CHAPTER 11: HABITAT AND CORRIDOR FUNCTION OF RIGHTS-OF-WAY

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1. Introduction

Roads, railroads and traffic can negatively affect plants, animals and other species groups (see reviews in Forman & Alexander 1998; Spellerberg 1998; van der Grift 1999). Transportation induced habitat loss, habitat fragmentation, reduced habitat quality and increased animal mortality can lead to serious problems for certain species or species groups, especially if they also suffer from other human-related disturbances such as large scale intensive agriculture and urban sprawl (Mader 1984; Ewing *et al.* 2005). Some species may even face local or regional extinction. However, other species or species groups can benefit from the presence of transportation infrastructure. Depending on the species and the surrounding landscape, the right-of-way can provide an important habitat or their only remaining functional habitat in the surrounding area. Rights-of-way may also serve as corridors between key habitat patches. The habitat and corridor function of rights-of-way can help improve the population viability of meta-populations of certain species in fragmented landscapes. This chapter aims to illustrate the habitat and corridor function of rights-of-way. While our focus is on roads, we include some examples of ecological benefits of railroads and railroad rights-of-way.

For this chapter we define the term "right-of-way" as the area between the edge of the road surface, which is usually asphalt, concrete or gravel, and the edge of the area that is not owned or managed by the transportation agency. In developed landscapes the latter usually coincides with a right-of-way fence and a change in land use, e.g. agricultural lands, gardens, or buildings (Figure 1). In undeveloped or less developed landscapes the far edge of the right-of-way usually coincides with a transition to native vegetation, e.g. native grasslands or forest (Figure 2). The vegetation in the right-of-way is usually disturbed as a result of road construction, alien soil, grading, seeding of native or non-native grasses and herbs to prevent soil erosion, trampling, dust and pollutants in air and water, mowing practices and the application of herbicides. The vegetated zone adjacent to the pavement is usually smooth and free from trees, shrubs, rocks or other large objects (e.g. higher then 10cm (4inches) above the ground) to allow drivers to regain control of their vehicle if they happen to run off the road. The width of this "clear zone" varies depending on the type of road, the speed limit and local conditions such as steep slopes that may not allow for the "ideal" clear zone width. However, in the United States the clear zone is often about 9-11m wide (about 30ft) (Forman *et al.* 2003). Depending on the climate, the clear zone may require regular mowing to prevent trees and shrubs from getting established. Regular mowing also allows drivers to see and read road signs. Furthermore, it improves the sight distance for drivers on the inside of curves and into the right-of-way so that they can see oncoming traffic, pedestrians or cyclists or large animals that may be present in the right-of-way (Rea 2003). A narrow zone immediately adjacent to the pavement may require a more intensive mowing regime, e.g. to prevent tall grasses and herbs from blocking reflectors that demarcate the road.

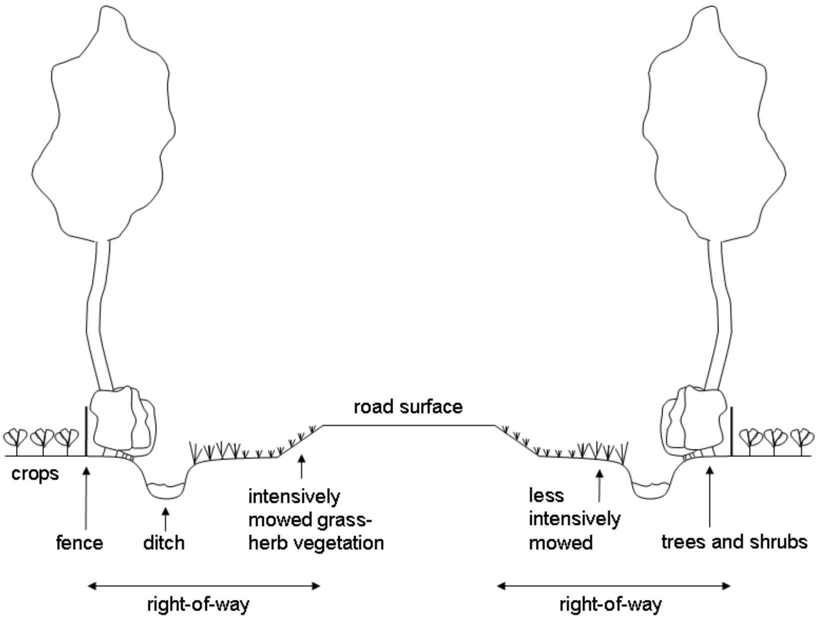

Figure 1. Cross-section of a road and its rights-of-way in a developed agricultural landscape.

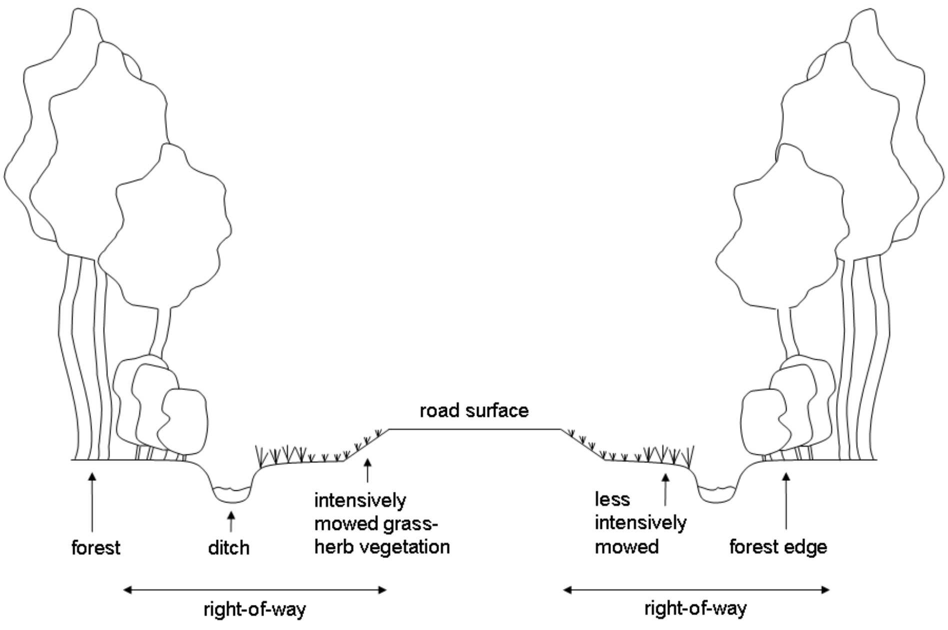

Figure 2. Cross-section of a road and its rights-of-way in an undeveloped forested landscape.

Rights-of-way vary greatly in width, but always run parallel to the road orientation by nature. Because most roads connect to other roads, right-of-ways can form extensive networks.
While there are many different types of rights-of-way and surrounding landscapes, we use the concept of rights-of-way in developed and undeveloped landscapes to illustrate different aspects of the habitat and corridor function of rights-of-way and how these may be valued.

2. Extent of road, railroad and rights-of-way networks

The density of the road and railroad network varies greatly between countries (Table 1). Not surprisingly, small and densely populated countries such as Belgium and The Netherlands have a relatively dense road and railroad network while larger countries with lower population density and vast regions with very low population density such as Russia and Australia have a relatively sparse road and railroad network. Nevertheless, the road density may be very high in densely populated regions of large countries as well, and the total length of road and railroad networks is enormous (Table 1).
The width of rights-of-way usually depends on the type of road, vehicle speed, and regional factors and may vary between just a few metres and a few hundred metres. For example, transportation corridors (road and rights-of-way combined) in some areas in Australia are up to 1,609m wide as they were originally designed for moving livestock from farms to water sources and towns (Spooner 2005a).
Estimates on the area covered by rights-of-way (excluding the road surface) are scarce, but they may cover 0.5-2.5% of a country or region’s land area (Table 1). While these percentages seem small, they may be substantial when compared with the percentage land cover of nature areas in densely populated countries or regions. For example, nature areas, excluding multi-functional forests, only cover 3.9% of the land in The Netherlands (CBS 2000), and road reserves in New South Wales, Australia, were estimated to occupy 80% of the combined area of national parks (Bennett 1991). This means that the potential of rights-of-way to enhance habitat availability and connectivity for some species may reach or surpass that of designated natural areas.

Table 1. Road, railroad and rights-of-way statistics[*1]. Total road density is for paved and unpaved combined. Total road and railroad density is per km^2 of land (excluding water).

Country	*Road length (km)*	*Railroad length (km)*	*Total road density (km/km^2)*	*Railroad density (km/km^2)*	*Road right-of-way area (ha) and % of land area*
Belgium	paved: 116,687 unpaved: 31,529	3,518	4.90	0.12	
The Netherlands	paved: 104,850 unpaved: 11,650	2,808	3.44	0.08	50,000-70,000 (1.5-2.1%) (Schaffers 2000)
Japan	paved: 534,471 unpaved: 627,423	23,705	3.10	0.06	
France	total [*2] 1,565,669	32,175	2.87	0.06	
Germany	total[*3]: 656,182	46,039	1.88	0.13	
United Kingdom	total[*2]: 365,232	17,186	1.51	0.07	212,220 (0.9%) for England, Scotland and Wales (Way 1977)
Spain	paved: 657,157 unpaved: 6,638	14,268	1.33	0.03	
India	paved: 1,517,077 unpaved: 1,802,567	63,140	1.12	0.02	
United States	paved: 4,148,395 unpaved: 2,257,902	228,464	0.70	0.02	±4,856,400 (0.5%) (Forman *et al.* 2003)
Brazil	paved: 94,871 unpaved: 1,630,058	29,412	0.20	<0.01	
Canada	paved: 497,306 unpaved: 911,494	48,909	0.15	<0.01	
China	paved: 314,204 unpaved: 1,088,494	70,058	0.15	<0.01	
Australia	paved: 314,090 unpaved: 97,513	44,015	0.11	<0.01	±500.000 (2.5%) for Victoria (Straker 1998)
Russia	paved: 358,833 unpaved: 173,560	87,157	0.03	<0.01	

[*1] CIA (2005); [*2] Trocmé *et al.* (2003); [*3] FHWA (2000)

3. Habitat function of rights-of-way

In this section two categories of the habitat function of rights-of-way are distinguished:

a. Partial habitat: individual animals may use the habitat in rights-of-way as part of their home range or they may use habitat in rights-of-way during part of their life cycle. Foraging, including mineral acquisition, mate searching, and reproduction are examples of the partial habitat function of rights-of-way.

b. Complete habitat: individual plants or animals may spend their entire life in the right-of-way, and rights-of-way may support viable populations of these species.

We give examples of the partial and complete habitat function that rights-of-way can have for various plant and animal species and species groups. The examples are grouped based on the particular function of the right-of-way and the species or species groups concerned.

3.1 PARTIAL HABITAT

The partial habitat function of rights-of-way implies that the individuals are mobile. Therefore the examples relate to animal species rather than plant species.

In agricultural landscapes in France flowering vegetation in the right-of-way can be an important source of nectar for butterflies (Ouin *et al.* 2004). However, in this study butterflies did not tend to stay long in the rights-of-way; they only used it as partial habitat and rested in others.

In French and Spanish agricultural landscapes diurnal raptors and owl species selected rights-of-way and perches in the rights-of-way when hunting for small mammals or other prey (e.g. Fajardo *et al.* 1998; Meunier *et al*. 2000). Corvidae (South Africa, United Kingdom, Canada) and bald eagles (*Haliaeetus leucocephalus*) and turkey vultures (*Cathartes aura*) (Canada; Yellowstone National Park, United States) have been reported to scavenge on road- and train-killed animals (Wells *et al*.1999; Gunther *et al*. 2000; Slater 2002; Dean & Milton 2003), and Corvidae, Columbidae, Anatidae have been observed eating grain spilled along a railroad (Wells *et al.* 1999). In forested landscapes edge and gap specialist bird species tend to be more abundant adjacent to roads than in forest interiors (Mumme *et al.* 2000; Laurance 2004). However, foraging on or near infrastructure also exposes birds to traffic which may result in high mortality (e.g. Fajardo *et al.* 1998). In some cases the habitat along a road may even form a population sink (e.g. Mumme *et al.* 2000; Ramsden 2004).

Grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), elk (*Cervus elaphus*), white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), red squirrel (*Tamiasciurus hudsonicus*), Columbian ground squirrel (*Spermophilus columbianus*) and unidentified mice species have also been attracted to grain spills along railroads (Wells *et al*. 1999). Mammals are also known to be attracted to roads to feed on road- or train-killed animals. Species observed scavenging along roads in the United Kingdom include domestic cats, Eurasian badger (*Meles meles*), western polecat (*Mustela putorius*), red fox (*Vulpes vulpes*) and western hedgehog (*Erinaceus europaeus*) (Slater 2002). Grizzly bear, black bear, wolf (*Canis lupus*), coyote (*Canis latrans*), wolverine (*Gulo gulo*), and American marten (*Martes americana*) have all been observed scavenging on train-killed animals in Canada (Wells *et al.* 1999). Grizzly bears and coyotes have been reported to scavenge on road-killed animals in Yellowstone National Park, United States (Gunther *et al.* 2000). As with birds, mammals that spend time on or along roads or railroads run increased risk of being hit by vehicles or trains (e.g. Conover *et al*. 1995; Groot Bruinderink & Hazebroek 1996).

Several Cervid species are known to forage on the vegetation in rights-of-way. Roe deer (*Capreolus caproelus*) in Denmark were especially attracted to the vegetation along roads when there was little food available on the surrounding agricultural lands (Madsen *et al*. 2002). In Pennsylvania (United States) white-tailed deer were seen grazing or lying along roads year-round, but their numbers were especially high in spring and fall (Bellis & Graves 1971; Carbaugh *et al*. 1975). The spring and fall peak may be related to deer activity patterns (e.g. migration, dispersal, rut, hunting), but it has also been suggested that the deer are attracted to the right-of-way vegetation itself. The vegetation along roads may start to grow earlier in the season (light, partially sloped towards sun) than in the surrounding forested habitats and it may also remain relatively succulent in the fall (Bellis & Graves 1971; Feldhamer *et al.* 1986). Relatively green and abundant vegetation along roads has also been reported from Australia (Lee *et al*. 2004). Run-off from roads and relatively high levels of nitrogen deposition (Angold 1997) may also help explain the sometimes relatively abundant and attractive vegetation in rights-of-way.

In Pennsylvania the right-of-way vegetation is thought to be especially attractive in forested areas and less so in areas surrounded by agricultural lands (Carbaugh *et al*. 1975). Allen and McCullough (1976) suggested that white-tailed deer are mainly attracted to the vegetation in rights-of-way when foraging opportunities in the surrounding landscape are poor. Foraging of white-tailed deer on the vegetation in rights-of-way has also been reported from British Columbia, Canada (Kinley *et al.* 2003). Other species, including mule deer and black bear have also been reported foraging on the vegetation along roads and railroads (Lehnert & Bissonette 1997; Wells *et al*. 1999). Fabaceae (e.g. clovers (*Trifolium sp.*), alfalfa (*Medicago sativa*), vetches (*Vicia sp.*)) seem to be particularly attractive (Carbaugh *et al*. 1975; Wells *et al*. 1999).

Run-off of road salt used for de-icing may accumulate in low-lying areas along a road (Miller & Litvaitis 1992). This seems to be an important source of sodium for moose (*Alces alces*) in New Hampshire, United States, which are attracted to the salt in rights-of-way (Miller & Litvaitis 1992).

In the Midwest (e.g. Illinois, Iowa) of the United States most of the original prairie has been converted to intensively managed crops such as corn and soybeans. Rights-of-way are now among the few remaining open areas with a mixture of native and non-native grass and herb species. These rights-of-way have become very important to grassland birds for nesting and foraging (Warner 1992; Camp & Best 1993). However, traffic noise can cause bird species to avoid nesting close to roads (Reijnen *et al*. 1996) and remnant habitat strips away from a road may host more bird species than rights-of-way with similar vegetation (Bolger *et al*. 2001). Rights-of-way may also form nesting habitat for threatened or endangered mammal species in agricultural lands. In Europe hamsters (*Cricetus cricetus*) now often make their nests in rights-of-way, especially if the adjacent farmlands are ploughed deeply and frequently (Nechay 2000).

As illustrated above, various animal species and species groups use rights-of-way for nesting or foraging on vegetation, animal carcasses, minerals, or human caused food spills along transportation corridors. However, transportation corridors may also function as shelter. For example, in Alaska, caribou (*Rangifer tarandus*) walk, stand and run on gravel roads, apparently to seek relief from oestrid flies as the flies avoid the non-vegetated gravel roads (Noel *et al.* 1998).

3.2 COMPLETE HABITAT

The complete habitat function of rights-of-way implies that the individuals can be either sedentary or mobile. Therefore the examples relate to both plant and animal species.

Rights-of-way can be important relicts for plant communities or individual plant species if the surroundings are mostly developed and characterised by intensive large-scale agriculture or urban sprawl (Cousins & Eriksson 2001). The vegetation of interest is often a grassland community (e.g. Sýkora *et al*. 1993; Tanghe & Godefroid 2000; Tikka *et al*. 2000; Ries & Debinski 2001), but relatively wide rights-of-way, such as the ones in some parts of Australia, can contain substantial remnants of native forests (Bennett 2003; Spooner *et al.* 2004a). Rights-of-way can also be one of the last remaining growing sites for rare or endangered plant species (e.g. Godt *et al*. 1997; Yates & Broadhurst 2002; van Rossum *et al*. 2004).

Despite the conservation value that some plant communities in rights-of-way have, they may lack certain rare or indicative species when compared with natural or semi-natural habitats away from infrastructure. In addition, vegetation management (e.g. inappropriate mowing regime, herbicides), trampling, and air and water pollution can result in unfavourable conditions for the plant community or individual plant species (Liem *et al*. 1985; Tikka *et al.* 2000; Bryson & Barker 2002; Swaileh *et al.* 2004). On the other hand, the disturbance and specific environmental conditions in rights-of-way may allow other plant species to thrive (Dunnett *et al.* 1998). These may include invasive and non-native species (e.g. Wilcox 1989; Tyser & Worley 1992; Parendes & Jones 2000), and also species that are tolerant of, for example, trampling, road salt or heavy metals (e.g. Scott & Davison 1985; Sýkora *et al.* 1993; Yorks *et al*. 1997; Welch & Welch 1998).

Some animal species can also thrive in rights-of-ways. Invertebrate numbers were found to be highest within the first 5m away from a gravel road by Luce and Crowe (2001). Edge effects and a gradient in environmental conditions may help explain these high numbers, but it seems that the relatively high nitrogen levels along high volume roads play an important role too, as they lead to increased plant productivity (Port & Thompson 1980; van Schagen *et al.* 1992; Angold 1997). Defoliating larvae of moth species are even known to reach outbreak proportions along roads in the United Kingdom and Australia (Port & Thompson 1980; van Schagen *et al.* 1992). Other invertebrate species may benefit from other resources. For example, the species richness of ants in rights-of-way is higher than in adjacent rangeland, and rights-of-way also contain more rare species (Samways *et al*. 1997; Tshiguvho *et al.* 1999). Possible explanations include relatively low grazing pressure from large herbivores, relatively high moisture levels because of run-off from the road surface and greater variation in temperature because of slopes (Tshiguvho *et al*. 1999). However, the availability of food in the form of road-killed animals is also believed to be an important factor for ants (Samways *et al*. 1997; Tshiguvho *et al.* 1999). Depending on the vegetation and management practices, rights-of-way can also host a large and diverse butterfly population (Munguira & Thomas 1992; Ries *et al*. 2001). A certain mowing frequency and vegetation structure may not only promote plant species that provide nectar, but also create a habitat in which some butterfly species live and reproduce (Munguira & Thomas 1992; Ries *et al*. 2001).

In agricultural landscapes, right-of-way vegetation can form an important and complete habitat for small mammals (van der Reest 1992; Bellamy *et al*. 2000). The species richness and abundance of small mammals in rights-of-way may be similar to or higher than in similar habitat away from roads in agricultural fields (Adams & Geis 1983; Bellamy *et al.* 2000; Bolger *et al.* 2001). However, vegetation structure and mowing frequency influence the quality of the habitat (Adams 1984). Relatively wide and forested rights-of-way can provide a complete habitat for a wide range of mammal species (Downes *et al*. 1997).

4. Corridor function of rights-of-way

In this section three categories of the corridor function of rights-of-way are distinguished:

1. Home range movements: animal species may travel within rights-of-way as part of their movements within their home range.
2. Spread: plant or animal species may spread in rights-of-way over relatively short distances, e.g. through occupying growing sites or habitat adjacent to their original location.
3. Dispersal: plant or animal species may disperse in rights-of-way over relatively long distances. The seeds or animals may move in the rights-of-way but skip potential growing sites or travel many times the diameter of an average home range before reaching their final destination, either in the right-of-way or in a key habitat patch away from infrastructure.

We give examples of these three corridor functions for rights-of-way for various plant and animal species and species groups.

4.1 HOME RANGE MOVEMENTS

Home range movements imply the movements of individuals. Therefore the examples relate to animal species rather than plant species.

A butterfly species in a right-of-way in Iowa, United States, responded strongly to edges such as tree lines and tended to stay within the right-of-way (Ries & Debinski 2001). This suggests that the individuals moved mostly within the rights-of-way. However, the response to edges was reduced at low butterfly densities, and another butterfly species did not respond when edge habitat was encountered.

In Victoria, Australia, forested rights-of-way were part of the home range for southern brown bandicoot (*Isoodon obesulus*), long-nosed potoroo (*Potorous tridactylus*) and bush rat (*Rattus fuscipes*) (Bennett 1990). They used these linear landscape elements in addition to the larger forest patches. In south-east Australia, squirrel gliders (*Petaurus norfolcensis*) made their home ranges in forested rights-of-way (Van der Ree & Bennett 2003). Their home ranges were relatively small, indicating high quality habitat. In The Netherlands, road-killed hedgehogs (*Erinaceus europaeus*) were associated with road-railroad intersections (Huijser *et al*. 2000). This suggests that the hedgehogs travelled along railroads, either because they perceived the railroads as a barrier, or because they travelled in the vegetation along the railroads. In the United Kingdom, railroad rights-of-way are used by the red fox (*Vulpes vulpes*) (Trewhella & Harris 1990). The rights-of-way may influence red fox movements within their home ranges, but they appeared to have little effect on the distance or direction of dispersal movements. Bison (*Bison bison*) sometimes travel along roads in Yellowstone National Park, United States, but this type of use did not increase as a result of snow removal and grooming for snowmobiles (Bjornlie & Garrott 2001). Most movements along roads (61%) were less than 1km, but 12% were 5km or more.

Roads with low traffic volume may be attractive to predators as easy travel routes and provide greater access to prey (Thurber *et al*. 1994, James & Stuart-Smith 2000). In Nova Scotia, Canada, lynx (*Lynx canadensis*) followed road edges and forest trails for considerable distances (Parker 1981) and similar observations were made during winter for lynx in Washington State, United States, for roads less than 15m wide (Koehler & Brittell 1990).

4.2 SPREAD

A wide range of non-native plants were almost completely restricted to rights-of-way along roads, streams and clear cuts in Oregon, and along roads in Utah, United States (Parendes & Jones 2000; Gelbard & Belnap 2003). Disturbance, traffic and light were all associated with higher occurrence of these non-native plants. The spatial pattern suggested that the non-native plant species had spread in the rights-of-way. In New York, United States, the occurrence of a non-native plant, purple loosestrife (*Lythrum salicaria*), was investigated along a road (Wilcox 1989). Again, the spatial pattern suggested that purple loosestrife was spreading in the right-of-way, in this case from east to west. However, the species was believed to spread mostly through the transport of seeds in the water in the ditches in the rights-of-way.

In Australia non-native cane toads (*Bufo marinus*) were found to have relatively high density in rights-of-way, travelling on the road and in the right-of-way, especially along roads through rainforest (Seabrook & Dettmann 1996). The concentration of the cane toads in rights-of-way suggested that cane toads use rights-of-way to spread and expand their range.

The meadow vole (*Microtus pennsylvanicus*) expanded its range by 90-100km in about six years in Illinois, United States (Getz *et al*. 1978). The vole used the 5m wide dense grassy verges along recently constructed interstates. Bait removal rates along roads through forests on the island of Tenerife, Canary Islands, suggest that the non-native black rat (*Rattus rattus*) forages mainly along roads and that this may have enabled the species to spread (Delgado *et al.* 2001).

4.3 DISPERSAL

In a forested landscape in Finland, sites in rights-of-way that were several hundreds of metres to several kilometres apart were more similar than one would expect based on seeding of right-of-way vegetation and spatial autocorrelation (Tikka *et al.* 2001). The results suggest that grassland species dispersed along roads and railroads. Non-native and salt tolerant plant species in The Netherlands, Finland, United Kingdom, Canada and the United States are also known to have dispersed along roads and railroads (Scott & Davison 1985; Brunton 1989; Ernst 1998). Seeds in rights-of-way can be transported by water in roadside ditches (Wilcox 1989), crows, primates, cows or horses (Dean & Milton 2000; Campbell & Gibson 2001; Pauchard & Alaback 2004), mowing equipment (Strykstra *et al*. 1997), cars (Schmidt 1989; Lonsdale & Lane 1994) or trains (Brunton 1989; Ernst 1998). However, not all studies have been able to demonstrate spread or dispersal of non-native plants along roads (e.g. Harrison *et al*. 2001). In addition, depending on the dispersal capacity of the species and the width of the right-of-way, dispersal may be slow (van Dorp *et al*. 1997).

Dispersal distances for heathland carabid beetles in rights-of-way in The Netherlands were rather limited (Vermeulen 1994). The beetles dispersed up to 50-150m per year. In Germany, the cinnabar moth (*Tyria jacobaeae*) colonised a new area using linear landscape structures including rights-of-way along roads (Brunzel1 *et al.* 2004).

Multiple translocated hedgehogs in the United Kingdom favoured edge habitat and other linear habitats, including roads, when dispersing up to 3.8km from their release points (Doncaster *et al.* 2001). In Australia, dispersal (1.1km) between forest patches through a forested corridor along a road has been demonstrated for the long nosed potoroo and the bush rat (Bennett 1990). The Australian sugar glider (*Petauru breviceps*) was also found to disperse in a forested right-of-way, only several trees wide (Suckling 1984).

5. Factors affecting the quality of rights-of-way as a habitat or corridor

Right-of-way characteristics, both intrinsic and extrinsic, not only influence what species use rights-of-way, but they also have an effect on the quality of the habitat and corridor function of rights-of-way. These characteristics include traffic volume, the width of right-of-way habitat, whether the right-of-way is managed and how, the amount and type of disturbance to the right-of-way habitat, and the habitat adjacent to the right-of-way. In this section, we describe these features and how they may influence the quality of rights-of-way as habitat or corridor for a range of plant and animal species.

5.1 TRAFFIC VOLUME

Butterflies are known to be sensitive indicators of environmental change associated with natural and human-induced disturbances (Hogsden & Hutchinson 2004). Saarinen *et al*. (2005) studied butterfly and diurnal moth communities along Finnish roads with similar environmental conditions but varying in road size and traffic volumes. They found that species richness and total abundance of butterflies and moths were similar in each road type and not affected by traffic volume. Similarly, traffic levels had no apparent effect on butterfly and burnet (Zygaenidae) populations on rights-of-way in the United Kingdom (Munguira & Thomas 1992).

Traffic volume may affect the activity patterns of some sensitive raptor species. The occurrence of three raptor species along rights-of-way in southeastern Spain diminished on weekends associated with high traffic volumes compared with weekdays with relatively low traffic volumes. However, for six other raptor species the amount of traffic had no effect on occurrence. Potential explanations were noise, visual disturbance and prey concealment (Bautista *et al*. 2004). Similarly, little owls (*Athene noctua*) were found foraging in rights-of-way when traffic volumes were lowest (Fajardo *et al.* 1998). However, this is probably best explained by their nocturnal behaviour rather than a response to traffic levels.

5.2 WIDTH OF RIGHTS-OF-WAY

Wider rights-of-way result in larger areas that usually provide greater habitat and vegetation diversity, with more and diverse breeding habitats and food supply for certain animal species.

There is a tendency for butterfly diversity to increase with the increasing width of the verge, from the narrow verges of rural roads to wider rights-of-way along highways. The highest number of meadow species was recorded along highways and the total abundance, particularly diurnal moths, decreased in line with decreasing road size along Finnish roads (Saarinen *et al*. 2005). Similarly, the density of adults and number of species were positively correlated with right-of-way width in the United Kingdom (Munguira & Thomas 1992). Broad corridors can also result in fewer losses of individuals to the surroundings and longer dispersal distances (Vermeulen & Opdam 1995).

Meunier *et al.* (2000) surveyed the relative abundance and activity of diurnal raptors along motorways and secondary roads in agricultural landscapes of western France. They found that kestrels (*Falco tinnunculus*) and buzzards (*Buteo buteo*) used rights-of-way for hunting and their abundance was directly related to the width of right-of-way habitat and availability of perch sites. Width of right-of-way habitat was also shown to influence positively the number of field voles (*Microtus agrestis*) and wood mice (*Apodemus sylvaticus*) along roads in the United Kingdom (Bellamy *et al*. 2000).

5.3 MOWING AND HERBICIDES

There are many reasons why roadsides are managed, e.g. to maximise human safety, enhance visual quality, control non-native species, enhance biodiversity, or reduce erosion and sediment flow (Forman *et al.* 2003). To manage right-of-way areas, transportation agencies often delineate roadside zones, each having a different management regime. In Washington State, United States, Zone 1 is closest to the road (usually <4m from the edge of the pavement) and usually kept bare and clear of vegetation unless the vegetation is not a fire hazard, does no damage to the pavement and does not obscure visibility. Zone 2 (usually <9-11m from the edge of the pavement), is often referred to as the “recovery zone” and is managed so that vehicles that have run off the road can recover. This zone is kept clear from objects >10cm (4inches) in height. Zone 3 is farthest from the road and normally abuts utility access and neighbouring land use (agricultural, residential, public etc). The management of these zones and the activities within them influence the quality of rights-of-way as habitat and corridors for plant and animal populations. Roadside mowing not only weighs heavily on maintenance budgets, but it also requires important decisions regarding time, space and intensity because of the ecological consequences. Regular mowing can affect normal periods of vegetation growth, flowering of plants, genetic diversity of certain plant species, attractiveness of plants to pollinators, pollination of flowering plants, nesting and denning opportunities for various animal species, and shelter from late or early frosts (Godt *et al.* 1997; Forman *et al*. 2003).

Less frequent mowing is less costly and can enhance plant species diversity, whereas frequent mowing usually favours a few grass species that out compete more diverse native plant species. On the other hand, frequent mowing (e.g. once in spring and once in autumn) in combination with hay removal can eventually deplete the soil of nutrients. In some rights-of-way in The Netherlands this has resulted in a reduction of the productivity and biomass of the right-of-way vegetation, allowing smaller plant species characteristic of relatively nutrient poor conditions to re-establish or increase in abundance (Sýkora *et al.* 1993). As the soil is depleted and right-of-way vegetation productivity reduced, mowing frequency can be decreased to less than it was before more intensive mowing began. Thus, in the long run the conservation value of the vegetation in the right-of-way can be increased and mowing frequency reduced. However, the timing of mowing needs to be carefully planned based on the phenology of the species of interest. Furthermore, it is important to remove the hay within one or two weeks of mowing to prevent leaching of nutrients back into the soil (Schaffers *et al*. 1998). However, immediate hay removal may not allow sufficient seeds to ripen and fall from the cuttings; this should be weighed against minimising the leaching of nutrients.

High nectar abundance has been shown to be the most important factor increasing the numbers of meadow butterflies along road verges (Munguira & Thomas 1992; Dover *et al*. 2000; Croxton *et al*. 2005; Saarinen *et al*. 2005). However, mowing and herbicides can suppress flowering and density of nectar plants. The most intensively mowed rights-of-way generally have the shortest vegetation and lowest amount of nectar, which together result in decreased butterfly abundance (Gerell 1997; Saarinen *et al*. 2005). Ries *et al*. (2001) demonstrated that roadside native prairie restoration involving vegetation management with restricted use of herbicides can benefit butterfly populations. They found species richness of habitat-sensitive butterflies was two to five times greater on restored sites and butterflies spent more time on restored rights-of-way and were also less likely to leave them, thus suggesting the rights-of-way were being or could be used as corridors. In order to enable the restoration and expansion of two reintroduced myrmecophilous butterflies in The Netherlands (*Maculinea teleius*, *M. nausithous*) road verges and canal borders were targeted and management practices changed to enhance the development of rough vegetation where the specific host ant species occurs (Wynhoff *et al*. 2000).

Road rights-of-way and central medians are often good habitat because of greater food and cover for herbivorous animals compared with neighbouring habitat outside of these areas. Cover is usually higher when the right-of-way and median habitat are not mowed but allowed to grow wild (Adams 1984; Meunier *et al*. 1999a). Road mitigation projects that include wildlife fencing can result in an effective “exclosure” for ungulates on the highway side of the fence. This can result in high quality habitat and enhancement of existing habitat through abundant forage and cover for smaller fauna (e.g. small mammals). In an extensive study carried out along the United States interstate highway system, Adams and Geis (1983) found that there were more small mammal species present and in higher densities on the right-of-way than in adjacent habitat. Their results also indicated that right-of-way habitat and its accompanying edge were attractive not only to grassland species but also to many generalist species that make use of the right-of-way and the edge with the adjacent habitat complex. At six interchanges along a highway in Ottawa, Canada, the density of woodchucks (*Marmota monax*) per hectare exceeded any density previously reported for this species in any habitat (Woodward 1990).

In Sweden, shrub and tree clearing in rights-of-way has reduced moose-vehicle collisions by 20% (Lavsund & Sandegren 1991). When trees and shrubs were removed along a railroad and sprayed with herbicides to prevent re-growth, this led to a 40-72% reduction in moose-train collisions (Jaren *et al*. 1991). Rea (2003) suggested that right-of-way shrub and tree cutting in the early season, just after their leaves have sprouted, would help to minimise right-of-way attraction to moose. Cutting later in the season promotes regrowth, which may be an attractant to moose.

5.4 SOIL DISTURBANCE AND BURNING

A number of studies focused on the effects of disturbance from heavy equipment on plant populations (Webb *et al*. 1983; Olander *et al*. 1998; Milchunas *et al.* 2000). Roadwork and the associated disturbance to the right-of-way and surrounding habitat are considered a major threat to native plants in roadside environments (see Godt *et al.* 1997). In addition, disturbance facilitates invasion of non-native plant species (Greenberg *et al*. 1997; Parendes & Jones 2000). Further, roadwork promotes spread and dispersal of non-native species by providing suitable linear habitat. Roads and railways are well known sites for non-native plant invasions (Borowske & Heitlinger 1981; Wilcox 1989; Tyser & Worley 1992; Gelbard & Belnap 2003; Hansen & Clevenger, in press).

For some native plant species, soil disturbance from roadwork is analogous to periodic disturbance from a natural fire regime or other natural disturbance events. The importance of disturbance processes in shaping the spatial structure and temporal dynamics of ecological systems has been reviewed by White and Pickett (1985) and Hobbs (1987). The effects of natural and anthropogenic disturbances on plant populations also depend on complex interactions between the life history attributes of individual species, and the spatial and temporal structure of the disturbance regime (Spooner *et al.* 2004a). Anthropogenic disturbance from roadwork, in conjunction with historical changes in grazing pressure, are suggested as the main causes of increased recruitment for some *Acacia* species in rights-of-way in Australia (Spooner *et al*. 2004b). Ongoing management and disturbance regimes in roadside environments may even be critical to the persistence of some *Acacia* species and associated fauna habitat (Spooner 2005b). Frequent and intensive soil disturbance regimes appear to favour *Acacia* species that have strong re-sprouting ability, whereas *Acacia* species that are obligate seeders may be eliminated from roadside environments unless disturbance regimes are less frequent (Spooner 2005b).

Prescribed burning is one of the most important management tools in grassland areas (Engle & Bidwell 2001) and is commonly used to control the spread and establishment of non-native plants. However, fire can also increase non-native plants. In sclerophyll woodlands along highways in south-western Australia, fire enhanced the spread of weeds into the remnant right-of-way habitat (Milberg & Lamont 1995). They found that the number of weed species, their frequency, and cover increased after the fires, while the abundance of native species often decreased. Fire also caused the non-native Coolatai grass (*Hyparrhenia hirta*) to increase in south-eastern Australia (McArdle *et al*. 2004). In contrast, two rare *Acacia* species occur now mostly in Australian rights-of-way and depend on fire for germination (Yates & Broadhurst 2002).

Fires in grassland habitats like rights-of-way are known to affect bird abundance, distribution, nesting success and predation (Zimmerman 1997; Kirkpatrick *et al*. 2002). Burning can also cause changes in vegetative cover and arthropod abundance (Swengel 2001). Shochat *et al.* (2005) found that prescribed burning of right-of way vegetation increased bird nest success after the fire, possibly through an increased arthropod biomass on the re-growth. Similar results came from a study of bird density and nesting success on utility rights-of-way. Cool burns in early spring produced high structural diversity of herbs, shrubs and trees and supported a high density of birds and bird species (Confer & Pascoe 2003).

5.5 VEGETATION STRUCTURE & SURROUNDING LANDSCAPE

The composition of the landscape and vegetation structure along rights-of-way can have a strong effect on the quality of the right-of-way as habitat or corridors for many species. For example, tree lines along grassland habitat may be important for directing the movement of certain butterfly species (Ries & Debinski 2001). Saarinen *et al.* (2005) found high nectar abundance was the most important factor increasing meadow butterflies along road verges. However, for diurnal moths shelter provided by tall vegetation was the most important factor increasing their numbers (Saarinen *et al.* 2005), and the number of food plants is not always the most limiting factor for the presence of butterflies either. In The Netherlands, sections of motorway that were mowed twice a year appeared to have the highest diversity and density of nectar plants, but butterfly density was highest in right-of-way sections with a mowing frequency of only once every three years (Bak *et al.* 1998). High butterfly density occurred where there was relatively low diversity and density of nectar plants. The authors concluded that butterfly presence in their study area was most related to vegetation structure and favourable microclimate rather than food plants.

Meunier *et al.* (1999b) found that the structure of vegetation (trees and shrubs) was the most important factor influencing bird species richness along rights-of-way in France. In Central Amazonia, the height and density of forest re-growth markedly affected road-crossing movements by understorey rainforest birds (Laurance *et al*. 2004). In that study, clear differences were observed among different bird guilds, and species within the same guild often responded very differently to roads; even narrow dirt roads had large effects on some bird species movement. These authors recommended that land managers encourage forest regeneration along road verges and establish continuous canopy cover over road surfaces to facilitate movements of edge- and gap-avoiding species.

Small mammals on rights-of-way in the United Kingdom had affinity for tall vegetation, big hedges, and cover (Bellamy *et al*. 2000). Vegetation structure on road verges and adjacent habitat may also strongly influence road-crossing movements by mammals. Studies have shown that bears tend to prefer crossing roads at places where vegetation is most dense close to the road (Brandenburg 1996; Chruszcz *et al*. 2003).

Above we described how the structural complexity and type of vegetation along rights-of-way may influence the quality as habitat or corridors for many taxa. However, the habitat type and conditions adjacent to rights-of-way also strongly influence plant and animal distribution, abundance, and movements along or across roadway corridors. Thus, the surrounding landscape is also an important factor in assessing the habitat and corridor function of rights-of-way.

In Finland, the environment adjacent to the right-of-way had an effect on the species composition of butterflies (Saarinen *et al*. 2005). The authors studied three road types. Rights-of-way surrounded by cultivated fields were generally associated with low numbers of butterflies, whereas adjacent forests increased the total number of all species and favoured several butterflies inhabiting forest edges. Their results indicated that road verges should be considered as an important reserve for species that were dependent on semi-natural grasslands. The same was true in the United Kingdom, but here the abundance and diversity of butterflies was not correlated with adjacent habitats (Munguira & Thomas 1992). Beetle assemblages have also been found to depend on adjacent crops and have seasonal fluctuations in right-of-way habitats (Varchola & Dunn 1999).

Shrubland bird density and nesting success on utility rights-of-way in forested habitat were high compared with other habitat types (Confer & Pascoe 2003). However, the composition of the surrounding landscape can also affect nest predation levels in road-side habitat (Bergin *et al*. 2000).

Meunier *et al*. (1999a) specifically investigated the effects of surrounding landscape type on the use of motorway rights-of-way by small mammals. In farmland landscapes they found that perturbations from agricultural activities (ploughing, harvesting etc.) largely explained the relative abundance of small mammals in rights-of-way. Other studies documented that mice inhabit crops for most of the year but take refuge in field margins and right-of-way habitats during intensive harvesting and when the fields are bare (Tew *et al*. 1994; Fitzgibbon 1997).

6. Potential problems

Throughout this chapter we have described the habitat and corridor function of rights-of-way and factors that influence the abundance and movements of a wide range of taxa. While rights-of-way can be beneficial to many species they also have the potential to lead to harmful effects as some animal species may experience consistently high rates of mortality, sometimes exceeding recruitment, and rights-of-way allow certain non-native species to establish themselves and spread along the right-of-way and into the surrounding landscape.

6.1 ROAD KILL AND POPULATION SINK

Several studies demonstrated that roadside territories can become population sinks and that young or inexperienced individuals are more vulnerable to road-related mortality as they tend to live closer to roads. In a 9-year study of Florida scrub jays (*Aphelocoma coerulescens*), Mumme *et al*. (2000) found that scrub jay habitat adjacent to highways was a demographic sink in which breeder mortality exceeded production of yearlings by a wide margin, and the scrub jays persisted only because of immigration from non-road territories. Road-naive immigrants that established roadside breeding territories suffered high annual mortality during their first two years as breeders, in many cases not surviving long enough to attempt nesting. The mortality of breeders and fledglings on road territories was caused by traffic and not by road-related habitat modifications.

However, two studies from The Netherlands showed that willow warblers (*Phylloscopus trochilus*), with greater experience or age, learned to avoid roads (Foppen & Reijnen 1994, Reijnen & Foppen 1994). They found that breeding territory densities were lower near busy highways and road zones were occupied primarily by first-year males that often bred unsuccessfully, and in subsequent years actively moved away from the highway.

Several populations of grizzly bears showed sex-related variation in habitat use adjacent to roads. Gibeau *et al*. (2002) found that sub adult male grizzly bears were found closer to highways than all other age and sex classes, when within or adjacent to high quality habitat near roads. He believed that social structure in grizzly bears was a large factor in explaining this result. Other grizzly bear studies have shown that cohorts of subordinate bears were found in poorer quality habitats near developments and displaced by more dominant classes, particularly adult males (Mattson *et al.* 1987; McLellan & Shackleton 1988). Thus, certain sex and age groups may be more vulnerable to traffic mortality than others.

Roads, their construction, and adjacent rights-of-way can create high-quality habitat where food resources are more abundant compared with adjacent areas. Lush forage along medians and verges created by exclusion fencing is attractive to herbivores. Locally abundant small mammal populations found in these habitats become targets for predators seeking easy and accessible prey, but the right-of-way habitat may also become a population sink for these predators (e.g. Ramsden 2004). In extensively forested areas the right-of-way created by the road corridor may be one of few open habitats around. This is the first place that grass will green up after winter (attracting ungulates) and is ideal for dandelions (*Taraxacum officinale*) and fruit-bearing shrubs that appeal to a variety of fauna, including bears. With herbivores grazing and predators hunting near the road, collisions with vehicles are inevitable, resulting in attractive carrion for avian and terrestrial scavengers, if carcasses are not removed promptly.

As opposed to what we have seen above, where road-side habitat is attractive to wildlife, there are some examples where animals are drawn to the actual road surface and the vehicles that travel on it. On roads requiring snow removal and the application of salt-based de-icing agents, problems arise during and after winter when mineral-deficient ungulates come to the road gleaning salt from the edge of the road and cracks in the pavement (Fraser & Thomas 1982). In warmer climes, reptiles that come to the road surface to bask during the day or thermoregulate at night quickly become road-kills and ultimately carrion for scavengers (Rosen & Lowe 1994; Kline & Swann 1998). Lastly, humans feeding wildlife from vehicles, food discarded from motorists while travelling, unsecured garbage containers along roads, or dead invertebrates on the grille or window of vehicles can be an easy, predictable source of food for wildlife such as coyotes, bears, corvids, grackles (*Quiscalus sp.*), house sparrows (*Passer domesticus*), squirrels, and raccoons. In 1997 there were more than 80 “bear jams” (traffic snarls caused by motorists stopping to look at bears) reported along roads in Banff National Park, Alberta, Canada (Pilkington 1997). This exposure to people and anthropogenic food sources results in bears becoming food-conditioned, habituated to humans, road-kills, or being removed from the area (Gibeau & Herrero 1998).

6.2 INVASIVE SPECIES

High concentrations of non-native species have been observed near roads in many ecosystems (Forcella & Harvey 1983; Tyser & Worley 1992; Hansen & Clevenger in press). There has been a growing interest in the effects of roads and other linear features on plant species composition (Angold 1997; Safford & Harrison 2001; Gelbard & Belnap 2003), and particularly the spread and establishment of invasive non-native species (Parendes & Jones 2000; Tyser & Worley 1992; Hansen & Clevenger in press). Studies have documented roads as suitable habitat and corridors for non-native plant dispersal (Forman *et al*. 2003; Gelbard & Belnap 2003; Watkins *et al.* 2003). Vehicle traffic on roads may aid in the invasion and dispersion of non-native species within road corridors (Clifford 1959; Wace 1977; Schmidt 1989; Lonsdale & Lane 1994). Heavy traffic can cause air turbulence and vehicles may act as vectors for spread of seeds and vegetative plant parts (Panetta & Hopkins 1991; Tyser & Worley 1992; Forman *et al.* 2003).

Road corridors also have enabled the dispersal of non-native fauna. Non-native beetles spread from populations of relatively high density located in the right-of-way into adjacent forest interior habitat in central Alberta, Canada (Niemela & Spence 1999). In Australia, cane toads (*Bufo marinus*), a species introduced to Australia, were more abundant in road corridors than in many surrounding habitats (Seabrook & Dettman 1996). Roads and rights-of-way assisted in extending their range and facilitated colonisation by toads of previously inaccessible areas. In general, however, the extent to which roads influence the distribution and abundance of exotic species, such as foxes, cats and dingoes, and the consequences for native fauna, are poorly known (May & Norton 1996; Forman *et al.* 2003).

The edge effect created by road construction, right-of-way habitat and the adjacent landscape matrix can benefit edge-foraging, generalist predators and nest parasites (Fagan *et al.* 1999). Edges that function as travel lanes for predators are considered to be key components of the ecological trap hypothesis, whereby fauna behaviourally favour edge habitat, but at the cost of high rates of mortality from edge-foraging generalist predators and nest parasites, e.g. brownheaded cowbird (*Molothrus ater*) (Gates & Gysel 1972; Angelstam 1986).

Both native and non-native small mammals frequently find optimal foraging conditions near road edges (Adams & Geis 1983; Downes *et al.* 1997). In Australian rain forests, edge generation creates opportunities for interspecific competition among rat species, perhaps leading to the local extirpation of one species (Laurance 1994). Goosem (2000) found that tropical rainforest roads did not affect community composition of small mammals, but roads did allow non-native mammal species to penetrate the forest interior from the right-of-way. High road densities that fragmented forests in the Canary Islands, Spain, and facilitated high non-native rat abundance along edges explained damaging effects on the native biota (Delgado *et al.* 2001).

7. Discussion and conclusion

This chapter has illustrated the habitat and corridor function of right-of-way habitat, including factors that influence the quality of these functions, and some of the potential problems. Species with large home ranges that are not tied to one particular habitat are more likely to use rights-of-way as only part of their home range than species that are sedentary, that have small home ranges and that are tied to a specific habitat. Therefore most examples of species that use right-of-way habitat but do not restrict their movements to these relatively narrow strips are birds and larger mammals.

While the habitat function of rights-of-way is generally well documented and understood, the corridor function is not. Dispersal, movements over relatively long distances, has rarely been documented. Most of the evidence is indirect; i.e. based on distribution patterns rather than the actual recording of dispersing individuals in the right of way. This might be expected as dispersal is typically a rare event and we would be fortunate to catch it in action in the right-of-way rather than simply observing that movement had happened and making the assumption that the individual had dispersed along the right-of-way rather than through the surrounding landscape. However, the corridor function has been suggested or demonstrated for various species, particularly for species that depend on specific habitat and conditions provided in the right-of-way which may not exist in, or that have disappeared from, the surrounding landscape. Depending on the species, disturbance, vegetation structure and the composition of the surrounding landscape seem to be among the most important variables. Nonetheless, we are only beginning to have some insight into the parameters that may influence animal movements in rights-of-way.

The habitat and corridor function of rights-of-way is not often discussed. Most studies address the negative effects of roads, including habitat loss, road mortality, reduced habitat quality and the barrier effect, and how we may mitigate these effects. When the habitat and corridor function of roads is discussed, there is often a marked difference in how we value these functions in different landscapes. In less developed landscapes, e.g. forested landscapes or landscapes dominated by natural grasslands, rights-of-way are usually perceived as disturbance zones that provide a habitat and corridor for non-native species. They may disrupt ecotones and ecosystem processes, and contribute to the habitat fragmentation caused by the actual road and the traffic that uses it. In some cases non-native species may not only spread or disperse along the transportation corridor itself, but they can also spread into the surrounding landscape and cause an additional threat to the integrity of the ecosystem. Reduction of disturbance and restoration of the native vegetation in the right-of-way, including transplanting large native plants, may reduce these problems (e.g. Harper-Lore & Wilson, 1999). In developed landscapes, for example in intensively managed agricultural landscapes, rights-of-way are often the only remaining natural or semi-natural habitat. They may form a refugium for certain native species in an otherwise hostile environment. Their linear shape and interconnectedness may provide an important habitat for such native species and they may help individuals move through the landscape, either for daily movements within their home ranges, gradual spread, or dispersal between larger habitat patches that are connected by rights-of-way (e.g. Viles & Rosier 2001). Even though right-of-way habitat and corridors are continuously exposed to disturbance from the roads and traffic, and even though they may be of lesser quality than habitat and corridors away from infrastructure, they can be important to the survival of some species, especially in developed landscapes.

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