Ascensão (2013) the place where a Beech marten (*Martes foina*) crosses a highway depends on three things:

1. the animal's activity near the highway;

2. the proximity to an available passageway;
3. knowledge of available passageways.

So, a marten may be near to a highway because he wants to cross it or the animal is there for other reasons (e.g. food). When the animal wants to cross, the distance to the nearest safe passageway (a fauna underpass or other structure) determines if the animal goes to the safe passageway or crosses at the point where he is. Finally, only resident animals will know the distance to safe passageways, vagrants will not and will cross the road even though a safe passageway is nearby.

The knowledge that animals follow linear structures is used extensively to guide animals to safe road crossings, when the original commuting route is severed by road construction. However, directing animals to a new point of crossing is a difficult task. Berthinussen & Altringham (2012a) noted that bats did not cross at the new safe crossing more than at their unmitigated traditional road crossings, even though a line of trees was planted towards the new crossing connecting it with the severed former commuting route. In a field experiment in Sweden, Christensen *et al*. (2015) placed a screen across a commuting route of Daubenton's bats (*Myotis daubentonii*) to force them to either fly up and continue their flight at a higher altitude or to move along the screen to another crossing. Interestingly, the bats did neither. They moved to another route that was already in use by other members of their colony. Van der Grift & Ottburg (pers. com. F. Ottburg) noted that of 800 individually marked Common toads (*Bufo bufo*) only 300 passed through an amphibian tunnel under a local road. Though screens were placed along the road on both sides of the entrance to the tunnel, many animals walked in the wrong direction when reaching the screen or returned back to their wintering habitat. These examples show that it is important to test or monitor wildlife over- and underpasses to find out if they are effective. In many cases the target species use mitigation measures but their effectiveness can be improved.

Wildlife-vehicle collisions (WVC) only occur when animals get on the road to cross it or for another reason (e.g. to scavenge on road kill or hunt for prey in the verge). Common toads (*Bufo bufo*) cross roads when the road dissects their migration route between their winter habitat and breeding habitat. For example, hotspots of herpetofauna road mortality on highways in New York State, USA, were located where wetlands approached within 100 m of the road, and the best predictor was a causeway configuration of wetlands (wetlands on both sides of the road) (Langen *et al*. 2009). Orłowski *et al*. (2008) noted the same results for amphibians in South-western Poland.

If there is no reason to cross (both breeding and winter habitat are on the same side of the road) WVCs will be absent or less. The studies of Ries *et al*. (2001) and Skórka *et al*. (2013) proved this for butterflies. Along verges with optimal habitat (lots of flowers) relatively less animals were killed compared to verges with suboptimal habitat. However, when the animals were disturbed (by mowing activity) WVCs increased (Skórka *et al*. 2015).

5 Intraspecific differences

5.1 Age, sex or behaviour dependent differences

Lizards and snakes are known to use the warm pavement of roads to thermoregulate, when the ambient temperature is low (Andrews *et al*. 2006). This makes them more prone to wildlife-vehicle collisions. However, the susceptibility of mortality on roads may vary among individuals. For example, gravid female black rat snakes (*Elaphe obsoleta*) tended to maintain higher body temperatures in order to thermoregulate more effectively and were more likely to use edge habitats along roads than males, juveniles and nongravid females (Blouin-Demers & Weatherhead 2001a, b). Female tortoises that lay their eggs in sandy verges are also more susceptible to road kill than male tortoises (Fahrig & Rytwinski 2009, Gvozdenović & Iković 2014).

Figure 5-1 Snakes, like this Viper (*Vipera berus*), sometimes sunbath on the carriageway to warm up in the morning (Photograph: Dennis Wansink).

It is not only the traffic that affects the sexes of animals differently. Light from roads near seacoasts with breeding sites of sea turtles can disrupt the normal behaviour of sea turtle females searching for appropriate nest sites and of hatchlings attempting to orient towards the ocean (Salmon 2006).

Intraspecific differences were also found in the preferences where to cross roads. Eighteen years of monitoring data of the use of under- and overpasses in Banff National Park, Canada, showed that female Grizzly bears (*Ursus arctos*) with cubs (i.e. family groups), as opposed to males and non-family groups, nearly exclusively used the largest crossing structures only (Barrueto & Clevenger 2015). In the previous chapter the research of Ascensão (2013) was mentioned who hypothesised that non-resident Beech martens are more likely to cross roads at ground level instead of using safe passageways and thus are more susceptible to wildlife-vehicle collisions. For Moose Beckmann *et al*. (2015) found differences in the locations where migratory and non-migratory animals cross a highway.

Interestingly, non-migratory Moose were more often involved in wildlife-vehicle collisions than migratory Moose, though the speed limit as well as the animal density at the crossing sites of the non-migratory Moose was lower than at the crossing sites of the migratory Moose.

5.2 Differences between locations

The importance of the factors and the direction of the effect may also differ between locations, regions or countries within a species. For example, Rytwinski & Fahrig (2015) found in their literature review that grey wolves in northern Wisconsin and upper Michigan, USA, respond negatively to increasing road density, while in northern Ontario, Canada, they respond positively. The difference may be due to the different road types in the two regions. In northern Ontario most roads are lightly used gravel logging roads, whereas in northern Wisconsin and Michigan, they are paved roads with higher traffic volumes. On the other hand it is also possible that populations of the same species in different regions react differently to a road, because of intrinsic differences. For example, calls of frogs and songs of birds living near roads are different from the calls and songs of their conspecifics living farther away from the road (Brumm 2004, Parris *et al*. 2009, Parris & Schnieder 2009, Lukanov *et al*. 2014).

It has also been shown that roads affect life history traits of animals that make them more adapted to life near roads than their conspecifics living away from roads. Brady (2012) found a strong negative effect on embryonic survival of Spotted salamanders (*Ambystoma maculatum*) in pools in northeastern Connecticut, USA. Both animals from pools near roads as well as animals from pools from roadless areas had lower survival rates in pools near roads than in pools in roadless areas. However, in pools near roads the animals from these pools had higher survival rates than their conspecifics from pools in roadless areas. On the other hand both populations had comparable survival rates in pools in roadless areas. This suggests that the response of species to human-altered environments varies across local populations, and that adaptive processes may mediate this response. It also suggests that results about the effects of roads on a species in one area/country cannot directly be applied to the same species in other areas/countries. In other words, though the factors that determine the presence of wildlife near roads are universal, the effect of the factors on a species is location dependent and may also differ between populations of the same species. Therefore, extrapolation of road effects for a species from one country or region to another should be carefully scrutinised.

6 The road network as facilitator of the spread of non-native species

Roads and other infrastructure can play a role in the spreading of both native and non-native species. For example, woodland and greenhouse (*Armadillidium nasatum*) species of pill-bugs (Isopods) were found incidentally in some Hungarian highways verges indicating the role of the human activity in the spreading. Most of the species were native, however some cosmopolitan species and one invasive alien species also occurred in the samples (Vona-Túri *et al*. 2013). Red imported fire ants (*Solenopsis invicta*) were detected on 21 of the 80 transects on the lower Florida Keys, US, and were equally abundant in all habitat types. While all of the development and road variables differed significantly between bait transects with and without red imported fire ants, transects that were closest to roads and that had the largest amount of development within a 150 m radius had the highest probability of presence of red imported fire ants (Forys *et al*. 2002). DeMers (1993) argues that roadside ditches acted as corridors for the range expansion of the Western harvester ant (*Pogonomyrmex occidentalis*) in North Dakota, US. In a study by Noordijk *et al*. (2006) the ground beetle species *Agonum sexpunctatum* did show a marked tendency to walk alongside the road, particularly in the ditch. In the same study individuals of *Poecilus versicolor* also seemed to have a preference for moving parallel to the road and walking in the ditch.

Though roads may facilitate the spread of invasive animal species because they are accidently transported by humans or follow roads themselves, there is no literature that roads create a favourable habitat for invasive animal species. On the other hand, non-native plant species that settle in roads verges or are seeded there to embellish the verge may affect the fauna composition in the verge in a negative way. Valtonen *et al*. (2006) noted that the abundance of butterflies was lower in verges with the invasive plant species Lupine (*Lupinus polyphyllus*) compared to non-lupine verges. As the lupine cover approached 100%, fewer butterflies were observed in lupine transects compared to the adjacent non-lupine transects. The probable cause was a lower species richness and diversity of flora in verges with Lupine. In particular, the cover and species richness of low growing (<20 cm) plant species was lower in verges with Lupine. Ries *et al*. (2001) also found that verges with non-native plants in Iowa had lower species richness than verges with native prairie plants, and the richness and abundance of butterflies was higher in the verge with native plant species. However, a study of Schilthuizen *et al*. (2016) showed that Black cherry (*Prunus serotina*), an invasive tree species from North America in Europe, harbours a herbivore community less dense but more diverse than its native relative, Bird cherry (*P. padus*), with similar proportions of specialists and generalists. Black cherry arrived in Western Europe at the beginning of the twentieth century. While the damage caused by plant-eating insects on Bird cherry remained stable over the past century, damage to Black cherry gradually doubled. For one leaf beetle, *Gonioctena quinquepunctata,* it was shown that it changed genetically when shifting its preference from the native European mountain ash (*Sorbus aucuparia*) to the Black cherry. Black cherry also changed. The plants in Western Europe produce less cyanide (to ward off plant-eating insects) than plants in their native range in North America. In other words, in the long run, evolutionary processes may generate a specialized herbivore community on an invasive plant, allowing prognoses of reduced invasiveness over time.

7 The conservation value of the road network

The results from this review show that roads and their components can fulfil ecological functions for wildlife. They provide food, shelter, breeding and hibernation sites and for some species a lifelong habitat. Moreover, not only common or opportunist species use roads, but also species that are nationally or internationally rare find habitat here. But does this mean that roads have conservation value? There are different levels to consider: species and community.

7.1 Conservation value at the species level

Verges can be a permanent habitat (for the whole life cycle) or just part of the home range of animal species. Species that spend their whole life cycle in verges are found among snails, crustaceans (pill-bugs), centipedes, springtails, insects, spiders, reptiles and small mammals (Vona-Túri *et al*. 2013, Schaffers *et al*. 2012, Sabino-Marques & Mira 2011). These species have small home ranges. Butterflies such as the Grizzled Skipper (*Pyrgus malvae*), Ilex Hairstreak (*Satyrium ilicis*), Silver-studded Blue (*Plebejus argus*), Scarce Large Blue (*Phengaris teleius*) and Small Pearl-bordered Fritillary (*Boloria selene*) require only 0.5 to 2 ha of their favourite habitat to live and reproduce (Wallis de Vries 2010). In a piece of a verge of only 750 m^2 Schaffer *et al*. (2012) found several species of ground beetles, spiders and weevils that went through their whole life cycle there. Home ranges of voles, shrews, hazel dormouse (*Muscardinus avellanarius*), slow worm (*Anguis fragilis*) and viviparous lizard (*Zootoca vivipara*) tend to be smaller than 0.5 ha, most of which can be within road verges (Wansink *et al*. 2013, Creemers & van Delft 2009, Edgar *et al*. 2010).

It is not only common or generalist species that are found in road verges. Several of the arthropod species inventoried in the Dutch verges by Noordijk *et al*. (2009) are classified as threatened: five grasshopper and eleven bee species appear on national Red Lists and six ant species on the IUCN Red List. Schaffers *et al*. (2012) found seven Carabid beetle species in road verges that are declining in the Netherlands. An analysis of sightings of reptiles in the Netherlands showed that of the seven species native in the country (all of them threatened) six were associated with road and railway verges (Creemers & Van Delft 2009). In a highly urbanised country railway and road verges are one of the few places where these species can find undisturbed habitat. As was shown earlier in this review, it is in certain circumstances where the road network offers better habitat conditions than the surrounding landscape that the road network has a conservation value. This seems to be especially true when road verges are less intensively maintained than the surrounding landscape. For example, captures of small mammals by Sabino-Marques & Mira (2011) in intensively grazed Mediterranean landscapes were 4.6-fold higher immediately beside roads and streams than 12 m away in the surrounding landscape. They concluded that roadside verges act as important refuges and constitute equally vital habitats for small mammals as do riparian vegetation strips in landscapes where other suitable habitats are scarce. De Redon *et al*. (2015) came to the same conclusion for verges along highways and roads around Paris, France. The relative abundances of Common vole (*Microtus arvalis*) and Millet's shrew (*Sorex coronatus*) in the verges were higher than in the neighbouring fields. Road verges that are less maintained than the surrounding area have a higher plant diversity and cover, resulting in more stable food resources, more shelter or less disturbed resting and breeding sites.

The above-mentioned relationship accounts for small animals whose home ranges can fit completely or for a large part in verges. For larger animals roads may increase their survival chances by offering a specific resource that is temporary not available within their home range or is more difficult to acquire in other parts of their home range, e.g. salt or fresh vegetation for Moose, road kill for Griffon vulture, sunny spots for snakes in forests, etc.,

In hostile landscapes road verges provide corridors to traverse the landscape if conditions in the verge are favourable. This allows resources on the opposite side of the hostile landscape to become available or new areas can be colonized making it possible for a species to survive in this otherwise unsuitable landscape. However, this is also true for invasive species. They follow infrastructure to colonize new areas or are spread by hitchhiking with vehicles. As described earlier non-native plant species may have detrimental effects on the animal species composition in road verges. Also, in some areas the presence of a natural barrier may have separated closely related species. The construction of a road forms a passageway through the barrier and may lead to the disappearance of the less competitive species or to a decrease in genetic variability within a species (Ligtvoet 1992, Delgado García *et al*. 2007).

In addition, when animals die as victims of vehicle collisions, which affects their reproductive success (e.g. nestlings die when parents die), one can wonder if the road really has conservation value. Also less direct impacts may make roads a less than optimal place to stay (stress hormones, genetic changes; Navarro-Castilla *et al*. 2014). On the other hand one can argue that for rare species whose habitat is disappearing due to intensive agriculture or urbanisation any place that substitutes this loss is welcome.

In conclusion, roads can have conservation value for a particular animal species, but it depends on the local situation near the road compared to surrounding areas and the severity of negative impacts of roads on the species at that location.

In general, when considering the issue of conservation value at species level one has to consider:

- The conditions in the surrounding landscape relative to the conditions near the road. What does the road add to the local species survival or abundance and does the presence of a road remove them from otherwise good places (create an ecological trap or a vacuum)? Improving the conditions along roads should not be an excuse to neglect possibilities for improvement farther away from roads.
- The detrimental impacts of roads. Is the species susceptibility to vehicle collisions, disturbance by sound and light, poisoning by heavy metals? Can these impacts be diminished?
- The spreading of invasive or competing species. What is the effect of invasive species on the native species? How can the spreading of invasive and competing species along roads be prevented or their negative effects be diminished?

7.2 Conservation value at the community level

Certain components of the road network can be surprisingly rich in animal species and numbers (Koivula *et al*. 2005, Noordijk *et al*. 2009, Schaffers *et al*. 2012, McCleery *et al*. 2015). Several studies showed that species richness within a species group (birds, small mammals) near roads was higher than farther away from the road. This was the case when the roadside had more diverse vegetation or a more diverse vegetation structure than the surrounding landscape. E.g., in forests roads create an open space with a clear edge. This has a positive effect on species with a preference for edges (Meunier *et al*. 2000, Blouin-Demers & Weatherhead 2001a, Helldin & Seiler 2003, Saarinen *et al*. 2005). Meunier *et al*. (1999) found species richness of small mammals was greater in extensively managed motorway verges than in the neighbouring intensive farmland and pine plantations, but there was no difference in the more diverse garrigue landscape. A positive effect on species richness by a contrasting and more diverse road verge compared to the surrounding landscape was also shown for birds (Meunier *et al*. 2000) and butterflies.

Comparing verges, it appeared that besides the presence or abundance of resources the width of the verge and traffic intensity are important factors. Species richness increases with verge width and decreases with traffic intensity. Verge width can diminish the effect of traffic intensity, but only to a certain extent. At a certain traffic intensity, effects reach too far beyond the verge to measure an effect of verge width.

The presence of a road can have cascading effects on wildlife, favouring some and being detrimental to others. In wet areas the elevated embankment of roads may offer dry places to breed or hibernate, but it also facilitates predators to find prey. E.g. within the Bear River Migratory Bird Refuge in northern Utah, USA, upland nesting habitats for ducks are limited to the levee banks and roadsides. Red foxes (*Vulpes vulpes*), Raccoons (*Procyon lotor*), and Striped skunks (*Mephitis mephitis*), that prey on upland nesting birds frequented these linear structures more often than places farther away, resulting in low duck production because of high rates of nest predation (Frey & Conover 2006).

Also a verge may be rich in species, but not in species of conservation concern. In vegetated central reservations of three Ring Roads around the city of Helsinki, Finland, Koivula *et al*. (2005) collected a total of 1512 individuals and 110 species of beetles. Ground beetles (Carabidae) were the most abundant beetle family, followed by rove beetles (Staphylinidae) and weevils (Curculionidae). As expected, most species collected were associated with open habitats, habitat generalists and capable of flight. The more rare habitat specialists or flight-less species were absent.

Another aspect to consider is the so-called 'vacuum effect'. Insects attracted by the light of street lanterns provide a food source for some toads, birds and bat species (Neill 1950 in Andrews *et al*. 2006, Jochimsen *et al*. 2004, Lacoeuilhe *et al*. 2014). Animals insensitive to light profit from this, but for others it may be detrimental. By aggregating around lit areas insects may be attracted away from dark areas creating a 'vacuum effect' (Eisenbeis 2006). The 'vacuum effect' may negatively affect bats by reducing prey availability for species that do not forage in lit areas (Stone *et al*. 2015). The effect is not the same for all lamp types (mercury, sodium-xenon, sodium etc.), but depends on wave length, intensity etc. Also the attractiveness of streetlights depends on the amount of other light sources in the surrounding, for example, during full moon the attraction by artificial light is less (Eisenbeis & Hänel 2009).

Summarizing, in monotonous landscapes the species community near the road, more specifically in the road verge, can be more diverse than the species community in the surrounding landscape. In the light of the global goal to preserve biodiversity this is good news, at first glance. However, if the community near the road consists mainly of common, non-threatened species one can question if this effect is desirable. Especially, when bearing in mind that the species richness depends on verge width, and a broader verge means that more of the original habitat is removed, leaving less space for potentially less common species. When also considering possible side-effects of roads, such as facilitating non-native or competing species to reach previously isolated places, or the above-mentioned 'vacuum effect', it is recommended to study the local situation first before taking measures to increase the species diversity near a road.

In general, considering the issue of conservation value at the community level one has to consider:

- What does the road (verge) add to the local species diversity? If the road crosses an intensive agricultural or urbanised landscape than it may have a positive effect offering habitat to rare species and increasing the local species richness. However, when the road crosses a sensitive habitat or a landscape with specialised or rare species then the impact of the road on this habitat or landscape should be minimised as much as possible, including diminishing the chances that competitive species can enter the sensitive habitat.

7.3 Conservation value of crossing structures

Crossing structures certainly have a conservation value, but only when they are combined with measures to prevent or diminish road kill. Modelling work by Jaeger and Fahrig (2004) showed that when the traffic volume is high and animals have a low chance of crossing the road alive direct mortality generally has a greater negative effect on wildlife populations than barrier effects caused by road or traffic avoidance (see also Summers *et al*. 2011). Jackson & Fahrig (2011) also showed that the vast majority of potential variation in genetic diversity is governed by depletion (mortality) rather than by barrier effects. In other words, fencing is a useful measure to increase the viability of a population near to a road. Crossing structures are actually only needed when animals have to go to the other side of the road, e.g. to reach necessary resources or for dispersal. If the necessary resource is (created) on the same side of the road, crossing structures are only needed for dispersal.

The effectiveness of crossing structures depends on species-specific requirements for the physical construction, but most importantly on their location. The passageways must be easy to find, which means preferably on an existing commuting route. Existing guiding structures must be kept intact or when newly constructed they must leave the animals no alternatives to cross the road at other places. If the latter is not possible, more crossing structures are needed.

Figure 7-1 A culvert used by Fire-bellied toad (*Bombina bombina*) to cross a highway in Hungary (Photograph Dennis Wansink).

So, when opting for crossing structures one has to consider:

- For which species is a crossing structure needed?

- Which function does the passageway have to fulfil for the target species? Is it to enable daily movements, for seasonal crossing for food, mating, hibernation, or for dispersal or (re)colonisation?
- What are the functional requirements of the target species in relation to the function the passageway has to fulfil? For example:
  - how does the species move (flying, walking, swimming, climbing etc.) and how far does it in general travel per day?
  - how does the species orientate?
  - what is its sensitivity to disturbance?
  - what is its vulnerability to predators?
  - does it need feeding or resting sites along the route of the passageway?
  - etc.
- What kind of barrier is needed to prevent animals of the target species from crossing at unsafe places?
- Is a crossing structure really needed or is it possible to preserve the local population by providing measures in the landscape surrounding the road?

8 Conclusions

Roads and their components can fulfil ecological functions for wildlife. Despite the dangers (e.g. wildlife-vehicle collisions) and detrimental effects on their well-being, animals venture near roads to eat, sleep, mate or even spend their whole life there. One theory is that animals flee to the road(side) because their habitat disappeared due to encroaching agriculture and urbanization. Though this is certainly true in many areas, some animals are attracted to road(side)s because the road offers resources that are easier to acquire or are of better quality than in the surrounding landscape.

From this review it also becomes clear that roads can have a positive effect on the biodiversity in the region. However, care should be taken about the impact of a more species rich road network on the existing species richness in the region. Increasing the species richness near a road should not lead to a decrease among the current habitat specialists or rare species. Of measures taken in the road network, the possible effects on the species community in the surrounding landscape should always be assessed.

It was noted that the effectiveness of mitigation measures (wildlife over- and underpasses) depends to a certain extent on their location in the landscape, notably on their position in relation to existing commuting routes. It was also noted that intra-specific preferences exists for the design of mitigation measures and that some groups, notably vagrants, may not use available mitigation measures at all. It is therefore necessary to consider in advance for which target species and for which function the mitigation measure will be build. The conclusion may be that a road crossing structure is not needed, and that optimizing the habitat of the target species in the surrounding area is more effective. In this respect it is interesting to note the finding of Ries *et al*. (2001) and Skórka *et al*. (2015) that higher species abundances near roads result in more road kill but that the proportion of wildlife vehicle collisions is less along roads with optimal habitat than along roads with suboptimal habitat; at least for species with small home ranges.

This review shows that the attractiveness of the road network to animal species depends on factors relative to the surrounding landscape, e.g. the presence of a resource. This ecological principle applies everywhere, but it is not possible to extrapolate road effects for a species from one country or region to another. The effect of the factors on a species is location dependent and may also differ between populations of the same species. When planning to develop a road network that has less detrimental effects on the natural value of an area or that actually contributes to the conservation of rare or threatened species one has to carefully consider:

- The conditions in the surrounding landscape relative to the conditions near the road. What does the road add to the local species survival or abundance and does the presence of a road remove them from otherwise good places (create an ecological trap or a vacuum)? Improving the conditions along roads should not be an excuse to neglect possibilities for improvement farther away from roads.
- The detrimental impacts of roads. Is the species susceptibility to vehicle collisions, disturbance by sound and light, poisoning by heavy metals, barrier effects etc.? Can these impacts be diminished?
- The spreading of invasive or competing species. What is the effect of invasive species on the native species? How can the spreading of invasive and competing species along roads be prevented or their negative effects be diminished?

These considerations have to be taken into account when designing new roads or retrofitting existing roads, but also when developing a maintenance strategy for the natural part of the road network (verges, resting sites, green bridges etc.).

Figure 8-1 Design and location are decisive factors enhancing the use of road components by wildlife. The text on this panel along a Dutch highway emphasises the coherence between the road and the surrounding landscape. An intelligent route design makes the Dutch landscape visible for the drivers. Mitigation measures diminish the negative impacts of roads on the landscape and the fauna (Photograph Floris Brekelmans).

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