

# Chapter 4

## Railways as Barriers for Wildlife: Current Knowledge

Rafael Barrientos and Luís Borda-de-Água

**Abstract** In this chapter we provide practical suggestions, together with examples, to identify, monitor and mitigate railway barrier effects on wildlife, as this is considered one of the railways' greatest impacts. Railways can be both physical and behavioral barriers to wildlife movement, as well as disturbance to populations living close to them. Also, mortality is recognized as an important contribution to the barrier effect. However, the consequences of habitat loss, and fragmentation due to railways alone remain largely unexplored. Barrier effects have mainly been mitigated with wildlife passes, with the effectiveness of this tool being one of the most-studied topics in Railway Ecology. Methods formerly employed to monitor pass usage, such as track beds or video-surveillance, are now being replaced by molecular ones. Among the latter methods, genetic fingerprinting allows individual-based approaches, opening the door to population-scale studies. In fact, genetic sampling allows for the assessment of functional connectivity, which is closely linked to successful reproduction and population viability, variables not necessarily coupled with crossing rates. There is strong evidence that railway verges offer new habitats for generalist species and for opportunistic individuals, a point that deserves to be experimentally explored in order to find wildlife-friendly policies. Preventing animals from crossing (e.g., by fencing), should be reserved for collision hotspots, as it increases barrier effects. Instead, it has been shown that warning signals or pole barriers effectively reduce collisions without increasing barrier effects. In this respect, we argue that computer simulations are a promising field to investigate potential impact scenarios. Finally, we present a protocol to guide planners and managers when assessing barrier effects, with emphasis on monitoring and mitigation strategies.

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## Introduction

We know today that linear infrastructures are one of the largest threats to biodiversity worldwide, including habitat loss and fragmentation (Forman et al. 2003; Benítez-López et al. 2010; van der Ree et al. 2015). As mentioned in the introductory chapter, most of what we know regarding this comes from studies on roads however, as some of these impacts are shared by roads and railways, many of the management tools developed for the former can be applied to the latter. Nevertheless, new approaches are needed in some cases, because some impacts are railway-specific (Dorsey et al. 2015).

This chapter provides some conceptual insight into, and summarizes in a single document, what is known about barrier effects caused by railways on wildlife populations, which is considered by some to be one of the greatest ecological impacts of these infrastructures (Iuell et al. 2003; Rodríguez et al. 2008). This review is organized as follows: We begin by identifying the factors contributing to railway barrier effects and we then describe the approaches used to study these effects, and the effectiveness of the measures implemented to mitigate them. Finally, we suggest management guidelines for railway companies, and present a protocol to minimize these barrier effects.

We searched the ISI Web of Science and Zoological Record databases for railway ecology studies. For all searches, our search terms were combinations of the following words: barrier effect, collision, fragmentation, habitat loss, impact, permeability, radio-tracking, railroad, railway, train, underpass, wildlife pass. We looked for publications in English, Spanish, Portuguese, and French. We also searched Google Scholar™ for additional studies not published in peer-reviewed journals (gray literature) but citing peer-reviewed papers, such as Ph.D. dissertations, reports, or conference papers.

## Barrier Effects

The various sources of railway barrier effects are closely related, and sometimes it is not easy to clearly separate them. For instance, noisy traffic can cause both habitat loss (if wildlife refuses to use the area adjacent to the railway right-of-way), and it can create a behavioral barrier if this noise implies a perceived risk. We identified four broad types of impacts causing barrier effects.

### *Physical and Behavioral Barriers*

Barriers can be physical, when a species cannot trespass the railway, or behavioral, when the species may be physically able to cross the barrier but does not do so because of unfavorable ambient conditions or perceived risk.

Physical barrier constraints mainly affect species of small size with reduced mobility, such as herptiles. For instance, Kornilev et al. (2006) reported that eastern box turtles (*Terrapene carolina*) in the USA enter a railway at crossings with roads (where surfaces are at the same level), but then become trapped between the rails as they are unable to climb over them, and finally die due to thermal stress. A study of Hermann's tortoises (*Testudo hermanni*) in Romania found that the impossibility of overtaking obstacles (e.g., ditches with angles of over 60°) led to an increase in the distribution of railway-kills at the end of the ditches (Iosif 2012).

Bumblebees (*Bombus impatiens* and *B. affinis*) in the USA (Bhattacharya et al. 2003) provide an example of a species to which the railway is a behavioral barrier. These species are reluctant to cross railways (and roads) because of their high fidelity to their foraging site. In experiments, individuals of these species could come back to their patches of origin after being translocated, or could leave their patch when their food was removed, but these movements were rarely in-control (non-translocated) individuals (Bhattacharya et al. 2003). Bhattacharya et al. (2003) observed that foraging bees turned back when they reached the edge of a patch (i.e., bisected by a railway); thus, rather than physically impassable barriers to bumblebees, railways acted as barriers because they are likely to be strong landmarks. On the other hand, most of the translocated gatekeeper butterflies (*Pyronia tithonus*) crossed the French High Speed Rail (hereinafter "HSR") to return to their capture plot, as this species shows a strong homing behavior (Vandevelde et al. 2012; see also Chap. 16). Mongolian gazelles (*Procapra gutturosa*) are able to cross fenced railways in Mongolia (Ito et al. 2008), but they usually do not do so (Ito et al. 2005, 2013, and see Chap. 14). Therefore, these fenced railways represented a barrier effect affecting population dynamics as it caused disruptions in long-distance gazelle migrations (Ito et al. 2005, 2008, 2013). Stopping migration routes prevents gazelles from reaching their traditional food-rich winter quarters, potentially increasing their winter mortality due to starvation (Ito et al. 2005, 2008, 2013). This conservation problem is compounded by the current climate change, as drought events reducing vegetation productivity could require gazelles to migrate longer distances, instead of the current average of 600 km (Olson et al. 2009). To date, railways do not seem to have been a barrier for gazelle gene flow, although this assertion should be explored with more suitable markers (Okada et al. 2012; see below).

Although it has been less studied, the conservation threat of the critically endangered saiga antelope (*Saiga tatarica*) in Kazakhstan—as a consequence of migration disruption due to fenced railways—seems to be similar to that of Mongolian gazelles (Olson 2013; see also Olson and van der Ree 2015). In a study carried out in Sweden, Kammonen (2015) found that a motorway and a railway running in parallel acted as barriers for two bat species (whiskered bat *Myotis mystacinus* and Brandt's bat *M. brandtii*) in a forest-dominated area. Although this author did not differentiate between these two infrastructures, she found that bats did not directly cross them; rather they used either the green bridge or the underpass both to cross it and to forage (Kammonen 2015).

## ***Disturbance***

Traffic noise, vibrations, chemical pollution, and human presence can impact animal populations living close to railways, contributing to the barrier effects (van der Grift 1999; Dorsey et al. 2015; see a more complete discussion in the Chap. 6). These impacts can be divided into those related to siting and construction, and those related to the operation of the railway line (De Santo and Smith 1993; see also Chap. 12). The former has received little attention, likely because they are considered short-term, but they can nevertheless affect local animal populations. For instance, although construction was halted during the migration period of the human-wary Tibetan antelopes (*Pantholops hodgsonii*) in China, the animals did not use wildlife passes because of the presence of machinery and debris (Xia et al. 2007). However, this species finally adapted to the presence of the railway and used wildlife passes once the was train operative (Yang and Xia 2008).

Among the long-term disturbances related to barrier effects, one of the most significant seems to be the noise produced by trains, because railways' right-of-way has little vegetation to absorb the sound, as it is frequently mowed. Studies to date have been carried out with simple census-based approaches, and have provided contradictory findings. For instance, whereas in the Netherlands, Waterman et al. (2002) found a reduction in the density of meadow birds close to railways, Wiącek et al. (2015), counting forest birds at 30, 280 and 530 m from the tracks, found higher species richness close to the railway in a Polish forest crossed by a railway. In fact, guilds like insectivorous or those ecotone-specialists were more common close to railways, and species with low-frequency calls were not averse to it (Wiącek et al. 2015). In a study in a Brazilian Atlantic forest, Cerboncini et al. (2016) did not find an effect of traffic noise (up to 120 dB, higher close to the track) on small mammals, probably because of the infrequent train passage.

Several field studies did not explore the potential causes of the abundance patterns observed and the distance to railway tracks. For instance, Li et al. (2010) found higher ground-dwelling bird richness and abundance in China close to the railway when sampled at 0, 300, 600, 900 and 1,200 m. In a study on the rodent community in the same railway, Qian et al. (2009) found no effect on species composition or densities at 50, 200 and 500 m from the railway in non-grazing areas, but grazing-disturbed areas showed different species ratios (Qian et al. 2009). The density of urban foxes (*Vulpes vulpes*) in the UK was similar in squares with and without railways (Trehwella and Harris 1990); however, in areas with poor habitat quality, fox dens were commonly placed in railway banks, most likely because they acted as refuges (Trehwella and Harris 1990).

## ***Mortality***

Chapters 2 and 3 deal exclusively with the impact of railways on wildlife mortality; however, because we consider mortality to be a barrier effect, and in order to ensure that current chapter is self-contained, we now summarize the main results.

Train-related mortality can directly prevent connectivity among sub-populations, or reduce their reproductive success, if individuals seeking mates die or if their offspring are railway-killed. Wildlife-train collisions (hereinafter “WTC”) are the most commonly documented source of animal mortality, although electrocution or collisions with wires can also occur (Rodríguez et al. 2008; Dorsey et al. 2015). A recently documented source of mortality is that of cavity nester birds in uncapped catenary poles from HSR in Spain, as these tubular poles act as pitfall traps for birds, because poles have smooth internal walls, not allowing birds that enter them to fall down to fly out (Malo et al. 2016). As the drainage hole at the base of the pole is too narrow to allow trapped birds to escape, the problem could be readily solved by simply capping the tops of all types of tubular poles (Malo et al. 2016). A non-exclusive mitigation alternative would be to widen drainage holes.

Most of our understanding about railway impacts on wildlife comes from studies focused on large mammal railway-kills, as they are the most conspicuous, and can cause accidents, delays to the trains’ operation, significant damage to trains due to their large size, and, overall, significant financial losses (Dorsey et al. 2015, and also Chap. 17). Among train-related factors influencing the rates of WTC, traffic flow is the most important one, with the highest mortality occurring, in fact, in lines with moderate traffic flow because higher traffic volume deters animals from attempting to cross (Dorsey et al. 2015). For instance, in the USA, the killing by trains of black bears (*Ursus americanus*) attempting to cross areas with low vegetation cover through train bridges in lines with moderate traffic has been documented (van Why and Chamberlain 2003). The existence of lapses of time without traffic encourages the bears to cross the valley by the bridge, and these are railway-killed when a train arrives and they cannot jump off the railway bed (van Why and Chamberlain 2003).

Animal behavior also determines their mortality rates. The isotope analyses using brown bear (*U. arctos*) hair in Canada showed that some individuals fed on carcasses from train-killed animals, or on plants growing in railway verges (Hopkins et al. 2014; see also Wells et al. 1999; see also Chap. 9). Similarly, granivore species in Canada consumed grain spilled by wagons (Wells et al. 1999), and in Norway moose (*Alces alces*) took advantage of the availability of branches resulting from logging activities in the right-of-way (Gundersen et al. 1998). On the contrary, despite Cerboncini et al. (2016) trapped more small mammals close to the tracks in Brazil, their body condition was similar to that of animals trapped far from the railway. Thus, it seems that this guild of Atlantic forest specialists was not taking advantage of grain falling from trains (Cerboncini et al. 2016). Railways can also facilitate the movements of some species, as wildlife uses these homogeneous surfaces for travelling faster. This was the case of moose and wolves (*Canis lupus*) in Canada, and moose and roe deer (*Capreolus capreolus*) in Sweden, when snow was very deep (Child 1983; Paquet and Callaghan 1996; Eriksson 2014), of brown bears in Slovenia, when the terrain was steep (Kaczensky et al. 2003).

One frequently neglected issue is to what extent WTCs could affect population dynamics. In some species, this impact seems small, but in others it could be important. This impact can also vary at the population level, as was the case of different moose populations in the USA, with WTCs ranging from less than 1%

(Belant 1995) to 70% (Schwartz and Bartley 1991) of the estimated population size, or 5% of adult radio-collared animals ( $n = 204$ ; Modafferi and Becker 1997). For brown bears, it varied from 5% of radio-tracked animals in the USA ( $n = 43$ ; Waller and Servheen 2005) to 18% in Slovenia ( $n = 17$ ; Kaczensky et al. 2003). The mortality due to collisions with trains affected 5% ( $n = 21$ ) of the radio-tagged eagle owls (*Bubo bubo*) in Switzerland, with WTCs being less important than electrocution and cable or car collisions (Schaub et al. 2010). However, all these figures provide little information without the corresponding population viability analyses (PVAs). In this sense, the latter paper estimated an annual 31% of population growth if the entire anthropogenic mortality of eagle owls was eliminated, but without information on the effects of removing WTCs alone (Schaub et al. 2010).

### ***Habitat Loss and Fragmentation***

Habitat loss takes place when railway construction leads to the reduction of the available habitat, since the transformed railway bed is unsuitable for several species. Habitat fragmentation is often, but not necessarily, mediated by habitat loss. During fragmentation, large, continuous fragments are divided resulting in smaller, often isolated, patches that may not be able to maintain viable populations in the long run (Fahrig 2003). Whereas general information on habitat fragmentation is abundant (see Fahrig 2003 for a review), studies exclusively focused on railway-related fragmentation are non-existent, because researchers did not differentiate between railway- and road-related fragmentation, assessing these two different infrastructures as a whole (e.g., Jaeger et al. 2007; Girvetz et al. 2008; Bruschi et al. 2015).

When a population's territory is bisected by a railway, part of its habitat is lost, and the remainder may be degraded, usually via cascade effects. The latter is what is happening to the woodland caribous (*Rangifer tarandus*) in Canada, as the construction of railways and other linear infrastructures facilitated the access of wolves to remote areas where there are still populations of this ungulate, being their viability threatened (James and Stuart-Smith 2000; Whittington et al. 2011).

Habitat changes also take place in railway corridors, as their verges commonly differ from the surrounding landscape, but are homogeneous along the railway network. These changes can be exploited by generalist species or by opportunistic individuals, using them as shelters or corridors. They can be used by invasive species as well (for more details on the latter, see Chap. 5). Some authors have suggested that the creation of new habitats by mowing the right-of-way, and the presence of associated structures like powerlines and their pylons, provide new opportunities for several species to breed or hunt (see Morelli et al. 2014 regarding birds). For instance, Vandavelde et al. (2014) (see Chap. 16) found that in France, in intensive agricultural landscapes, where linear semi-natural elements like hedgerows tend to disappear, bat species that forage in more open habitats benefited from railway verges. For Polish butterflies, railways not only acted as corridors, but also sheltered greater species richness than forest clearings or degraded meadows

(Kalarus and Bąkowski 2015). The wide range of environmental conditions occurring in tracks, led to the presence of a large number of nectar plant species, allowing the existence of many butterfly species, from those selecting dry and warm microhabitats to forest specialists (Kalarus and Bąkowski 2015). Similar results have been found for other pollinators due to the high diversity of bee forage flora, although their diversity is higher in lines with intermediate traffic volume, and differs between microhabitats within the embankments (Wrzesień et al. 2016). On the contrary, Cerboncini et al. (2016) found no effects of railway edge on microclimate in a Brazilian Atlantic forest, probably because railway track was narrow and the forest was well developed. Finally, especially in more impacted landscapes, there is an opportunity to integrate old tracks once they are abandoned into the regional conservation schema. They can act, for instance, as habitat corridors among protected areas, as many of their new uses—like rail-cycle or hiking—are wildlife-friendly activities. However, much more research is needed on the conservation potential of abandoned tracks as well as on cost-effective maintenance methods, like the weeding by domestic animals used in France (Orthlieb 2016). Also in France, Kerbiriou et al. (2015) found a strong increase in the population of hibernating pipistrelle bats (*Pipistrellus pipistrellus*) in a railway tunnel as a result of the end of the exploitation of the railway line, remarking on the idea that abandoned railway structures can have second-life fulfilling conservation purposes.

## Methods to Estimate Barrier Effects

Some of the methods we describe below were first used in road ecology studies (Smith and van der Ree 2015), but all of them are useful for railway ecology studies as well.

### *Direct Methods*

- (1) *Wildlife-train collisions data*. This is the simplest method to estimate barrier effects due to wildlife mortality. A reduction of WTCs after applying mitigation measures has been commonly argued to be a measure of the effectiveness of management policies (e.g., Andreassen et al. 2005; Kušta et al. 2015), although WTC data without PVAs may be a poor surrogate of the impact of the railway.
- (2) *Track beds*. These consist of a layer of fine sand, marble dust, or clay powder of 3–30 mm thick, spread across the entire pass (usually underpass or culvert), and smoothed with a brush. It should be fine enough to detect the tracks of small vertebrates such as mice or amphibians, or even macroinvertebrates. The pass must be reviewed every 1–2 days and, if necessary, the material must be removed and extra material added (Yanes et al. 1995; Rodríguez et al. 1996; Baofa et al. 2006). This method, combined with strips of soot-coated paper, as well as

trapping and indirect evidence, such as scat identification, was used in Australia for the first time by Hunt et al. (1987). This technique has been repeatedly improved, as it was the first widely used method to confirm culvert/wildlife pass usage. Due to its low costs, it is more cost-effective for short-term surveys than modern alternatives, like video-surveillance (Ford et al. 2009; Mateus et al. 2011). However, the use of track pads is limited to optimal conditions, as the material employed can become useless by rain or livestock passage (Rodríguez et al. 1996, 1997; Mateus et al. 2011), and there can be track misidentification and underestimation of crossings due to track overlapping (Ford et al. 2009). Tracks in snowy landscapes can help to estimate the qualitative crossing of certain sections (Olsson et al. 2010), although limitations of this method regarding misidentification and track overlapping are similar to those from sandy beds.

- (3) *Video-surveillance*. Modern technology allows the monitoring of pass usage thanks to cameras activated by infrared motion detectors at the pass entrance (Ford et al. 2009; Mateus et al. 2011). This method is constrained by the sensitiveness of the camera monitor sensor (Ford et al. 2009), which is especially limiting in large passes and with small animals (Mateus et al. 2011), because video cameras cover small areas and only animals close to the sensor are recorded (Ford et al. 2009; García-Sánchez et al. 2010; Mateus et al. 2011). Thus, a logical next step to evaluate the use of wildlife passes has been the development of wireless sensor networks (García-Sánchez et al. 2010). These are low-cost devices that, by using a camera at the entrance of the pass and an infrared motion sensor network deployed in the surrounding area, enable the recording of reactions of animals approaching the wildlife pass and their eventual crossings (García-Sánchez et al. 2010).
- (4) *Capture-mark-recapture* (hereinafter “*CMR*”). These are fine-scale methods as they are individual-based, but they are intrusive, time- and budget-consuming, and require safety measures both for the animals and the researchers working around the transport infrastructures; all this leads to small- to modest-sized samples (Simmons et al. 2010). Tagging must be adapted to the size and the ecology of the target species. *CMR* with numbered plastic tags allowed Bhattacharya et al. (2003) to monitor bumblebee movement across a railway, with a recapture rate of 31% ( $n = 367$ ). In France, Vandeveldé et al. (2012) (see Chap. 16) used a thin-point permanent pen to mark gatekeeper butterflies with a recapture rate of 30% ( $n = 149$ ). Alternatively, passive integrated transponders have been proven to be useful to monitor wildlife passages. Once the animal crosses, an antenna connected to a decoder unit installed in the pass records the individual, time, and date of crossing (recapture rate = 50%,  $n = 6$ ; Soanes et al. 2013).

Radio-tracking-based projects share some of the advantages (fine-scale, individual-based) and disadvantages (intrusive, time- and budget-consuming) of the previous methods, although the increasing effectiveness (e.g., satellite-based telemetry) and decreasing price currently make radio-tracking suitable for a wide variety of organisms (Simmons et al. 2010). Furthermore, the devices are becoming miniaturized to the point of being a feasible alternative for some invertebrates (e.g.,

Hedin and Ranius 2002). Radio-tracking can also provide detailed information, not only on individual crossings, but also on the full territory use by animals relative to the railway location, therefore allowing the impact of the linear infrastructure on the movements of individuals to be estimated (Clevenger and Sawaya 2010).

Non-invasive genetic sampling (hereinafter “NGS”) methods have been used mainly to measure the genetic sub-structure of a population bisected by a railway (see below). However, NGS also enables individual identification based on microsatellite analysis (Balkenhol and Waits 2009; Clevenger and Sawaya 2010; Simmons et al. 2010), the so-called “fingerprinting” or “DNA profiling,” which is a kind of capture-mark-recapture method. For instance, Clevenger and Sawaya (2010) showed that the passive hair-collection methods based on barbed wire and/or adhesive strings, followed by microsatellite analyses, was an effective technique for monitoring wildlife pass use at an individual level for cougars (*Puma concolor*), and black and brown bears in Canada. Furthermore, as costs for genetic analyses are become lower, the sample sizes have increased in recent studies (Simmons et al. 2010). The main limitation of this method is that it is only suitable for large animals whose remains (hairs, feathers, scats) can be found in the field in sufficient quantity to extract DNA from them. In addition, fingerprinting requires a relatively high number of microsatellites. If species-specific microsatellites have not been developed in the target species, they have to be specifically developed, increasing both time and costs. However, microsatellites already developed for related species can be tested, as sometimes they can amplify the DNA from the target species as well.

### ***Indirect Methods***

- (1) *Census at both sides of a railway*. This is the most simplistic approach, either to assess population densities (e.g., Waterman et al. 2002; Li et al. 2010; Wiącek et al. 2015), or to calculate diversity indices of community structures (e.g., Qian et al. 2009). However, it is also the most limited approach to identifying causal factors or population dynamic-related processes. Failure to control for potentially confounding variables makes that detected patterns cannot be clearly associated with railway impact.
- (2) *Genetic-based assessment of functional connectivity*. Even more important than confirming crossing is to assessing the functional connectivity (or the barrier effect)—that is, to detect whether individuals reproduce on both sides of the railway. It is worth noting that moderate to low crossing rates may not necessarily imply functional connectivity (Riley et al. 2006). This type of information is logistically difficult to obtain using other than genetic methods (Clevenger and Sawaya 2010; Simmons et al. 2010).  
Because the impact of railways is relatively recent, highly variable markers such as microsatellites are the most suitable method for estimating demographic

and population genetic effects. Balkenhol and Waits (2009) found that 76% of the 33 reviewed studies employed these markers in road ecology studies (see below for railway studies). Indeed, authors who used mitochondrial analyses failed to find genetic structuring related to railway-related barrier effects, as happened with the Mongolian gazelle (Okada et al. 2012).

The easiest design consists of sampling individuals at both sides of a railway to infer whether this acts as a barrier driving population differentiation. This approach was used by Gerlach and Musolf (2000) to study the genetic substructuring between bank vole (*Clethrionomys glareolus*) populations bisected by a railway in Germany and Switzerland. The authors found that a 40-year-old railway did not contribute to genetic substructuring in bank voles. In their study in the USA with the marbled salamander (*Ambystoma opacum*) in the USA, Bartoszek and Greenwald (2009) found that the populations from two ponds just separated by a railway, although potentially connected by a culvert, were genetically differentiated, although some gene flow was still occurring. On the contrary, the Qinghai-Tibetan railway seems not to be a barrier structuring the toad-headed lizard (*Phrynocephalus vlangalii*) populations, as samples from both sides of the railway were genetically similar, whereas those sampled at 20 km away were different, as expected due to the distance (Hu et al. 2012).

Genetics should be complemented with landscape analyses to control, among other things, for the relationship between genetic and geographic distances. Reh and Seitz (1990), using a sample design that included several sites and enzyme analyses, found that railways contributed to the isolation, and thus the inbreeding, of common frogs (*Rana temporaria*) in Germany. Yang et al. (2011) used landscape analysis and genetics based on microsatellites to identify the factors influencing the differentiation among Przewalski's gazelle (*P. przewalskii*) populations in China. Prunier et al. (2014) used a microsatellite individual-based sampling scheme combined with computer simulations to determine whether HSR in west-central France was old enough to cause genetic discontinuities in the alpine newt (*Ichthyosaura alpestris*). The latter authors did not detect any barrier effects, which could be due both to the relatively recent existence of the railway (29 years), or to the highly nomadic behavior of this amphibian. Also, the small size of newts could allow them to move under the rails, minimizing their risk of being railway-killed. The few smooth newts (*Lissotriton vulgaris*), a species of similar size, that were found railway-killed in Poland, were found at pedestrian crossings, where newts are forced to move over instead of under the rails (Kaczmarski and Kaczmarek 2016). On the other hand, the simultaneous use of genetic approaches and landscape analyses has also shown that linear infrastructures can, in some cases, increase connectivity. For instance, the use of microsatellites enabled Fenderson et al. (2014) to identify railways, powerlines, or even road sides as dispersal facilitators of New England cottontails (*Sylvilagus transitionalis*), but their approach was limited as they did not evaluate the relative importance of each of these infrastructures to the observed increase in connectivity. Such an increase in the landscape

connectivity can be detrimental in some cases, such as that of invasive species, a theme that is discussed at length in Chap. 5.

- (3) *Computer Simulations*. These tools have the potential to play a major role in understanding the impact of railways in wild animal populations and, accordingly, in planning new railway networks or developing mitigation measures. However, to the best of our knowledge, there are only a few simulation studies that specifically target the impact of the fragmentation caused by railways. Simulations can be used before and after railway construction. Before the construction phase, an impact assessment is desirable to compare alternatives. In particular, it is important to avoid cutting through areas of great natural value, but if this is unavoidable, then it is necessary to identify the sectors most affected in order to implement mitigation measures. In such situations, a region-wide focus that includes future projections is the most suitable approach. For these purposes, graph theory is being increasingly used in conservation biology, as graph models provide simplified representations of ecological networks with flexible data requirements (Urban et al. 2009). For instance, Clauzel et al. (2013) (see also Chap. 13) combined graph-based analysis and species distribution models to assess the impact of a railway line on the future distribution of the European tree frogs (*Hyla arborea*) in France. This study was able to identify—among potential routes—the railway line with the lowest impact on the species distribution.

Mateo-Sánchez et al. (2014) conducted computer simulations to assess the degree of connectivity of two populations of the endangered brown bear in north-western Spain. They used a multi-scale habitat model to predict the presence of bears as a function of habitat suitability, combined with a factorial least-cost path density analysis. With this model, the authors identified possible corridors that could connect the two populations and the locations that should be prioritized in order to ameliorate the permeability of the local railways (and roads). In a study to identify the most suitable corridor in a future railway line in Sweden, Karlson et al. (2016) integrated models with ecological and geological information by using spatial multi-criteria analysis techniques to generate a set of potential railway corridors, followed by the application of the lowest cost path analysis in order to find the corridor with the best environmental performance within the set.

Much of what has been learned from simulations applied to the impact of roads (e.g., Roger et al. 2011; Borda-de-Água et al. 2011) can also be used in railway ecology. Among the techniques used, we highlight the individuals-based models, (hereafter “IBM”) (e.g., Lacy 2000; Jaeger and Fahrig 2004; Kramer-Schadt et al. 2004; Grimm et al. 2006). While more traditional simulation approaches use variables to study the collective behavior of certain entities (for instance, an entire population could be characterized by a single variable describing the total number of individuals), IBMs explicitly simulate all individuals as separate entities, each with its own set of characteristics, and interacting among them and with the environment. The main advantage of

IBMs is that we are no longer constrained by the difficulties of obtaining analytical or numerical solutions using differential calculus, or are dependent on the mathematical tractability of complicated systems of differential (or integral) equations (Railsback and Grimm 2011). With IBMs, one can model a wide variety of behaviors, thus increasing the realism of the models—although often at the expense of time consuming simulations.

The most effective tools for reducing barrier effects, such as overpasses or viaducts, increase construction costs considerably (Smith et al. 2015). Therefore, either before or after railway construction, simulations at the landscape level can be used to identify the location and type of the mitigation measures to be implemented. For instance, Gundersen and Andreassen (1998) included both train- and environment-related variables to model the occurrence of WTCs during seasonal moose migration to valley bottoms, when WTC risk is highest (Gundersen et al. 1998). and they tested the model predictability with a subset of data not used for model development, a method that can be used to infer future WTCs (Gundersen and Andreassen 1998).

## Effectiveness of Mitigation Measures

### *Avoiding Crossing*

Several studies have tested measures, like fencing, to avoid animal crossings of railways. These can reduce WTCs but, on the other hand, they can increase barrier effects (e.g., Ito et al. 2005, 2008, 2013; see also Chap. 14). Thus, they should only be implemented in areas of high concentration of WTCs, and combined with wildlife passes to maintain railway permeability (van der Grift 1999). Building exclusion fences seems the most effective (van der Grift 1999; Ito et al. 2013), and is even the most cost-effective measure, in the long run (Dorsey et al. 2015). The application of odor repellents reduced animal mortality in a study in the Czech Republic, but with contrasting results among taxa (Kušta et al. 2015). This technique was less effective at low temperatures, when repellents froze (Kušta et al. 2015; see also Castiov 1999). Indeed, Andreassen et al. (2005) found odour repellents to have highly variable efficiency in reducing moose WTCs in Norway. Instead, these authors found a more consistent decrease in WTCs after the placement of feeding stations to keep animals away from railways, and forest clearing in the vicinity of the railway (Andreassen et al. 2005).

Interesting alternatives are those devices that aim to reduce WTCs without having barrier effects (see Chap. 17). For example, trains equipped with ultrasonic warning devices killed fewer moose in Canada than those without (Muzzi and Bisset 1990). More recently, Babińska-Werka et al. (2015) reported the development of a device in Poland that uses alarm calls from several wild animals in advance (30 s to 3 min) of an oncoming train that allows animals near the railway

to react and escape in a natural way. The proportion of wildlife escaping from the tracks was higher, and individuals reacted faster, when the device was switched on and, importantly, animals did not show evidence of habituation to the warning signals (Babińska-Werka et al. 2015).

Planting trees (Tremblay and St. Clair 2009) or erecting pole barriers (Zuberogitia et al. 2015) in the railway corridor can reduce the WTCs of flying animals. However, trees could attract animals as well, for perching or feeding, so pole barriers are preferred since they have fewer side effects. An experiment with medium- to large-sized birds in Spain showed that most birds shifted or raised the flight when approaching the pole barrier (Zuberogitia et al. 2015).

### *Habitat Management*

Vegetation mowing at railway verges was successfully applied to reduce moose WTCs in Norway, and it could have had three complementary benefits: first, reducing the attractiveness of the verges for animals, therefore reducing foraging close to railways (Jaren et al. 1991; Andreassen et al. 2005); second, reducing the time spent by animals close to the railway, as they could perceive the clearing as dangerous (Jaren et al. 1991); and, third, allow them ‘see and be seen’ rule, as provided for both the train driver and the animal, with a greater amount of time to react to each other and avoid a collision (Jaren et al. 1991). This technique reduced the number of moose WTCs by half (Jaren et al. 1991; Andreassen et al. 2005). On the contrary, Eriksson (2014) originally hypothesized that tree-clearing could be the factor behind the increase in moose and roe deer train collisions in Sweden, as early successional stages created after mowing provided attractive foraging opportunities for ungulates, but she found that it had no effect on the increase of WTCs in her “Before-After-Control-Impact”, the so-called BACI design (Eriksson 2014). Finally, it is worth mentioning that vegetation removal may increase barrier effects for small vertebrates, as these do not cross open spaces due to their associated high predation risks (Hunt et al. 1987; Yanes et al. 1995).

### *Crossing Structures*

Animals use both non-wildlife passes (i.e., those placed and designed for purposes other than to allow wildlife crossing, like drainage culverts), or wildlife passes specifically designed on the basis of the target species traits (small tunnels for amphibians or small mammals; underpasses, overpasses, ecoducts or green bridges for large mammals) (Smith et al. 2015). Large passes mimicking natural habitat are more expensive, but they are also the most effective technique for reducing barrier effects, commonly suitable for most species, including the most demanding ones, like large carnivores and ungulates (Iuell et al. 2003; Clevenger and Waltho 2005; Smith

et al. 2015). In some cases, structures that were not originally designed as wildlife passes have been adapted to better allow animal crossings. For instance, culverts were modified by the addition of a bench to facilitate wildlife crossing when the culvert is wet (Iuell et al. 2003). In some cases, the adaptation is as easy as removing the gravel below pairs of sleepers to create a gap to allow small vertebrates, like spotted turtles (*Clemmys guttata*) in the USA, to cross under the sleepers, to where they were funnelled by a fence (Pelletier et al. 2006). Culverts have been found to be used by animals to bypass railways in Australia (Hunt et al. 1987) and in Spain (Yanes et al. 1995; Rodríguez et al. 1996, 1997). However, culvert dimensions or the surrounding habitats influence their use by vertebrates (Hunt et al. 1987; Yanes et al. 1995; Rodríguez et al. 1996, 1997). For instance, small culverts were used by small mammals, but they were unsuitable for ungulates (Rodríguez et al. 1996) and the addition of natural vegetation and refuges such as stones increased crossing rates for small animals (Hunt et al. 1987; Yanes et al. 1995). Not unexpectedly, longer passes have lower crossing rates for several taxa (Hunt et al. 1987; Yanes et al. 1995).

Notice, however, that all the examples of pass monitoring reported, at the most, the intensity of crossing, not the functional connectivity—two variables that are not necessarily coupled (Riley et al. 2006). Thus the implementation of these mitigation measures should be complemented with genetic analyses at the population level to assess whether they contribute to the effective reduction of barrier effects (Riley et al. 2006).

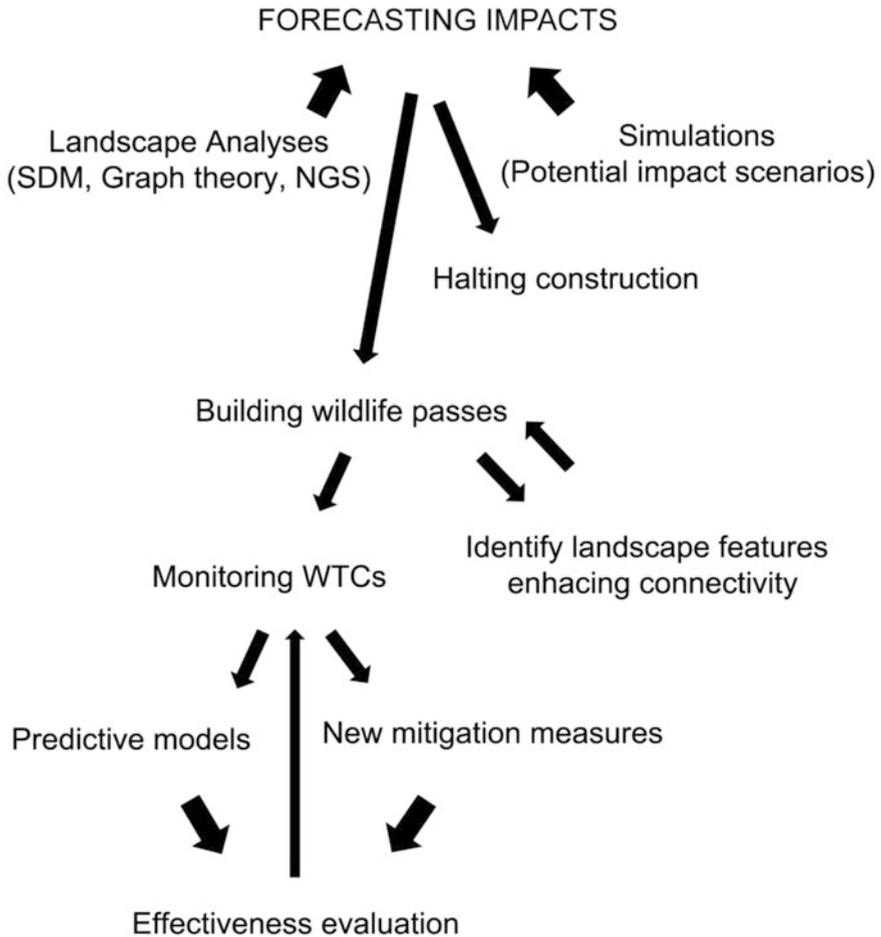
## Management Guidelines

In Fig. 4.1 we present in a schematic way the steps to be followed in an “Ideal Protocol to Mitigate Railway Barrier Effects”. These include:

### *Forecasting Impacts*

To know the wildlife status in the whole region, it is necessary to assess the impact of potential routes, to understand the target-species ecology, as WTCs are usually correlated with animal abundance (e.g., D’Amico et al. 2015), and the latter can temporally and geographically change along the biological cycle (e.g., moose in Canada or Norway; Child 1983; Gundersen et al. 1998; or sika deer *Cervus nippon* in Japan; Ando 2003). Impacts can be predicted by NGS (Balkenhol and Waits 2009) or by censuses (Species Distribution Models, Clauzel et al. 2013). In addition, individual assignment tests and graph theory could be combined in landscape analyses to identify connectivity zones that should be preserved, and computer simulations could be run to evaluate population dynamics under several barrier effect levels (Balkenhol and Waits 2009; Clauzel et al. 2013). Thus, by combining these approaches, planners will be able to select the alternatives with the lowest barrier effects on wildlife.

## IDEAL PROTOCOL FOR MITIGATING RAILWAY BARRIER EFFECTS



**Fig. 4.1** Ideal protocol for mitigating railway barrier effects

### *Halting Construction*

Disturbances should be minimized during strategic stages of the life cycle of the target species, as when construction of the railway was halted to allow the migration of the Tibetan antelopes in China (Xia et al. 2007) or the reproduction of wetland birds in Portugal (see Chap. 12).

### ***Wildlife Passes Combined with Funnelling Fencing***

This approach should be considered only in those railway sections previously identified with landscape analysis studies to be particularly suitable to maintain connectivity, since their construction is expensive. The option of elevating the railway on pile-supported structures is usually more feasible than it is for similar highway segments (De Santo and Smith 1993). Demanding species, such as large animals, prefer to cross under bridges rather than through underpasses (Rodríguez et al. 1996; Baofa et al. 2006; Yang and Xia 2008) but, on the other hand, bridges can represent a risk for flying species as they tend to cross above them (Tremblay and St. Clair 2009). Thus, bridges should be flanked by pole barriers to ensure safe passage well above moving traffic (Zuberogitia et al. 2015). Finally, functional connectivity should be evaluated with molecular methods and BACI designs implemented to know the effectiveness of mitigation measures (Balkenhol and Waits 2009; Corlatti et al. 2009; Clevenger and Sawaya 2010; Simmons et al. 2010; Soanes et al. 2013).

### ***Identify Landscape Features Enhancing Connectivity***

The identification of those features that enhance landscape connectivity and their adoption when designing and operating railways should be promoted. For instance, as mowed railway rights-of-way have been found to restore population connectivity the for New England cottontail, an early successional habitat specialist of conservation concern, a management recommendation to reduce the isolation of their populations is not to allow vegetation development beyond shrub stratum (Fenderson et al. 2014).

### ***Monitoring of WTCs to Identify Hotspots***

A periodic schema should be implemented to monitor the railway line to identify sections with high collision rates, i.e., hotspots, and simulation models should be built to forecast WTCs (Gundersen and Andreassen 1998). In identified hotspots, anti-collision measures, such as warning signals (Babińska-Werka et al. 2015; see also Chap. 17) or pole barriers, (Zuberogitia et al. 2015) should be placed. Their effectiveness should be monitored with BACI designs.

## Conclusions

Railways can cause barrier effects in several ways. Some, like mortality, have been widely studied for some charismatic species, but their effects for others are poorly known. Studies on barrier effects due to behavioral responses to disturbances or the effects of habitat loss and fragmentation due to railway implementation are scarce. The monitoring of the effectiveness of mitigation measures should incorporate more recent approaches, such as genetic tools. It would allow, for instance, to broaden the current scope based on the qualitative use of wildlife passes to a more interesting functional connectivity-based framework. The use of computer simulations has advantages not fully applied at present, but useful both before railway construction and during its operation.

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