Carnivores: struggling for survival in roaded landscape

Chapter 35

CARNIVORES: STRUGGLING FOR SURVIVAL IN ROADED LANDSCAPES

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SUMMARY

Carnivores are a diverse group of wildlife that occur in most environments around the world. Large, wide-ranging carnivores play key ecological roles in natural systems. They regulate population sizes of herbivores and other small- and medium-sized carnivores that in turn affect the growth, structure and composition of plant communities and habitats and the health of the small-animal populations that live in these habitats. Carnivores are particularly susceptible to the impacts of roads because many species require large areas to sustain their populations, have low reproductive output and occur in low densities.

35.1 Carnivores with large home ranges, long dispersal distances or inability to tolerate human disturbance are particularly vulnerable to the effects of roads and traffic.
35.2 Threats from roads and traffic such as wildlife-vehicle collisions barriers to movement, habitat disturbance and road avoidance jeopardise the persistence of certain carnivore populations.
35.3 Road and landscape-related features influence behavioural responses of carnivores to roads, mortality risk and barrier effects.
35.4 Different types of crossing structures are needed to increase habitat connectivity for the wide diversity of carnivore species.
35.5 Fencing, when paired with crossing structures, is critical to reducing the negative effects of roads on carnivores.

Handbook of Road Ecology, First Edition. Edited by Rodney van der Ree, Daniel J. Smith and Clara Grilo.

Companion website: www.wiley.com\go\vanderree\roadecology

The effects of roads and traffic on carnivores are well understood and vary significantly because of the diversity in their body size, movement ecology, prey selection and habitat preferences. Consequently, carnivores require a diverse suite of mitigation options, many of which have been well studied. Further research is needed to evaluate effects of roads and mitigation success in maintaining genetic integrity that supports long-term viable populations of carnivores.

INTRODUCTION

Carnivores are a diverse group of predatory mammals that consume animal tissue as part of their diet. There are terrestrial and aquatic representatives adapted to nearly every continental environment and climate on earth. Terrestrial species range from very small to quite large sizes, such as the least weasel (37–50 g) and polar bear (420–500 kg). Their foraging strategies are diverse and include hunting (e.g. stone marten), scavenging (e.g. hyena) and omnivory (e.g. bears), and social structures range from relatively solitary individuals (e.g. jaguar) to complex interacting family groups (e.g. wolf). Carnivores play a key role in maintaining ecosystem integrity and preserving biodiversity in a number of ways. Many animal and plant species are protected when large areas of habitat are set aside for carnivore conservation because their needs are also addressed. The removal of carnivores from the top of the food chain will negatively impact the abundance of prey and other species (e.g. Palomares et al. 1996). These effects can cascade through the food chain, altering the interactions among species as well as the structure and function of ecological communities and ecosystem processes (Ripple et al. 2014).

Although carnivores are often major conservation icons today, such as tigers, wolves and jaguar (Chapters 36 and 37), they have historically been subjected to many anthropogenic threats. These include habitat loss and degradation, depletion of their prey and direct human persecution for the fur trade, trophy hunting and extermination because of fear, ignorance and perceived threats to livestock and human life, which in combination have resulted in massive population declines and range contractions (Ripple et al. 2014). Today, persecution and loss of prey are the immediate threats, but continued loss of habitat and the additional mortality and barrier effect of roads and traffic are the greatest long-term threats to their persistence (Burkey & Reed 2006). The aims of this chapter are to (i) highlight the ecological and biological traits that make carnivores susceptible to roads; (ii) summarise the impacts of roads and traffic on this group of wildlife; and (iii) review the mitigation strategies necessary to conserve viable carnivore populations.

LESSONS

35.1 Carnivores with large home ranges, long dispersal distances or inability to tolerate human disturbance are particularly vulnerable to the effects of roads and traffic

Roads are a significant direct cause of habitat loss, fragmentation and disturbance and indirectly lead to widespread land transformation for agriculture and urban development (Liu et al. 2014; Chapter 2). Many carnivore species are vulnerable to the effects of road-network expansion (Cardillo et al. 2004), such as increased human disturbance, mortality due to wildlife-vehicle collision (WVC), reduction of sufficient space for home ranges and isolation of populations because of their large spatial needs and other biological and ecological traits. Due to past and present human persecution, some species do not tolerate areas of high human activity (e.g. jaguar, gray wolf), further reducing the amount of suitable habitat. As a result, many carnivores now occupy only small portions of their former geographic range (e.g. gray wolf, Florida panther).

Those species most sensitive to fragmentation and human disturbance typically have large home ranges, low population densities, low reproductive outputs and display territorial behaviour (e.g. grizzly bear, Iberian lynx). These biological characteristics translate into the need for large undisturbed areas to support viable populations and the inability to sustain high levels of mortality. Many of the most imperilled carnivores require large home ranges, such as 99–241 km^2 for wolves (Okarma et al. 1998), 18–324 km^2 for grizzly bears (Craighead 1976), 195–520 km^2 for Florida panther (FFWCC, 2014) and about 30 km^2 for leopards (Simcharoen et al. 2008). In addition, carnivores with large home ranges tend to occur in low population densities. For example, the primary habitat zone (9190 km^2) in south Florida for the Florida panther was estimated to support a stable population of only 71–84 individuals or at most one per 109 km^2 (Kautz et al. 2006). When the population in an area reaches its carrying capacity, young adults must disperse to new areas to find suitable habitat. Many carnivores disperse long distances, for example, 13–219 km for black bear (Rogers 1987) and an average of 123 km for puma in the United States (Maehr et al. 2002), further increasing the probability of encountering roads. When carnivores increase their movement range in search of food to feed their young or to find mates, they tend to search for new areas that may include suboptimal habitat, thus increasing the likelihood of encountering a road (Saeki & Macdonald 2004). This is especially significant for dispersers and other novice individuals exploring unknown areas that are also unfamiliar with roads or the danger they pose when attempting to cross. One study on black bears in Florida showed that 66 of 96 roadkills were inexperienced young males dispersing in search of mates in late spring/early summer or new food sources in autumn (Wooding & Brady 1987).

Although carnivores have a wide range of morphological, ecological and behavioural adaptations to coexist and adapt to diverse habitats (Gittleman et al. 2001), some are unable to compensate biologically for the increased mortality due to low reproductive output or overcome the barrier effect of roads (e.g. Iberian lynx, bears, African wild dogs – Chapter 38). In general, larger carnivores that require more space are more sensitive to the effects of habitat fragmentation and isolation than smaller carnivores that appear more able to adapt to human activities and land development (Crooks 2002).

35.2 Threats from roads and traffic such as wildlife-vehicle collisions barriers to movement, habitat disturbance and road avoidance jeopardise the persistence of certain carnivore populations

One of the major causes of mortality for carnivores is WVC (Fig. 35.1), which in certain cases is sufficient to threaten population viability. For example, in a high-traffic area of Ocala National Forest, Florida, United States, the rate of female black bear mortality due to WVC was 23%, which when combined with other sources of mortality was estimated to exceed the maximum sustainable annual mortality rate for populations of similar demographics and reproductive traits (Bunnell & Tait 1980; McCown et al. 2009; Textbox 35.1). Roadkills accounted for 35% of annual mortality of the federally endangered Florida panther (Taylor et al. 2002) and 17% of annual mortality of the most threatened felid species in southern Spain, the

Figure 35.1 Stone marten roadkill in southern Portugal. Source: Photograph by and reproduced with permission of Joaquim Pedro Ferreira.

Textbox 35.1 Landform, land cover, road alignment and traffic influence black bear movement and roadkill patterns.

Ocala National Forest (155,000 ha) in Florida, United States, contains the largest population of black bears (~825–1225 individuals) in the state (FFWCC 2012). WVC is a primary cause of mortality, with about 80 bears killed per year, including four hotspots of 5 or more roadkills annually on State Road 40 (SR40), which carries 5100 vehicles per day.

The occurrence and movement of bears around SR40 was studied from 1999 to 2003 using radiotracking and sand-tracking plots. In order to understand the factors influencing bear-vehicle collision hotspots, data on landform, road alignment and land cover was also collected and analysed. The number of bear tracks was consistent along a 19 km stretch of SR40 through the core of the forest; the analysis revealed no bias in bear movements or road crossings by land cover, habitat, road curvature, topography or presence of intersecting roads or trails (McCown et al. 2004). Rather, bear movements and crossings were in response to availability of food sources, and road geometry influenced the location of roadkills. Roadkills occurred on curves and hills (Fig. 35.2), strongly suggesting that reduced visibility was the ultimate cause. Relatively high vehicle speed (90 km per hour) along SR40 exacerbates the problem; combined with the hills and curves in the road, it reduces driver response times when encountering bears.

Subsequent research in a more fragmented and human-dominated area along SR40 with 15,700 vehicles per day revealed that (i) males crossed the road more frequently than females; (ii) the rate of road crossing by females was only slightly lower in the more fragmented area, despite having approximately three times more traffic volume; and (iii) more female WVC occurred at the higher traffic volume site (McCown et al. 2009). Males have larger home ranges than females and therefore encounter and cross roads more often. The higher rate of female mortality in the high-traffic volume site was somewhat unexpected because more traffic should increasingly act as a barrier to crossings. The most likely explanation is that bears increase their frequency of road crossings in fragmented areas because of a greater need to cover larger areas to access food and mates, attraction to human food sources, and a shift to more nocturnal movements to adapt to periods of minimal human activity and traffic levels. Vehicle collisions accounted for 23% of annual mortality of female bears in the high-traffic area.

Previous studies (Brody & Pelton 1989; Beringer et al. 1990) have documented road avoidance by bears when traffic volume is high; however, bears occurring in fragmented areas may need to cross busy roads (Fig. 35.3)

Figure 35.2 Typical topographic relief and curvature of State Road 40 through Ocala National Forest, Florida, United States, which resulted in high rates of bear-vehicle collision. Source: Photograph by D.J. Smith.

Figure 35.3 A black bear crossing State Road 40 in Ocala National Forest, Florida, Untied States. Source: Photograph by and reproduced with permission of Mark Cunningham.

to find mates, suitable den sites and food sources. The estimated annual mortality from all sources was 37.6% (McCown et al. 2004) in the fragmented area, making it unsustainable (Bunnell & Tait 1980), and any increase in mortality or habitat fragmentation will further imperil their existence (McCown et al. 2009). Current plans to widen the road to four lanes would exacerbate these effects; therefore, recommendations were made to include crossing structures and fencing in any future highway designs. This study demonstrates the importance of considering habitat use and movement patterns of the target species, landscape characteristics, traffic volume and road alignment in evaluating WVC locations and mitigation needs.

Iberian lynx (Ferreras et al. 1992). In Britain, more than 40% of the adult Eurasian badger population is killed annually by vehicles (Clarke et al. 1998). The estimated annual roadkill rates of carnivores along 314 km of national roads in southern Portugal was around 47 individuals per 100 km, with red fox and stone marten (Fig. 35.1) experiencing the highest rates (20 and 8 individuals per 100 km, respectively) (Grilo et al. 2009). While little is known about the implications of these mortality rates on the long-term viability of the populations, attention must also be paid to this added source of mortality on the potential reduction of genetic diversity (Jackson & Fahrig 2011).

Roads with high-traffic volumes and vehicle speeds can act as barriers to animal movement as well as disturb and displace carnivore populations due to road avoidance (Fig. 1.2; Riley et al. 2006). In some cases, populations of carnivores have declined due to increased hunting pressure as a result of improved access provided by the road (e.g. Van Dyke et al. 1986; Mech et al. 1988; Beldon & Hagedorn 1993; Chapter 37). Moreover, human disturbance while carnivores are hunting or feeding can reduce hunting efficiency and increase carcass abandonment, as shown for Amur tigers (Kerley et al. 2002). Similarly, the Asiatic leopard avoided habitat near a road bisecting a National Park in Thailand and also reduced their level of diurnal activity (Ngoprasert et al. 2007). Similarly, Eurasian lynx avoided areas with the highest road densities within their home ranges (Basille et al. 2013). The severity of these effects can vary between sexes, as shown by male jaguars that were more willing than females to use areas close to roads, and with higher levels of human occupation, even though the species generally avoids both land uses and preferentially moves in undisturbed forests (Colchero et al. 2011; Chapter 36).

35.3 Road and landscape-related features influence behavioural responses of carnivores to roads, mortality risk and barrier effects

The rate of WVC with carnivores is influenced by habitat suitability and landscape structure, as well as road and traffic characteristics (Gunson et al. 2010;

Textbox 35.1). Roads through high-quality habitat are especially problematic due to the high abundance and diversity of species (Barrientos & Miranda 2012) as well the often narrow and sinuous roads with low to medium traffic volumes. Roads in protected areas and parklands are often designed to blend into the landscape in order to improve aesthetics. However, the narrowness, curves and steep slopes in wilderness areas can severely limit driver visibility, decreasing their ability to detect and avoid animals on the road (Grilo et al. 2009). Vegetated roadsides can support populations of small mammals and other potential prey (Chapters 39 and 46), potentially attracting carnivores and increasing their risk of WVC. Scavenging carnivores are often attracted to roadkills as a source of food, which increases their probability of also being involved in WVC (Figs. 26.2B and 50.3). Roadkills are also more likely to occur where roadside fencing ends, such as where side roads join the fenced road (Clevenger et al. 2001; Cserkész et al. 2013; Chapter 20). Weather conditions also influence the rate of WVC. For example, the rate of mortality of river otters in England was higher during heavy rainfall periods when small culverts became impassable due to flooding or increased water velocity, forcing them to cross over the road (Philcox et al. 1999). Otters also travel over land more often during periods of drought in search of water, which increases their probability of WVC.

There are thresholds in traffic volume where the rate of WVC decreases and the barrier effect becomes intensified. For larger carnivores (e.g. coyote, wolf, puma), the threshold is approximately 2000–5000 vehicles per day (Alexander et al. 2005). In line with this study, stone martens seem to regularly cross a four-lane highway with nightly traffic volumes of 2000 vehicles (Grilo et al. 2012); consequently, WVC was the main threat to the population. On the other hand, significant genetic structuring was found in wildcat populations divided by a six-lane highway with 100,000 vehicles per day (Hartmann et al. 2013). Similarly, a 10–12 lane freeway in California with 150,000 vehicles per day was only permeable for dispersing bobcats and coyotes through the use of culverts or underpasses (Riley et al. 2006).

35.4 Different types of crossing structures are needed to increase habitat connectivity for the wide diversity of carnivore species

Many wildlife crossing structures (Chapter 21) built across roads in Europe and North America are used by carnivores (Beckmann et al. 2010). In addition to these, some carnivore species will also use drainage culverts and other types of multi-use structures (e.g. Clevenger et al. 2001; Lesson 21.3) to cross roads. The suitability of both dedicated and multi-use crossing structures is influenced by the type and size of the structure itself and the characteristics of the surrounding vegetation and landscape, the road and the degree of human disturbance. In summary, carnivores use a diversity of structures to cross roads, and there are several design parameters that should be considered to make them attractive to a wide range of species (Chapter 21 and 59):

(i) *Structure type and size* – Larger structures generally have higher rates of use by carnivores than smaller ones (Kusak et al. 2009). Small-sized underpasses (1–1.5 m wide) are also used by small- to medium-sized species, such as marten, coyote and bobcat (e.g. Cain et al. 2003; Grilo et al. 2008). Carnivores that require cover or concealment, especially those which live in burrows or dens, appear to prefer or be more tolerant of more constricted underpasses, such as badgers (Fig. 35.4), black bears and cougars, while others that use open habitat, such as grizzly bears and wolves, appear to prefer overpasses or high, wide and short underpasses (Clevenger & Waltho 2005; Sawaya et al. 2014). The use of structures by subordinate individuals or species appears to be negatively affected by the presence of established, dominant individuals or species. For example, use of a specific structure by wolves may reduce or preclude use by coyotes, as well as potential prey species (Clevenger 2011; Chapter 23). Thus, multiple structures of a range of types and sizes are required to allow crossing by many different species (Mata et al. 2008). Wildlife crossing structures have been included in many road projects for large carnivores (e.g. bears, wolves and lynxes – Textbox 35.2), including overpasses ranging in width from 30–50 m to over 200 m (e.g. Wieren & Worm 2001). Wildlife overpasses are used by a wide diversity of species (e.g. Brodziewska 2005) and have numerous other advantages over underpasses including the provision of wider areas for crossing, exposure to natural rainfall, temperature and light conditions, and the provision of continuous, vegetated habitat corridors across the road (Glista et al. 2009).

(ii) *Landscape context and local features* – Crossing structures should be located in areas with ecological significance for carnivores, such as within highly used areas and connecting corridors of forested habitat, which may include waterways with riparian vegetation, and low levels of human disturbance (e.g. Clevenger & Waltho 2005).

(iii) *Structure enhancements* – Crossing structures should be as similar as possible to the preferred habitat of the

Figure 35.4 Badger using a tunnel. Source: Photograph by C. Grilo.

Figure 35.5 Logs and brush were included inside this underpass to provide cover for carnivores and small mammals. Source: Photograph by C. Grilo.

target species. Low rates of use and avoidance of structures by weasels and polecats was attributed to the unnatural characteristics of most underpasses (Grilo et al. 2008). Guiding carnivores towards structures with the help of linear strips of vegetation and placing logs, rocks and bushes inside and outside passages to provide cover is highly recommended to improve function (Fig. 35.5).

(iv) *Spacing intervals* – Road permeability can be improved by placing crossing structures at intervals that correspond to the movements of the target species and the goals for mitigation (see Chapter 21; Lesson 21.6).

(v) Enhancements *to drainage structures* – Many standard drainage structures, including culverts and bridge underpasses, are unsuitable for use by wildlife (Fig. 35.6A), especially when carrying water or during periods of flooding (e.g. stone martens and genets – Villalva et al. 2013). Options for dry passage should be provided (Serronha et al. 2013), and there are a number of strategies: (i) bridge underpasses should include a strip of dry land on one or preferably both banks (Figs. 35.6B and 45.4; Lesson 45.4); (ii) install multiple culverts with one or more culvert being elevated to remain dry most of the time (Figs. 21.4 and 45.5); and (iii) install shelves or ledges on the walls of underpasses above the water level, with ramps to provide access (Figs. 35.6C and 39.3). Dry ledges are also easily retrofitted to existing culverts (Fig. 35.7). Swimming ledges, which float on the water surface and therefore can adapt to changing water levels, are also a possibility. Such ledges or shelves can circumvent impassable dams and also enhance the attraction to culverts by swimming species, for example, otters have the opportunity to exit the water to mark territory.

However, behavioural differences among individuals play an important role regarding the efficiency of crossing structures. Adaptation to and acceptance of new structures may take an extended period of time (e.g. an average of 4–6 years for carnivores, Clevenger 2011). Following this acclimation period, certain resident individuals often become accustomed to many types of crossing structures within their home ranges and use them regularly, while other individuals may have preferences for a specific structure type or location (Klar et al. 2009). Dispersing animals are often reluctant to use crossing structures, particularly when moving through unfamiliar areas (e.g. Zimmermann 2004).

Figure 35.6 Examples of river otter crossings: (A) unsuitable culvert design with high risk of submersion from flooding, (B) superior design with riparian strips and (C) retrofitted culvert with dry ledge including aquatic entry points for otters. Source: Photographs by N. Klar.

Figure 35.7 Bolt-on wildlife shelf retrofitted to an existing drainage culvert for use by weasels. Source: Photograph by and reproduced with permission of Kerry Foresman, Critter-Crossing Technology L.L.C.

Textbox 35.2 Enhancing population connectivity and minimising road mortality for Iberian lynx in Spain.

Iberian lynx (Fig. 35.8) is a highly endangered felid species with just 400 breeding individuals occurring in two isolated populations: 75% in Sierra Morena and 25% in Doñana, a fragmented habitat area (Simón 2012). Mortality due to WVC is one of the primary threats to the viability of the Doñana population – in 2006, 12% of this population was killed in collisions. Consequently, a series of measures to reduce mortality and restore connectivity for this population was implemented along 150 km of roads in the Donãna–Aljarafe region in southern Spain, including: (i) reduction of the attractiveness of roadside vegetation to lynx; (ii) installation of traffic calming devices to reduce vehicle speed; (iii) installation of 40 km of fencing to funnel animals to underpasses (Fig. 35.9A); (iv) construction of 53 crossing structures (33 wildlife underpasses, 2 wildlife overpasses, 11 retrofitted culverts and 7 bridges or viaducts) (Figs. 35.9B, C and D); and (v) installation of roadside reflectors (but see Chapter 25) in areas used by dispersing lynx. By 2012, the rate of roadkill had decreased to 5% of the Doñana lynx population, and many crossing structures were being used regularly by lynx with demonstrated increases in gene flow (Simón 2012).

Figure 35.8 Iberian lynx is one of the world's most endangered carnivores, with just 400 breeding individuals remaining in the wild. Source: Photograph by and reproduced with permission of Joaquim Pedro Ferreira.

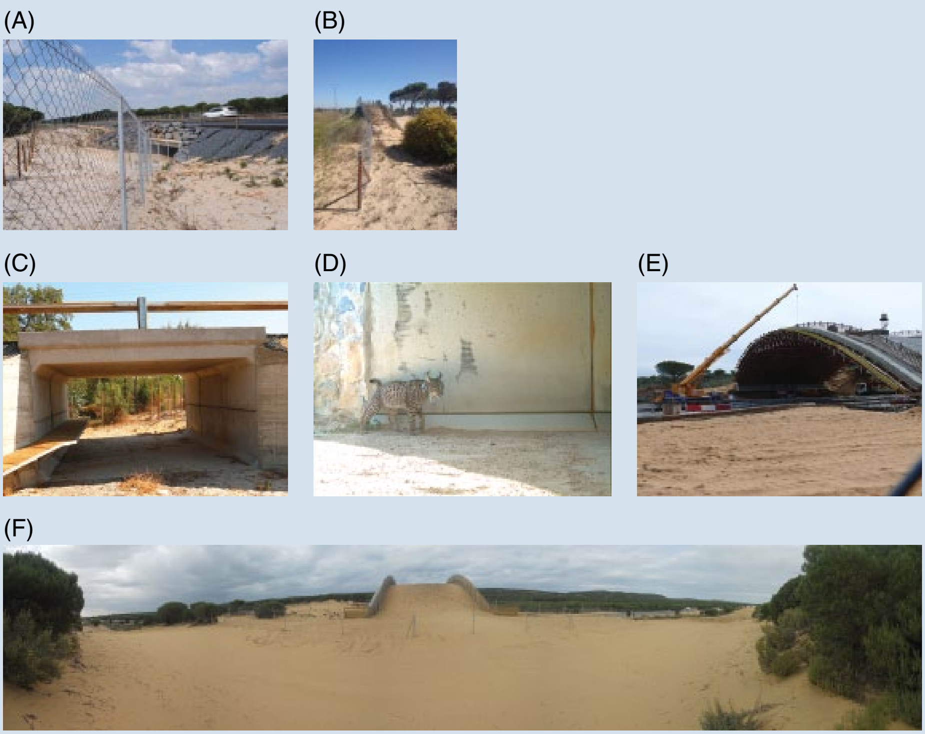

Figure 35.9 Mitigation measures to minimise road mortality of Iberian lynx and improve population connectivity: (A) fencing to prevent access to the roadway and funnel lynx to crossing structures, (B) earthen ramps as escape structures for Iberian lynx, (C) underpass with wooden ledge, (D) Iberian lynx using an underpass, (E) wildlife overpass specifically for lynx during construction and (F) the operational overpass. Source: Photographs by and reproduced with the permission of (A) Joaquim Pedro Ferreira, (B, C, E, F) Gema Ruiz, (D) Miguel Simón).

35.5 Fencing, when paired with crossing structures, is critical to reducing the negative effects of roads on carnivores

Fencing is an effective strategy to reduce WVC and is recommended for many species (Chapter 20), including carnivores (Klar et al. 2009). However, fences without crossing structures can exacerbate the barrier effect of the road and create genetically distinct populations, increasing the likelihood of local extinctions (e.g. Klar et al. 2006). Therefore, roadside fencing should always be combined with crossing structures to reduce fragmentation effects and provide the added benefit of directing animals to crossing structure entrances (Chapters 20 and 21). Standard livestock fences are typically ineffective at containing carnivores because most species are agile, capable climbers or persistent diggers (Grilo et al. 2009; Cserkész et al. 2013). Effective fences for species with a penchant for digging need to be buried, while those for climbing species require sufficient height and an overhanging edge to contain them (Chapter 20, Textbox 35.3).

The length of fencing necessary to effectively funnel wildlife to crossing structures varies by species. For instance, fencing with a small mesh size extending for 100 m on each side of culvert entrances was not enough to prevent roadkills of small- and medium-sized carnivores with larger spatial requirements (Villalva et al. 2013). Similarly, a 100 m section of fence around culverts did not generally increase use by bobcats, but it may have contributed to increased use of culverts previously frequented by bobcats (Cain et al. 2003). Interestingly, a simulation study with a common species such as stone martens in areas of high rates of roadkill showed that partial wildlife fencing alone may be more effective than crossing structures at reducing genetic differentiation, given its ability to eliminate road mortality, which in turn increased genetic diversity (Ascensão et al. 2013).

Textbox 35.3 Designing fences to prevent road mortality of wildcats.

European wildcats, similar to many other species of carnivore, are able to climb and jump standard wildlife and livestock fences with relative ease. Consequently, a fence design that prevented wildcats from accessing the road and guided them towards crossing structures was urgently needed. A series of trials with European wildcat in different types of fence enclosures was conducted in Germany, resulting in a fence that is 2 m high and has a mesh size of 5 cm^2, a 50 cm-wide overhanging metal sheet and a 30 cm-wide subterranean plastic board (Fig. 35.10; Klar et al. 2009). These are now installed as a standard measure along new motorways that traverse wildcat habitat. This fence is combined with a variety of crossing structures spaced a few kilometre apart and effectively reduces roadkill and restores permeability.

(A) (B)

Figure 35.10 (A) The European wildcat is identified by the circular black rings on its tail. (B) Fences for wildcats in Germany are 2 m high with mesh size of 5 cm^2, a 50 cm-wide overhanging metal sheet and plastic board buried 30 cm deep. Source: (A) Photograph by and reproduced with permission of Heiko Müller-Stieß; and (B) Photograph by N. Klar.

CONCLUSIONS

There is an abundance of scientific literature identifying the direct impacts of roads on carnivores including quantifying road mortality and crossing rates (see also Chapter 28). However, little is known about the implications of those values on the viability of carnivore populations over time. For example, the typical recording of use of crossing structures by carnivores is not sufficient to fully assess their effectiveness; identifying the minimum number of breeding individuals required to cross the road barrier to ensure adequate gene flow and maintain sustainable populations must be determined (Corlatti et al. 2009). Research should be conducted to find the thresholds in road density that threaten the persistence of various carnivore populations and to identify minimum specifications for mitigation efficacy required to provide connectivity for individuals, genetic exchange and long-term population persistence.

Long-term monitoring programmes that incorporate pre- and post-construction evaluation (Chapter 10) should be more widely employed across the geographic ranges of different carnivore species. Importantly, these programmes should specifically address the variation in responses to roads by different carnivore species and individual mitigation preferences. This information can be used to assess the effectiveness of crossing structures and fencing to adequately reduce mortality rates and facilitate gene flow across roads and thereby maintain viable populations across large scales (Corlatti et al. 2009).

ACKNOWLEDGEMENTS

C. Grilo was supported by Fundação para a Ciência e a Tecnologia through a postdoctoral grant (SFRH/BPD/64205/2009). Special thanks to Gemma Ruiz and Miguel Simón for information on Iberian lynx road mitigation measures.

FURTHER READING

Basille et al. (2013): Emphasises the hierarchical nature of habitat selection at multiple spatial scales, in particular concerning road density, where one carnivore species can shift habitat selection to avoid areas with the highest road densities within their home range, using a compensatory mechanism at fine scales.

Gittleman et al. (2001): Summarises the problems, approaches and solutions for carnivore conservation and provides a conceptual framework for future research and management, especially in changing landscapes.

Ripple et al. (2014): Assesses how threats such as habitat loss, persecution by humans and loss of prey combined can promote declines of large carnivores which pose a global conservation problem.

Sawaya et al. (2014): Highlights the importance of wildlife crossing structures to provide for interactions between individuals and consequently promote gene flow restoring landscape connectivity for carnivores in roaded landscapes.

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