Chapter 2
Current Knowledge on Wildlife Mortality in Railways

Sara M. Santos, Filipe Carvalho and António Mira

Abstract Wildlife mortality on roads has received considerable attention in the past years, allowing the collection of abundant data for a wide range of taxonomic groups. On the contrary, studies of wildlife mortality on railway tracks are scarce and have focused primarily on a few large mammals, such as moose and bears. Nevertheless, many species are found as victims of collisions with trains, although certain taxonomic groups, such as amphibians and reptiles, and/or small bodied species are reported infrequently and their mortality is probably underestimated. However, no assessment of population impacts is known for railways.

Keywords Wildlife mortality · Railway collisions · Collision risk

Introduction

One of the most obvious impacts of railways on wildlife is direct mortality from collisions with trains (Davenport and Davenport 2006; Dorsey et al. 2015; Forman et al. 2003; van der Grift 1999). In addition to collisions, mortality can also occur due to electrocution, wire strikes and rail entrapment (Dorsey et al. 2015; SCV 1996). In fact, some species of small body size can become trapped between the rails and die from dehydration or hunger (Budzic and Budzic 2014; Kornilev et al.

S.M. Santos (✉) · F. Carvalho · A. Mira
CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade de Évora, Pólo de Évora, Casa do Cordovil 2º Andar, 7000-890 Évora, Portugal
e-mail: smsantos@uevora.pt

A. Mira
Unidade de Biologia da Conservação, Departamento de Biologia, Universidade de Évora, Mitra, 7002-554 Évora, Portugal

F. Carvalho
Department of Zoology and Entomology, School of Biological and Environmental Sciences, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa

L. Borda-de-Água et al. (eds.), *Railway Ecology*,
DOI 10.1007/978-3-319-57496-7_2

2006). Nevertheless, collisions are the most common cause of railway mortality (Dorsey et al. 2015).

Wildlife mortality on roads has received considerable attention thanks to abundant data for a wide range of taxonomic groups and different continents. By contrast, studies on wildlife mortality on railway tracks are scarce, have focused primarily on large mammals, and are concentrated on a few countries, such as Canada and Norway (Dorsey et al. 2015; Gundersen and Andreassen. 1998; Seiler and Helldin 2006; van der Grift 1999). The mammal species receiving the most attention are frequently the larger ones, such as moose, bears or elephants as they cause more damage to trains, disrupt the normal operation of the train network, or hold higher conservation and economic status (Huijser et al. 2012; Rausch 1958; van der Grift 1999). Here we review and discuss the mortality impacts on different taxa.

Mammal Mortality

Mortality of mammals due to train collisions can be of considerable importance. In multispecies surveys (Heske 2015; SCV 1996; van der Grift 1999) of all vertebrate recorded, the approximate proportion of mammals found dead on rail tracks ranges from 26% (Netherlands), to 36% (USA) and 38% (Spain).

Train mortality can have large impacts on mammal populations, particularly for species that are already endangered, species with large home ranges and low density populations, and species with low reproductive rate (van der Grift and Kuijsters 1998; van der Grift 1999). The highest mortality numbers are usually found at sections where rail lines intersect important mammal habitats or migration routes (Child 1983; Gundersen and Andreassen 1998; van der Grift 1999).

Many species are victims of collisions. The body size of the mammal species that are killed varies greatly, ranging from small insectivores (as the hedgehog *Erinaceus europaeus*) and small carnivores (such as the Virginia opossum *Didelphis virginiana*), to large carnivores (such as the grizzly and brown bear *Ursus arctos* and the American lynx *Lynx canadensis*), to ungulates (such as moose *Alces alces* and deer *Cervus elaphus*), and even elephants (*Elephas maximus*) (Child 1983; Gibeau and Herrero 1998; Gibeau and Heuer 1996; Gundersen et al. 1998; Gundersen and Andreassen 1998; Heske 2015; Krofel et al. 2012; Rausch 1958; Singh et al. 2001; van der Grift and Kuijsters 1998). Still, most existing studies focus on large ungulates and carnivores, and most lack quantitative data (van der Grift 1999).

The High Frequency of Collision with Ungulates

Train accidents with ungulates are common worldwide. From Canada and Alaska to Norway and Sweden, moose commonly intercept and travel along the rails, being frequently killed (Child 1983; Eriksson 2014; Gundersen and Andreassen 1998; Huijser et al. 2012; Modafferi and Becker 1997). In British Columbia, Canada, the annual loss of moose to train collisions in the winters between 1969 and 1982 was estimated to range from several hundred to more than 1000 animals (Child 1983). In Norway, the number of moose killed in train collisions has increased from ca. 50 moose per year in the 1950s to a yearly average of 676 during 1990–1996. This has resulted in economic costs due to material damages and loss of income due to the lower number of hunting licenses issued (Gundersen and Andreassen 1998). Jaren et al. (1991) estimated these costs at around $2900 per train-killed moose in Norway. On average, 87 moose are killed along the Rørosbanen railway (Norway) each year, which sums to a socio-economic loss of ca. $250,000 (Jaren et al. 1991).

Although in Alaska moose are considered common species within their range, train kills accounted for 24% of known deaths, being the second cause of death in a studied population (Modafferi and Becker 1997). During the winter of 1989–1990 there was a 35% reduction of the moose population in lower Susitna Valley, Alaska, due to a combined effect of non-natural mortality and poor winter survival. Although train collisions alone were not the only reason for that reduction, they were the main cause of non-natural mortality (61.5%; 351 individuals). There was a reduction of about 70% of moose numbers along this railway between 1984 and 1991, presumably due to high mortality on both the railway and the highway (Modafferi and Becker 1997).

Some behaviours can contribute to this high mortality rate on railways. Moose annually migrate from traditional summer areas to lower elevation winter areas with snowfall determining the onset of these seasonal movements (Child 1983). Wherever railways intercept and/or are parallel to areas occupied by moose, large concentrations of animals may use the right-of-way of rails. Moreover, in winters with above average snowfall, moose use the railways as travelling routes more often, being more vulnerable to collisions (Child 1983; Gundersen et al. 1998; Gundersen and Andreassen 1998; Rausch 1958). About 79% of moose train accidents in Norway occurred from December to March, possibly due to their migratory behaviour (Gundersen and Andreassen 1998).

As observed by Child (1983), moose can return rapidly to train tracks even after a collision experience. A typical fatal event occurs when the animal attempts to leave the tracks, but rapidly returns to the rail, probably because it is free of snow, and then try to escape the approaching train by running on the rail. Sometimes moose show an aggressive behaviour, standing in front of the train and attacking the locomotive, with fatal consequences (Child 1983).

The factors influencing moose collision risk were studied by Gundersen and Andreassen (1998) who found that trains running at night, in the morning or in the evening had a higher risk of moose collision than daytime trains. The probability of collision was also higher during nights of full moon. This could be partially explained by the higher moose activity in those periods (Gundersen and Andreassen 1998). In a parallel study, it was found that the collisions increased in winter with increasing snow depth and ambient temperatures below 0 °C, and were located in the outlets of side valleys (Gundersen et al. 1998). The increase in the food availability close to the railways due to logging activities also increased the number of moose collisions (Gundersen et al. 1998).

Other ungulates are also killed frequently by trains. The elk (*C. canadensis*) and the bighorn sheep (*Ovis canadensis*) were the most frequent victims in Jasper National Park, Canada, while deer (*Odocoileus virginianus*) was the most common casualty in Mount Robson Provincial Park, Canada (Huijser et al. 2012). In Norway, although moose is the most reported victim of railway traffic, the roe deer (*Capreolus capreolus*) is also a common one with 12.4% of all mammals recorded from 1993 to 1996, while reindeer (*Rangifer tarandus*) and muskox (*Ovibus moshatus*) are killed more infrequently, with 2.8% and 0.17% respectively (Gundersen et al. 1998). The roe deer was particularly affected in the Czech Republic with 0.8 kills/km in 2009 (Kušta et al. 2014). In the Iberian Peninsula, although some deer and roe deer are reported to be killed by trains, the wild boar (*Sus scrofa*) is the most common ungulate victim (SCV 1996).

In addition, besides possible population decreases, railway kills may cause shifts in the age structure of populations. Huggard (1993) showed that American elks in Banff National Park, Canada, whose ranges overlap roads or railways are less likely to reach old age than animals away from these infrastructures. Additionally, Huggard (1993) also found differences in body condition of American elk predated by wolves and animals killed on the road or railway: elks killed by wolves were in significantly poorer condition than those killed on road or railways, suggesting a non-natural selection by trains and cars (Huggard 1993).

Train Accidents with Bears

Bears are often the most frequently reported carnivore killed by trains in Central Europe and North America. In Montana, USA, 29 grizzly bears were killed on 109 km section of a railway track between 1980 and 2002 (Waller and Servheen 2005), while nine brown bears were killed on the Ljubljana–Trieste railway, Slovenia, between 1992 and 1999 (Kaczensky et al. 2003). Train accidents with bears were also reported in the Abruzzo mountains, Italy (Boscagli 1987), and in Croatia, where 70% of all traffic killed bears occurred along the Zagreb–Rijeka railway (Huber et al. 1998). In Mount Robson Provincial Park, Canada, the black bear (*U. americanus*) was the carnivore with the highest mortality caused by trains, with a higher number of collisions in railways than on the highways (Huijser et al. 2012). In British Columbia, Canada, 13 black bears were killed on a 15 km railway section between 1994 and 1996 (Munro 1997; Wells et al. 1999).

Why are so many bears killed by trains? Historically, grizzly bears have been attracted to railways by grain leaked from trains along the tracks or that accumulated at sites of repeated derailments. Such concentration of food led grizzly bears being struck and killed by trains at these sites (Waller and Servheen 2005). However, grain spills have been reduced through the years and recent research suggests that most bears struck by trains are young individuals, which are unlikely to have acquired the behaviour of feeding on spilled grains (Kaczensky et al. 2003; Krofel et al. 2012). Some collisions happened because bears had used the railway as a movement route (Kaczensky et al. 2003), or were attracted by food resources in railway verges (Gibeau and Herrero 1998; Waller and Servheen 2005). When both railways and highways are present, however, bears seem to cross railways mostly at night, when highway traffic volume decreases, but when railway traffic volume increases (Waller and Servheen 2005). Apparently, bears have learned to avoid the periods of higher risk in highways but in the process have become more exposed to railway collisions, as suggested by different mortality rates between the two infrastructures (Waller and Servheen 2005).

Even though the railways may pose significant mortality risks for bears, not all populations are threatened by train accidents. This is the case of Slovenian bear population that appears to be increasing in spite of 6.6% of annual bear mortality being caused by railway collisions (Krofel et al. 2012).

The Case of Asian Elephants

In India the railway is quite extensive and train collisions with elephants have been identified as a conservation concern (Deka and Sarma 2012; Singh et al. 2001). From 1987 to 2001, 18 elephants were killed in train accidents in a section of 23 km of rail in the Rajaji National Park, India (Singh et al. 2001). These numbers accounted for 45% of total elephant mortality in the studied area for the same period (Singh et al. 2001). In addition, the Indian Forest Department records show that railway trains were responsible for killing at least 35 elephants in the Assam region between 1990 and 2006 (Deka and Sarma 2012).

Maximum elephant mortality occurred during the summer months of high temperatures and low rainfall. The high temperatures and water scarcity appeared to be the deciding factors forcing elephants to cross the rail tracks during the late dry season when water sources on the southern side of rail had dried up (Singh et al. 2001).

What About the Collisions with Other Mammal Species?

For most European countries most mammals killed in train collisions are of small size and efforts have been made to document all species accidents (SCV 1996; van der Grift 1999). In Netherlands, 38% of collisions comprises lagomorphs (*Lepus europaeus* and *Oryctolagus cuniculus*), and 30% carnivores (including the badger *Meles meles,* red fox *Vulpes vulpes* and stoat *Mustela erminea*). Small percentages were registered for ungulates (roe deer and wild boar: 9%), small insectivores (hedgehog and mole *Talpa europaea*: 6%) and rodents (red squirrel *Sciurus vulgaris,* muskrat *Ondatra zibethicus* and brown rat *Rattus norvegicus*: 4%) (van der Grift 1999). In the Czech Republic, 73.5% of the recorded collisions include roe deer, 20.4% European hare (*Lepus europaeus*), 4.1% wild boar and 2% red fox (Kušta et al. 2011).

In Spain, 18.4% of mammal casualties from trains were carnivores (excluding domestic species), mainly fox and stone marten (*Martes foina*). Ungulates (mostly wild boar) and lagomorphs were also frequently killed by trains, 14.4% each (SCV 1996). Bats may be also killed by trains, especially on railway tunnels and sections close to old buildings, but no data are available to document this for railways (SCV 1996). Information for roads indicates that bats are very difficult to detect (Santos et al. 2011). Thus, bat mortality on railways can be high but have been ignored.

In general, most reported mammal victims are common species, which suggests that the effects on population levels should be small for species with large and widespread populations (van der Grift and Kuijsters 1998). However, the death of a few individuals of a rare or endangered species may further increase species extinction risk (van der Grift 1999).

Bird Mortality

From the assessment of bird carcasses found on railway tracks, it has been frequently deduced from monitoring studies that the cause of mortality was due to collisions (Peña and Llama 1997), although collisions with the catenary, electrocution and barotrauma induced by the train movement are also possible bird mortality causes related to the railways (SCV 1996).

The frequency of bird mortality by trains when compared to other taxonomic groups varies from 11% (USA), to 55% (Spain) and 57% (Netherlands) (Heske 2015; SCV 1996; van der Grift and Kuijsters 1998). In Chicago state, USA, most frequent victims were mallard duck (*Anas platyrhynchos*), common grackle (*Quicalus quiscula*) and sora (*Porzana carolina*), while songbirds were infrequent (Heske 2015). In the Netherlands, accidents concerned mostly swans (*Cygnus* spp.), ducks (family Anatidae) and coots (*Fulica* spp.). Gulls (family Laridae) and raptors such as hawks and owls were also reported frequently (van der Grift and Kuijsters 1998). In Guadarrama (Spain), Peña and Llama (1997) monitored for two years the bird mortality in 8 km of railways. The tawny owl (*Strix aluco*) was the most frequent bird victim (18%), followed by the carrion crow (*Corvus corone*; 16%) and the little owl (*Athene noctua*; 9.6%). Nearly half (46.8%) of this mortality occurred in the summer, while much lower values (13.8 and 16%) occurred in the winter and spring, respectively. Another report for Spanish railways (SCV 1996) also found that owls were the most common victims (22.5% of all birds). Barn owl (*Tyto alba*), tawny owl and little owl were the main victims, although there were also records of eagle owl (*Bubo bubo*), long-eared owl (*Asio otus*) and scops owl (*Otus scops*). As in road-related night mortality, train lights are likely responsible for the majority of owl kills. It was observed that little owls when perched on the train catenary, became disoriented with the approaching train, hence increasing the likelihood of being killed (Peña and Llama 1997; SCV 1996).

Birds of prey were also frequently registered as train casualties in Spanish railways being 19.2% of all birds killed (SCV 1996). The most recorded species were the buzzard (*Buteo buteo*), black kite (*Milvus migrans*) and griffon vulture (*Gyps fulvus*). One possible explanation is the attractiveness of perches along the trails and of railway verges as a hunting ground for birds of prey and owls (SCV 1996; van der Grift and Kuijsters 1998). Moreover, all three species scavenge regularly the trails for food carcasses, increasing their vulnerability to collisions (SCV 1996).

In some areas, train drivers observed several partridges (*Alectoris rufa*) using the gravel from the track ballast or within the train track on rainy days, being thus killed altogether (Peña and Llama 1997). This last behaviour of galliforme birds, seeking refuge on the train tracks, has also been referred by Havlin (1987) for the common pheasant (*Phasianus colchicus*).

As is often the case, for small or isolated populations the death of a few individuals represents a serious risk to population decline (van der Grift and Kuijsters 1998). In particular, birds of prey and owls are sensitive in this respect, even though some species may be considered common. Railway traffic is the second cause of mortality in the Netherlands for the buzzard and the kestrel (*Falco tinnunculus*), with 7.1 and 4.6%, respectively, of all dead birds found (van der Grift and Kuijsters 1998 and references therein). For the barn owl, railway traffic is a genuine danger, as 16% of mortality in Brittany (France) was caused by trains (SCV 1996). Also, for the little owl, 3.6% of deaths result from train accidents (van der Grift and Kuijsters 1998 and references therein).

Concerning the mortality of protected birds, the Spanish train personnel referred one fatal collision with one young imperial eagle (*Aquila adalberti*) in a rail section close to the nest, and collisions with several black vultures (*Aegypius monachus*) when feeding on carcasses on the rail (Peña and Llama 1997). Also, in the Swiss Alps, the collisions with trains or cars were the third cause of mortality among eagle owls, accounting for 30% of the anthropogenic mortality (Schaub et al. 2010).

Not all deaths in railways are caused by train collisions. Some of the mortality arises from the collision with the rail electric lines. This has been clearly observed in Spain for the buzzard, barn owl, eagle owl, lesser kestrel (*Falco naumanni*), sparrowhawk (*Accipiter nisus*), song thrush (*Turdus philomelos*), and starlings (*Sturnus* sp). But, still, the most frequent cause of death was train collisions (SCV 1996).

Amphibian and Reptile Mortality

As stated before, most railway studies focus only on the mortality of large species (van der Grift 1999). In addition, reports on train-collisions often underestimate the true number of collisions, as detectability and persistence rates of carcasses are rarely estimated (see Chap. 3, and van der Grift 1999), problems that affect mainly small body size species (SCV 1996). Thus, there is still an important difference between the abundance of amphibian and reptile mortality in roads and in railways. While there are plenty of data on mortality of these taxa on roads (Beebee 2013;

Hels and Buchwald 2001; Carvalho and Mira 2011), records for railways are much rarer (van der Grift and Kuijsters 1998). Unfortunately, there are no studies that compare detectability and persistence rates of carcasses between road and railway surveys, so the difference in numbers remains an open question.

Considering only the studies that aimed to survey train casualties of all species, the frequency of amphibians can reach up to 47% of all vertebrate records (Heske 2015), while the records of reptiles represent ca. 4% (Spain) and 6% (USA) of carcasses (Heske 2015; SCV 1996). In Netherlands, for example, no carcasses of amphibians or reptiles were ever found (van der Grift and Kuijsters 1998), while in Spain, only reptiles were recorded (SCV 1996).

In Chicago state, USA, amphibians were the most abundant taxonomic group recorded in train collisions (Heske 2015), mainly northern leopard frogs (*Lithobates pipiens*) and American toads (*Bufo americanus*), common species in the region. Mortalities of amphibians were particularly high after rain events, when these species are most active and are also frequently found dead on the roads (Heske 2015).

Budzic and Budzic (2014) conducted a survey specifically aimed to estimate amphibian mortality on 34 km of Polish railways. They found that three species were most affected by train accidents: the common toad (*Bufo bufo*), the common frog (*Rana temporaria*) and the green frog (*Pelophylax kl. esculentus*), and most of dead individuals (77%) were adult common toads. Although mortality rates can be high, all three species are considered common in Europe. In fact, two of the species affected by railway mortality (common toad and common frog), are among the most common European amphibians, for which there is also evidence of high road-mortality (Hels and Buchwald 2001; Matos et al. 2012; Orłowski 2007).

As in roads, the spring migration (or autumn migration, in some regions) seems to be the period of highest amphibian mortality on railway tracks, as 87% of all accidents occurred in that season (Budzic and Budzic 2014). Yet, railway mortality of amphibians seems to depend on animals' physical features (such as body size and limb length) and should be associated with the agility of the species (Budzic and Budzic 2014). While in the case of roads, the velocity of individuals is used as a proxy for agility (Hels and Buchwald 2001), in the case of railway tracks, agility relates mainly to the ability to overcome obstacles (Budzic and Budzic 2014; SCV 1996). Due to its physical features, the common toad was more likely to become trapped between rails, indicating that this species (and others with similar physical features) may be more vulnerable to railway mortality (Budzic and Budzic 2014). Some species of small size may be less vulnerable because they cannot cross the rail track (Heske 2015). However, they may be affected by railways at the level of gene flow due to barrier effects (Holderegger and Di Giulio 2010), which may be also a conservation problem.

Concerning reptile mortality, 13 snakes (4%) were recorded across the whole Spanish railway network between 1990 and 1995. Only two species were identified: the ladder snake (*Elaphe scalaris*) and the Montpellier snake (*Malpolon monspessulanus*), both common reptiles in the country (SCV 1996).

The railway bed may be lethal itself for smaller animals that can become trapped between the rails, where they may be susceptible to predation or physiological stress. This is the case of railway-induced mortality of Eastern box turtles (*Terrapene carolina*), in the USA, that often cannot escape when trapped between railway tracks. In a controlled experiment with 12 turtles, Kornilev et al. (2006) showed that most turtles clearly have the ability to escape at railway crossings, although mortality rates within the railway were still high. Notice, as well, that when between railway tracks, turtles can quickly reach critically high body temperatures, even on relatively mild days (Kornilev et al. 2006).

How Different Is Mortality in Railways and Roads?

Only a few studies have directly compared railway and road mortality, a comparison that is not easy because railway impacts are more difficult to detect (SCV 1996). Considering the diversity of taxonomic groups that are frequently killed on railways, it may be surprising that trains can cause such high mortality among some species (see ungulates, for example), because, compared to cars, trains are often less frequent, noisier, larger and, most of the times, travel at low to medium speeds (Heske 2015; Morelli et al. 2014). However, even freight trains can sometimes reach speeds close to 200 km/h and cannot stop quickly when encountering animals on the rails. This obviously leads to high mortality numbers on railways that could be avoided more easily on roads (Dorsey et al. 2015; Heske 2015). Accordingly, the number of dead bears and moose along railways often exceed death rates along roads (Belant 1995; Boscagli 1987; Modafferi and Becker 1997; Waller and Servheen 2005). On the other hand, for other species the railways may lead to lower mortality. For instance, the vibrations of approaching trains can be felt along the rails and this may give warning to some terrestrial vertebrates. This seems to be the case of snakes that may be warned of approaching trains by vibrations transmitted through the rails or the ballast (Heske 2015). In addition, while the traffic on roads can be simultaneously two-way, trains approach from one direction at a time, and the width of a road is greater than the width of a railway, decreasing the vulnerability of vertebrates that cross railways (Heske 2015). In a study that compared mortality rates between roads and railways, it was found that railways had notably lower mortalities of songbirds, small mammals, and turtles when compared to those of roads (Heske 2015), suggesting that diurnal and vagile species may be more efficient at avoiding trains than avoiding cars and trucks on busy two-way roads (Heske 2015).

Future Directions

In Spain, estimates of vertebrate mortality due to train collisions averages 36.5 vertebrates/km/year (not including high speed trains; SCV 1996). In high-speed railways, this estimate grows to, at least, 92 vertebrates/km/year (SCV 1996). Nevertheless, in general, most of the species recorded as train casualties are considered common within the adjacent natural areas (Budzic and Budzic 2014; Heske 2015; van der Grift and Kuijsters 1998). However, determining the impacts of high-speed railways is crucial because this type of railway is expanding rapidly across the world. We expect that the differences in noise levels, speed and the common fencing practices in high-speed lines promotes different impacts between these and the traditional rails (Dorsey et al. 2015).

Acknowledgements We would like to thank Infraestruturas de Portugal, and in particular João Morais Sarmento, Ana Cristina Martins, Cândida Osório de Castro and Graça Garcia, without which this book would not have been possible.

We also would like to thank Sasha Vasconcelos for her willingness to help with our constant questions on English.

Finally, we would like to thank Margaret Deignan at Springer for her invaluable help in putting together this book.

References

Beebee, T. J. C. (2013). Effects of road mortality and mitigation measures on amphibian populations: Amphibians and roads. *Conservation Biology, 27,* 657–668.

Belant, J. L. (1995). Moose collisions with vehicles and trains in Northeastern Minnesota. *Alces, 31,* 1–8.

Boscagli, G. (1987). Brown bear mortality in central Italy from 1970 to 1984. *International Conference on Bear Research and Management, 7,* 97–98.

Budzic, K. A., & Budzic, K. M. (2014). A preliminary report of amphibian mortality patterns on railways. *Acta Herpetologica, 9,* 103–107.

Carvalho, F., & Mira, A. (2011). Comparing annual vertebrate road kills over two time periods, 9 years apart: A case study in Mediterranean farmland. *European Journal Wildlife Research, 57,* 157–174.

Child, K. (1983). Railways and moose in the central interior of BC: A recurrent management problem. *Alces, 19,* 118–135.

Davenport, J., & Davenport, J. L. (Eds.). (2006). *The ecology of transportation: Managing mobility for the environment*. Dordrecht: Springer.

Deka, R. N., & Sarma, K. K. (2012). Pattern recognition based anti collision device optimized for elephant-train confrontation. *IRNet Transactions on Electrical and Electronics Engineering, 1* (2), 92–97.

Dorsey, B., Olsson, M., & Rew, L. J. (2015). Ecological effects of railways on wildlife. In R. van der Ree, D. J. Smith, & C. Grilo (Eds.), *Handbook of road ecology* (pp. 219–227). West Sussex: Wiley.

Eriksson, C. (2014). *Does tree removal along railroads in Sweden influence the risk of train accidents with moose and roe deer?* Dissertation, Second cycle, A2E. Grimsö och Uppsala: SLU, Dept. of Ecology, Grimsö Wildlife Research Station.

Forman, R. T. T., Sperling, D., Bissonette, J. A., Clevenger, A. P., Cutshall, C. D., Dale, V. H., et al. (2003). *Road ecology: Science and solutions*. Washington, DC: Island Press.

Gibeau, M. L., & Herrero, S. (1998). Roads, rails and Grizzly bears in the Bow River Valley, Alberta. In G. L. Evink, P. Garrett, D. Zeigler, & J. Berry (Eds.), *Proceedings of the international conference on wildlife ecology and transportation* (pp. 104–108). Florida Department of Transportation, Tallahassee, Florida, USA.

Gibeau, M. L., & Heuer, K. (1996). Effects of transportation corridors on large carnivores in the Bow River Valley, Alberta. In G. L. Evink, P. Garrett, D. Zeigler, & J. Berry (Eds.),

Proceedings of the international conference on wildlife ecology and transportation (pp. 67–79). Florida Department of Transportation, Tallahassee, Florida, USA.
Gundersen, H., & Andreassen, H. P. (1998). The risk of moose *Alces alces* collision: A predictive logistic model for moose-train accidents. *Wildlife Biology, 4,* 103–110.
Gundersen, H., Andreassen, H. P., & Storaas, T. (1998). Spatial and temporal correlates to Norwegian moose-train collisions. *Alces, 34,* 385–394.
Havlin, J. (1987). On the importance of railway lines for the life of avifauna in agrocoenoses. *Folia Zoologica, 36,* 345–358.
Hels, T., & Buchwald, E. (2001). The effect of road kills on amphibian populations. *Biological Conservation, 99,* 331–340.
Heske, E. J. (2015). Blood on the tracks: Track mortality and scavenging rate in urban nature preserves. *Urban Naturalist, 4,* 1–13.
Holderegger, R., & Di Giulio, M. (2010). The genetic effects of roads: A review of empirical evidence. *Basic and Applied Ecology, 11,* 522–531.
Huber, D., Kusak, J., & Frikovic, A. (1998). Traffic kills of brown bears in Gorski Kotar, Croatia. *Ursus, 10,* 167–171.
Huggard, D. J. (1993). Prey selectivity of wolves in Banff National Park. II. Age, sex and condition of elk. *Canadian Journal of Zoology, 71,* 140–147.
Huijser, M. P., Begley, J. S., & van der Grift, E. A. (2012). *Mortality and live observations of wildlife on and along the yellowhead highway and the railroad through Jasper National Park and Mount Robson Provincial Park, Canada*. Calgary, Canada: Salmo Consulting Inc., On behalf of Kinder Morgan Canada.
Jaren, V., Andersen, R., Ulleberg, M., Pedersen, P., & Wiseth, B. (1991). Moose-train collisions: The effects of vegetation removal with a cost-benefit analysis. *Alces, 27,* 93–99.
Kaczensky, P., Knauer, F., Krze, B., Jonozovic, M., Adamic, M., & Gossow, H. (2003). The impact of high speed, high volume traffic axes on brown bears in Slovenia. *Biological Conservation, 111,* 191–204.
Kornilev, Y., Price, S., & Dorcas, M. (2006). Between a rock and a hard place: Responses of eastern box turtles (*Terrapene carolina*) when trapped between railroad tracks. *Herpetological Reviews, 37,* 145–148.
Krofel, M., Jonozovič, M., & Jerina, K. (2012). Demography and mortality patterns of removed brown bears in a heavily exploited population. *Ursus, 23,* 91–103.
Kušta, T., Ježek, M., & Keken, Z. (2011). Mortality of large mammals on railway tracks. *Scientia Agriculturae Bohemica, 42,* 12–18.
Kušta, T., Holá, M., Keken, Z., Ježek, M., Zíka, T., & Hart, V. (2014). Deer on the railway line: Spatiotemporal trends in mortality patterns of roe deer. *Turkish Journal of Zoology, 38,* 479–485.
Matos, C., Sillero, N., & Argaña, E. (2012). Spatial analysis of amphibian road mortality levels in northern Portugal country roads. *Amphibia-Reptilia, 33,* 469–483.
Modafferi, R. D., & Becker, E. F. (1997). Survival of radiocollared adult moose in lower Susitna river valley, southcentral Alaska. *Journal of Wildlife Management, 61,* 540–549.
Morelli, F., Beim, M., Jerzak, L., Jones, D., & Tryjanowski, P. (2014). Can roads, railways and related structures have positive effects on birds? A review. *Transportation Research Part D, 30,* 21–31.
Munro, R. (1997). Assessing the impact of the Trans-Canada Highway and the Canadian Pacific Railway on bear movements and habitat use patterns in the Beaver Valley, British Columbia. In A. P. Clevenger & K. Wells (Eds.), *Proceedings of the second roads, rails and the environment workshop* (pp. 8–13). Parks Canada, Banff National Park, Alberta & Columbia Mountains Institute of Applied Ecology, Revelstoke, British Coliumbia, Canada.
Orłowski, G. (2007). Spatial distribution and seasonal pattern in road mortality of the common toad Bufo bufo in an agricultural landscape of south-western Poland. *Amphibia-Reptilia, 28,* 25–31.
Peña, O. L., & Llama, O. P. (1997). *Mortalidad de aves en un tramo de linea de ferrocarril* (32 pp.). Grupo Local SEO-Sierra de Guadarrama, Spain.

Rausch, R. A. (1958). *The problem of railroad-moose conflicts in the Susitna valley*. Federal aid in wildlife restoration completion reports (Vol. 12, no. 1). Alaska Resources Library & Information Services, Anchorage, Alaska, USA.

Santos, S. M., Carvalho, F., & Mira, A. (2011). How long do the dead survive on the Road? Carcass persistence probability and implications for road-kill monitoring surveys. *PLoS ONE, 6,* e25383.

S. C. V. (1996). *Mortalidad de vertebrados en líneas de ferrocarril*. Documentos Técnicos de Conservacion SCV 1, Sociedad Conservación Vertebrados, Madrid.

Schaub, M., Aebischer, A., Gimenez, O., Berger, S., & Arlettaz, R. (2010). Massive immigration balances high anthropogenic mortality in a stable eagle owl population: Lessons for conservation. *Biological Conservation, 143,* 1911–1918.

Seiler, A., & Helldin, J.-O. (2006). Mortality in wildlife due to transportation. In J. Davenport & J. L. Davenport (Eds.), *The ecology of transportation: Managing mobility for the environment* (pp. 165–189). Dordrecht: Springer.

Singh, A. K., Kumar, A., Mookerjee, A., & Menon, V. (2001). *A scientific approach to understanding and mitigating elephant mortality due to train accidents in Rajaji National Park*. An occasional report no 3 by Wildlife Trust of India and the International Fund for Animal Welfare of a Rapid Action Project on understanding and mitigating the problem of elephant mortality due to train hits.

van der Grift, E. A. (1999). Mammals and railroads: Impacts and management implications. *Lutra, 42,* 77–98.

van der Grift, E. A., & Kuijsters, H. M. J. (1998). Mitigation measures to reduce habitat fragmentation by railway lines in the Netherlands. In G. L. Evink, P. Garrett, D. Zeigler, & J. Berry (Eds.), *Proceedings of the international conference on wildlife ecology and transportation* (pp. 166–170). Florida Department of Transportation, Tallahassee, Florida, USA.

Waller, J. S., & Servheen, C. (2005). Effects of transportation infrastructure on grizzly bears in northwestern Montana. *Journal of Wildlife Management, 69,* 985–1000.

Wells, P., Woods, J. G., Bridgewater, G., & Morrison, H. (1999). *Wildlife mortalities on railways: Monitoring methods and mitigation strategies*. Revelstoke, British Columbia. Unpublished report.