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Manual

Fauna Sensitive Transport Infrastructure Delivery Chapter 4: Impacts of roads, railways, traffic, and trains on fauna

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Key Points

- The impacts of roads, railways, traffic, and trains on fauna are numerous, significant, and mostly deleterious.
- Impacts can extend many hundreds to thousands of metres from transport infrastructure, over an area called the 'road and railway effect zone' (REZ).
- Impacts can occur at any stage of a project, as well as during the operation and maintenance of transport infrastructure.
- Effects include fauna mortality from wildlife-vehicle collisions (WVC), electrocution, barrier effects, habitat loss, and habitat degradation from noise, light, and environmental pollution.
- The severity of the impacts is influenced by the design and location of the infrastructure, vehicle movements, and species involved.
- Transport infrastructure corridors can sometimes provide important habitat and corridor functions, especially for threatened species.

Contents

Tables

Figures

Case Studies

1 Introduction

This chapter describes the impacts of transport infrastructure on fauna. It does not explore solutions or mitigations for these impacts. These are discussed in detail in mitigation (Chapter 6), maintenance (Chapter 8), and the species profiles (Chapter 9–21) chapters.

The impacts of transport infrastructure on fauna are numerous, varied, and often harmful. Transport infrastructure can directly and indirectly affect fauna. The extent and severity of each impact is influenced by numerous interacting factors, including the:

- Characteristics and behaviour of the fauna species (e.g. body size, movement patterns, tendency and ability to avoid oncoming traffic).
- Design and location of the transport infrastructure (e.g. number of lanes, in cuttings or on fill, passing through urban or natural areas).
- Adjacent habitat and topography (e.g. type and quality of habitat, conservation status of the habitat type).
- Characteristics of the vehicles using the transport corridor (e.g. the speed, volume, and/or timing of vehicles).

This chapter describes:

- The different types and categories of ecological impacts of transport infrastructure on fauna.
- Differences and similarities in impacts of different transport infrastructure.
- The road- and railway-effect zone (REZ).
- When impacts can occur.

2 Types of ecological impacts

The ecological impacts of transport infrastructure can be direct, indirect, associated, cumulative, and/or synergistic (Table 2(a)).

While there has been considerable debate about the classification of impacts and effects, the critical aspect is that the full range of potential impacts of a project are identified, and their importance evaluated[1]. In some contexts, 'direct' is used to describe physical impacts (e.g. wildlife-vehicle collisions (WVC), habitat clearing) while indirect describes more behavioural impacts (e.g. avoidance of the road clearing, artificial light at night (ALAN)). However, this chapter uses the definitions in Table 2(a).

[1] (Treweek 1999)

Table 2(a) – Definition of impact types

TYPE OF IMPACT	DEFINITION	EXAMPLE
Direct	An impact that is directly attributable to a defined action.	WVC, habitat clearing to build the transport infrastructure, electrocution on overhead powerlines.
Indirect	An impact that is attributable to a defined action or stressor, but that affects an environmental or ecological component via impacts on other components. Indirect impacts are often, but not necessarily, time-delayed or expressed at some distance from their source.	Weed invasion, changes to the food chain resulting from attraction to ALAN.
Associated	Ecological impacts attributable to linked or associated actions or activities.	Quarrying rock for transport infrastructure construction.
Cumulative	An umbrella term for one or more impacts that accumulate over space or time.	The combined impact of the transport infrastructure network in an area.
Synergistic	A type of cumulative impact where multiple impacts, each with their own significance levels, become even more significant when combined. The multiple impacts are greater than the sum of their parts.	The impact of mortality from WVC is even higher when a species population is also experiencing mortality pressure from feral predators and vice versa

Source: adapted from Treweek (1999)

A direct impact occurs when an activity affects a specific environmental receptor without being mediated in any way through interaction with other components[2]. An indirect impact is attributable to the transport infrastructure but occurs via other effects on components in the ecosystem. The classification of many impacts of transport infrastructure is straightforward but calculating the 'degree of causality' for an indirect impact can be difficult when the impact can be attributed to the transport infrastructure, but not directly caused by it. In these situations, indirect impacts can occur along a continuum. For example, the mortality of fauna due to WVC is clearly a direct impact, but the severity of the impact of the loss of those individuals on the local population and interacting community can be more uncertain. The flow-on effects of these changes in populations and communities are also indirect impacts but are another step beyond the direct impact (i.e. WVC) and the initial indirect impact (the effect of the loss of animals). This demonstrates that attempting to attribute the 'degree of causality' can be fraught with uncertainty. Rather, the key is to understand how an impact affects an ecological receptor, the mechanism(s) behind the impact, and the effects on fauna.

The same broad impact category can have direct or indirect impacts as described in Table 2(b). For example, ALAN can have a direct impact on invertebrates that are attracted to or repelled by the light, a direct impact on bats that avoid lit areas, an indirect impact on bats that are attracted to the increased abundance of invertebrates, and a direct loss of suitable habitat in the REZ (Section 4).

[2] (Treweek 1999)

It is also important to understand that the significance of an impact is not related to the type of impact. In other words, it should not be assumed that direct impacts are worse and require greater effort to avoid, minimise, and mitigate than indirect impacts. In some cases, the consequences of indirect impacts can exceed a direct impact, such as the indirect loss of habitat in the REZ rather than direct loss of habitat through clearing.

Table 2(b) and Figure 2 outline the main categories of impacts of transport infrastructure on fauna.

Most impacts of transport infrastructure have negative consequences for biodiversity, however they can also have positive impacts, such as the provision of habitat and corridors for movement in highly cleared landscapes (Section 9). Sometimes these positive benefits can result in negative impacts, such as WVC for species utilising habitat along transport infrastructure.

Table 2(b) – Examples of direct and indirect ecological impacts of transport infrastructure[3]

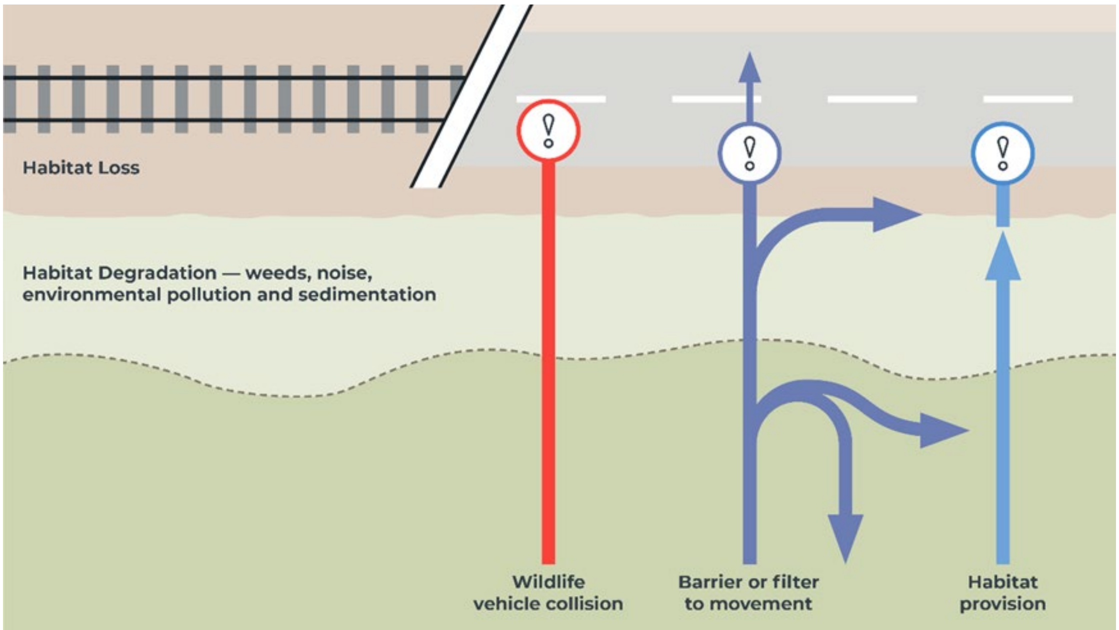
IMPACT CATEGORY	DIRECT IMPACT	INDIRECT IMPACT
Wildlife-vehicle collision (WVC)	• Injury or death of fauna. • Injury or death of motorists. • Vehicle damage. • Electrocution on overhead powerlines	• More scavengers in the area feeding on dead fauna. • Higher rates of predation and WVC occurring because more predators in area.
Barrier or filter to movement	• Reduced fauna movement. • Reduced gene flow. • Reduced foraging success. • Inability to seek and utilise refuge habitats. • Reduced reproductive success where obligatory movement is required past the barrier.	• Reduction in genetic diversity over time. • Decline of species reliant on movement of a host for survival, dispersal etc. (e.g. dispersal of fleshy fruit by cassowary). • Changes in food chain and ecosystem relationships if species are blocked from or filtered through an area.

[3] (van der Grift 1999, Morelli et al. 2014, van der Ree et al. 2015a, Morelli 2017)

IMPACT CATEGORY	DIRECT IMPACT	INDIRECT IMPACT
Habitat loss and modification	• Reduced food and shelter, increased competition, smaller population size, local extinction. • Reduced breeding opportunities. • Mortality during clearing. • Increased risk of zoonotic disease spillover.	• Fauna responding to altered microclimate due to opening-up of vegetation cover. • Reduced pathogen resistance due to ongoing stress. • Increased abundance of edge species outcompeting native flora and fauna. • Increased abundance of red foxes (*Vulpes vulpes*) and feral cats (*Felis catus*), which preferentially use cleared track. Increased predation risk for prey species near these tracks. • Reduced movement of aquatic species where loss of in-stream habitat increases water velocity.
Habitat degradation - weed invasion	• Increased cover of non-native plant species. • Reduced plant biodiversity when weeds invade native vegetation	• Loss of habitat for fauna when weeds invade native vegetation. • Increased density of red foxes (*Vulpes vulpes*) and feral cats (*Felis catus*), and predation on small mammals when weed thickets provide fox and cat harbour. • Increased WVC due to weeds attracting fauna to roadsides.
Habitat degradation - Traffic noise	• Animals can't hear their prey, predators, or each other, and suffer increased predation and/or reduced hunting / breeding success.	• To be heard, animals call louder or at frequency above or below traffic noise. • Lower survival because fauna use more energy to call louder or at higher frequency.
Habitat degradation - Environmental pollution and erosion	• Accumulation of nutrients and chemicals in fauna, resulting in reduced longevity, increased disease, reduced reproductive output, etc. • Increased sediment loads in waterways, reducing dissolved oxygen, turbidity etc. and resulting in stress and/or morality for flora and fauna species. • Shorter lifespan for fauna, due to teeth wear from ingesting dust while eating leaves.	• Downstream habitats and fauna species impacted by sediment and chemicals. • Reduced pollination of flowers that are covered in dust, reducing vegetation health and reproduction, and thus reducing food and habitat resources for fauna.

IMPACT CATEGORY	DIRECT IMPACT	INDIRECT IMPACT
Habitat degradation - ALAN	• Reduced habitat quality due to disturbance, resulting in lower density fauna populations. • Increased activity at lights for certain species. • Disorientation and mortality of fauna (e.g. turtle hatchlings).	• Increased predation of fauna by species using ALAN to detect prey. • Increased mortality of insectivores that are attracted to insects which are attracted by lighting.
Habitat provision	• Fauna attracted to road- and rail- side corridors where suitable habitat is maintained in otherwise cleared landscapes. • Fauna able to use suitable road and rail side habitat. • Fauna able to move between patches of habitat along suitable road and rail side corridors.	• Increased risk of WVC because attraction of fauna to the road and rail side. • Increased predation risk for native fauna in or adjacent to roadside habitat because attraction of dingoes, foxes, and cats to roadsides. • Negative indirect impact of some road and rail side habitat by attracting pest fauna (e.g. noisy miners (*Manorina melanocephala*)).

Figure 2 – Main categories of ecological impacts of transport infrastructure on individual fauna, populations, and ecosystems



Source: Adapted from van der Ree et al., (2015a).

3 How much do we know: roads vs railways?

The field of road ecology is significantly more advanced than railway ecology[4], with approximately ten times more ecological studies globally on roads than railways published between 1990 and 2015[5]

[4] (Dorsey et al. 2015)
[5] (Popp and Boyle 2017)

Fortunately, there are many similarities in the design and function of road and railway infrastructure that enable the use of information from road ecology to anticipate the ecological impacts of railways and to inform their management.

However, there are some key differences between roads and railways:

- The surface material and the width and extent of each network is significantly different, with roads typically having more 'lanes', wider corridors, and more extensive networks compared to railways[6].
- Trains typically occur less frequently, are typically slower in speed (except for high-speed trains), and run to a set schedule, while cars are often faster, more frequent, and more variable in their timing.
- Trains have limited locations where people can enter and exit compared to the greater flexibility for motor vehicles[7].
- Railways include electrified (typically urban and suburban commuter rail) and non-electrified (typically rural and reginal freight).

These differences mean that the response of fauna and the degree of impact to fauna and adjacent habitats from roads and railways is likely to differ[8]. For example, there is an overall greater risk of fauna mortality from cars compared to trains due to higher speeds, greater traffic volume, and roads distributed more widely across the landscape. However, railways can also result in significant rates of mortality, especially in locations where fauna may be trapped within fencing or in cuttings and where trains travel at relatively high speeds and frequencies[9].

4 The road- and railway-effect zone

The road effect zone (REZ, or alternatively railway effect zone) is the distance or area over which the combined impacts of the road or railway extend into the surrounding landscape and impact fauna[10] The REZ is a result of both direct and indirect impacts that may include habitat loss, habitat degradation and disturbance (including noise, light, and environmental pollution), and wildlife mortality[11] The REZ is measured as the reduced density or abundance of fauna from the road or railway and is always wider than the road or railway itself[12].

WVCs and other causes of mortality contribute to the REZ by reducing population sizes and/or lowering population densities in the area around the road or railway. This is because the road or railway acts as a 'sink' on the local population, with ongoing mortality causing the reduction in population density for long distances from the transport infrastructure itself.

The REZ can be estimated by approximating the distance that impacts extend from the transport infrastructure into the surrounding habitat, and by monitoring the response of populations (e.g. surveying population density in the surrounding habitat before and after the impact). The size of the

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[6] (Morelli et al. 2014, Heske 2015, Barrientos et al. 2019)
[7] (Heske 2015, Barrientos et al. 2019)
[8] (Dorsey et al. 2015)
[9] (Dorsey et al. 2015)
[10] (van der Ree et al. 2015a)
[11] (Forman and Deblinger 2000)
[12] (Pocock and Lawrence 2005)

REZ varies among species with early research suggesting it can extend up to approximately one kilometre for birds and five kilometres for mammals[13] More recent research indicates it can be much larger, with one study finding that chimpanzee abundance is reduced for up to 17 kilometres from roads[14]

The size and severity of the REZ is influenced by[15]:

- Landscape characteristics, such as topography, habitat type, hydrology, wind speed, and direction.
- Type of infrastructure and its characteristics (e.g. road vs railway, infrastructure width, height above grade, construction technique, vehicle frequency).
- The vehicle type (i.e. cars, trucks, trains), volume, timing, and speed.
- The traits and sensitivities of the local fauna species to the impacts of the transport infrastructure.

As a result of these contributing factors, the REZ is highly asymmetric, generally extending greater distances downslope and downwind of the transport infrastructure and extending further in open habitat types[16]. The severity of the REZ decreases as distance from the road or railway increases.

There have been few studies of the REZ in Australia, with the only peer-reviewed studies to date focussing on microbats and nocturnal flying insects in central Victoria[17] and frogs in the tropics of Queensland[18] There was little evidence for an effect of a four-lane freeway in central Victoria on nocturnal flying insects[19] However, the activity of seven out of ten species of microbats was significantly lower near the same freeway, with an effect distance ranging from 123 to 890 metres[20] The impact of the Kuranda Range Road on frogs in Queensland was variable, with the abundance of two species – the common mist frog (*Litoria rheocola*) and the white-browed whistle frog (*Austrochaperina pluvialis*) – positively correlated with increasing distance from the road on two transects that were studied[21]. In contrast, the white-browed whistling frog showed no such response on two other transects, and the tapping green-eyed frog (*Litoria serrata*) showed no response at all.

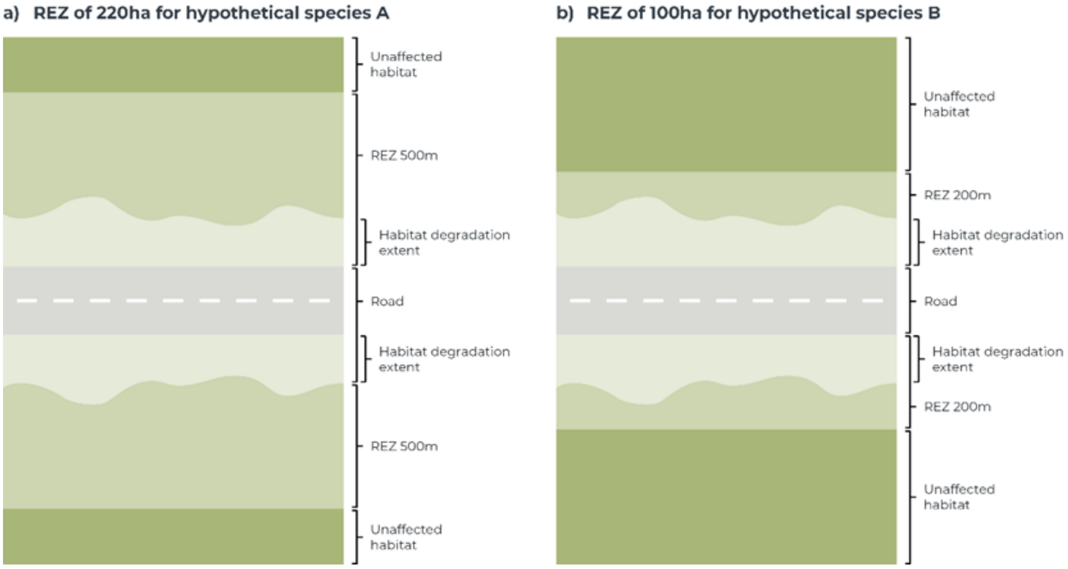
There are no studies quantifying the railway effect zone in Australia, and comparatively fewer studies globally on railways compared to roads. However, evidence suggests the effect zone is likely to be less severe and smaller for railways than roads because railways are narrower than roads, have fewer vehicle movements, typically slower speeds, and less lighting[22]. Nevertheless, the railway effect zone is still likely to exceed the typical investigation zone considered in impact assessments and study areas should reflect the spatial scale of impact.

[13] (Benítez-López et al. 2010)
[14] (Andrasi et al. 2021)
[15] (Forman et al. 2003, van der Ree et al. 2015a)
[16] (Forman and Alexander 1998, Forman and Deblinger 2000, Forman et al. 2003)
[17] (Bhardwaj et al. 2018, 2021)
[18] (Hoskin and Goosem 2010)
[19] (Bhardwaj et al. 2018)
[20] (Bhardwaj et al. 2018)
[21] (Hoskin and Goosem 2010)
[22] (Dorsey et al. 2015)

4.1 Role of the road- and railway-effect zone in transport planning and design

The REZ is a useful concept for environmental assessments of transport infrastructure because it enables a wholistic picture of the potential impacts of the project. For example, a two-kilometre stretch of new highway through a greenfield location may result in the removal of a 100-metre-wide strip of vegetation, totalling 20 hectares of habitat that is physically removed. However, the total area of degraded and potentially unusable habitat for a species may exceed the 20 hectares of habitat removed. If the REZ extends (in this hypothetical example) for 500 metres on each side of the cleared corridor, the additional area of habitat that is effectively lost is 100 hectares on each side. This results in the removal of 20 hectares and the effective loss of 220 hectares of usable habitat for that species. Figure 4.1 demonstrates this hypothetical REZ and how it can change depending on factors such as species.

Figure 4.1 – Schematic depicting a hypothetical REZ of two species



The REZ of existing transport infrastructure can be quantified using some of the following metrics:

- Over what distance is the density or activity level of fauna lower than in areas of similar habitat type and quality in the absence of transport infrastructure?
- How far have weeds spread from the road or railway?
- How far from the road or railway can traffic noise or artificial light be detected, and at what intensity does it affect different fauna populations?

Further details of how to predict the likely REZ in environmental assessments is provided in Chapter 5.

5 Pre-construction, construction, and operational impacts

The impacts of transport infrastructure can occur in any stage of a project. Some impacts are typically immediate (e.g. habitat clearing) compared to others that may take some time to become evident (e.g. consequences of reduced gene flow on population fitness).

The types of impacts are related to the activities that are occurring in each project stage, however all impacts can be grouped under the categories shown in Figure 2 and described in Sections 6 to 10.

Pre-construction activities are undertaken to inform planning and design or to facilitate the main construction works. Typical pre-construction activities include:

- Small scale clearing and construction of access tracks to undertake surveys.
- Surveys, such as soil testing or other geotechnical work.
- Relocation of services, such as pipelines and powerlines.

Construction activities typically include extensive clearing of vegetation and habitat, bulk earthworks, and the construction of the transport infrastructure. The impacts and mitigation associated with construction is discussed in detail in Chapter 7.

6 Wildlife-vehicle collision

6.1 The scale and severity of wildlife-vehicle collision

The injury and mortality of fauna due to WVC is the most obvious impact of transport infrastructure on fauna. Numerous studies have attempted to quantify rates of mortality regionally and globally, often with startling results. For example, more than 350 million vertebrates are estimated to be killed on American roads annually[23] and an estimated 194 million birds and 29 million mammals are killed on European roads annually[24]. Closer to home, between 377,000 and 1,500,000 animals larger in size than bandicoots and small birds were estimated to be killed on Tasmanian roads each year[25]. While rates of WVC should be assessed with respect to local population sizes, estimates in these orders of magnitude indicate that current rates of WVC globally are extremely high.

There have been numerous localised field-studies in Australia and globally that have documented rates of fauna mortality due to collision with vehicles, and to a lesser extent trains. These studies have included roads through protected areas (e.g. Royal National Park in NSW)[26], ecotourism hotspots such as Phillip Island in Victoria[27], and major roads in rural areas – such as north-eastern New South Wales[28] and north-western Victoria[29].

Most studies caution that the rates of WVC and fauna mortality that they report are almost certainly underestimates as small species, such as amphibians, reptiles, and small birds, are likely to go unreported and may be quickly scavenged[30]. Estimates of the rates of collision and mortality of larger species of fauna are probably more accurate than for smaller species because of their higher economic value (e.g. for hunting), often higher conservation status (e.g. large carnivores), higher detectability during surveys, and longer persistence time on roads and railway. For example, the rate of collision with kangaroos and other macropods has been documented at numerous locations in Australia because they cause significant economic damage to vehicles and trains and injury to motorists[31].

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[23] (Forman and Alexander 1998)
[24] (Grilo et al. 2020)
[25] (Hobday and Minstrell 2008)
[26] (e.g. Royal National Park in NSW Ramp et al. 2006)
[27] (e.g. Rendall et al. 2021)
[28] (e.g. Taylor and Goldingay 2004)
[29] (e.g. Coulson 1982)
[30] (Ruiz-Capillas et al. 2015)
[31] (Coulson 1989, Visintin et al. 2017)

The overall rate of fauna mortality due to transport infrastructure is likely to keep increasing as transportation networks expand and traffic volumes increase. While there are few long-term published studies of WVC, a recent study on Phillip Island in Victoria shows that rates have increased from 1.59 dead fauna per kilometre per month in 1998 – 1999 to 2.39 per kilometre per month in 2014[32].This increase was likely associated with an increase in both traffic volume and the density of native fauna due to predator control programs (red foxes have been eliminated from the island).

There are many sources of information that can be used to quantify the rate of WVC, and these are given in Chapter 5. Species-specific information on WVC has been included in the relevant species profiles (Chapters 9 to 21) where this information is available.

6.2 The conservation impacts of wildlife-vehicle collision

There is a growing body of evidence from around the world that mortality from WVC has a significant impact on the conservation and persistence of many species[33] The mortality of threatened fauna, as well as those with small or low-density populations, is a conservation concern because it can have major impacts on the survival of the species. Even relatively low rates of mortality from WVC may be sufficient to cause the local extinction of a species if that species occurs at low densities, the population size is already low, and/or if the intrinsic rate of population growth is low. Therefore, it is important to consider not only the total number of animals killed, but also the rate of collision and mortality relative to the size of the local population. In other words, a species subject to relatively low rates of WVC may be at a much greater risk of local extinction from WVC than a species with higher rates of WVC.

Importantly, a decline in rates of WVC may not represent a reduction in rates of mortality, but rather reflect a decline in the background size of the local population. This also means that the relative significance of each case or mortality increases as the population declines, as each incident is proportionally more important at a population-level.

The rates of WVC and mortality of even common species can also have significant population-level effects. Analysis of WVC rates and population dynamics of the relatively common and widespread common wombat (*Vombatus ursinus)* found that rates of WVC were high enough that if they could be stopped, it would have the greatest impact on the survival of the species in the north-western area of Kosciuszko National Park in NSW[34]. The viability of other common species, such as swamp wallaby (*Wallabia bicolor*), were similarly threatened by WVC and even a 20% reduction in the rate of WVC was enough to reverse a population decline[35].

WVCs also have animal welfare and human health concerns and economic costs, including:

- Injury and mortality of motorists.
- Damage to cars, trucks, and trains from collisions.

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[32] (Rendall et al. 2021)
[33] (Fahrig and Rytwinski 2009, Borda de Agua et al. 2011, Jackson and Fahrig 2011, Ceia-Hasse et al. 2017, Grilo et al. 2020, Moore et al. 2023)
[34] (Roger et al. 2011)
[35] (Roger et al. 2011)

- Injured animals may die slowly, especially if they move away from the road or railway and are not attended to by wildlife carers.
- Dependent young, including those in pouches or in nests, will likely die if their parent is injured or dies from WVC.

6.3 Characteristics of species subject to wildlife-vehicle collisions

All species of Australian fauna that encounter transport infrastructure are at risk of WVC if they attempt to cross at the same time as a vehicle is passing. There have been many studies quantifying rates of WVC in Australia, including on kangaroos[36], wallabies[37], koalas[38], bandicoots[39], quolls, and Tasmanian devils (*Sarcophilus harisii*)[40]. Arboreal mammals have also been a focus, including possums in urban areas[41] and gliders in rural landscapes[42]. There have also been many studies that recorded mortality for multiple species[43]. Studies have consistently found that common species, such as possums, macropods, small mammals, and common birds such as ravens and magpies, are some of the most frequently killed native Australian animals as a result of WVC[44].

The risk of WVC varies among species and is greater for those species:

- Where a large proportion of their habitat is adjacent to transport infrastructure, especially in highly cleared landscapes[45].
- Whose movement pathways are dissected by transport infrastructure. For example, many species of Australian turtles undertake overland movements among ephemeral wetlands and in search of suitable breeding habitat, resulting in high rates of mortality at certain times of year[46]. Movement pathways can also occur at shorter temporal and spatial scales, such as for nightly foraging movements.
- That move slowly or 'freeze' when crossing the transport infrastructure, such as freshwater turtles that move slowly[47], and less agile species of amphibians[48].
- With large home ranges or territories and long-distance migrants, as they are more likely to encounter transportation infrastructure while moving around.
- That feed or utilise resources on, above, or adjacent to transport infrastructure, such as reptiles basking on roads and roadsides, predators scavenging on dead fauna, or microbats foraging above roadways.

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[36] (Coulson 1982, Coulson 1989, Coulson 1997, Visintin et al. 2018)
[37] (Osawa 1989, Ramp and Ben-Ami 2006)
[38] (Dique et al. 2003, Ellis et al. 2016)
[39] (Driessen et al. 1996, Mallick et al. 1998, Scott et al. 1999)
[40] (Jones 2000)
[41] (Russell et al. 2009)
[42] (McCall et al. 2010, Soanes et al. 2016)
[43] (Taylor and Goldingay 2004, Nguyen et al. 2019, Rendall et al. 2021, Nguyen et al. 2022)
[44] (Taylor and Goldingay 2004, Hobday and Minstrell 2008)
[45] (van der Ree and Bennett 2003, Maclagan et al. 2020)
[46] (e.g. Santori et al. 2018)
[47] (Hamer et al. 2016, Santori et al. 2018)
[48] (Budzik and Budzik 2014)

- That are not deterred or scared away from transport infrastructure.
- Whose activities coincide with when vehicle movements are most frequent. For example, kangaroo-train collisions often occur at dawn and dusk when kangaroos are most active, and trains are most frequent[49] and similar trends have been observed with cars.

6.4 Effects of transport infrastructure design on rates of wildlife-vehicle collision

Rates of WVC are typically higher in areas where the design of the infrastructure limits the visibility of drivers to fauna on or adjacent to the road / railway and limits the ability of fauna to detect oncoming vehicles. This occurs on tight horizontal and vertical curves (i.e. hilly and windy terrain) and shoulders where vegetation grows close to the edge of the transport infrastructure[50]. These are important considerations during the design and maintenance phases of transport infrastructure projects (Chapter 8).

Rates of WVC are also typically higher on sealed roads compared to gravel roads[51], mostly because sealed roads support higher traffic volume and faster speeds, both of which are positively related to WVC for many species (Section 6.5). The colour of sealed and gravel roads might also impact visibility, with animals being less visible against a dark bitumen surface, especially when raining, compared to the paler colour of an unsealed road[52].

The effect of road width on WVC rates has also been researched, with some studies finding higher rates of mammal WVC on narrower roads[53]. One possible explanation is that wider roads have higher traffic volume and speeds which present a greater hurdle to mammal movement, and greater noise disturbance, resulting in fewer animals attempting to cross them.

Another study reported higher rates of WVC with birds on roads with a centre median[54]. Vegetated medians can reduce the gap between habitat and encourage the movement of some species (see Section 7.2) but it can also increase their vulnerability to WVC.

Some species of fauna can be trapped within cuttings, crash barriers or tunnel entrances, however the actual rate of occurrence is unknown and further research is needed.

6.5 Traffic conditions on rates of WVC

The timing, volume and speed of vehicles and trains has a significant effect on rates of WVC. The rate of WVC is typically higher when fauna activity coincides with periods of higher traffic volume, primarily around dawn and dusk[55].

The relationship between traffic volume and WVC is not always linear, and rates of collision are often higher in intermediate traffic volumes[56]. At very low traffic volumes there are few cars or trains and rates of WVC are low. At very high traffic volumes the road will appear as an impenetrable wall of traffic, and many species of fauna will not attempt to cross the road, thus resulting in relatively low rates of WVC. The roads with intermediate traffic volumes have enough gaps in traffic that fauna are

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[49] (Visintin et al. 2018)
[50] (Lee et al. 2004, Popp et al. 2018, Collinson et al. 2019, Nguyen et al. 2022)
[51] (Magnus et al. 2004, Hobday and Minstrell 2008, Fielding et al. 2021)
[52] (Magnus et al. 2004)
[53] (Dorsey et al. 2015, Santos et al. 2017)
[54] (Clevenger et al. 2003)
[55] (Visintin et al. 2018)
[56] (Seiler and Helldin 2006)

prepared to cross, but with enough vehicles to result in high rates of mortality. It is also conceivable that areas with high traffic volume may have lower-density populations of fauna due to ongoing mortality over many years.

There is a strong positive relationship between the speed of vehicles and trains and rates of WVC for a wide range of species and regions[57]. This pattern is likely because there is less time for motorists and/or fauna to detect each other and react to avoid a collision (i.e. motorists slow down or safely swerve to avoid collision and fauna to leave the road or railway).

6.6 Human-health and economic impacts of wildlife-vehicle collision

A significant impact of WVCs are the human-health and economic costs from collisions, as well as the subsequent delays, damage to vehicles and infrastructure, clean-up operations, and insurance claims[58]. Estimates of the annual cost in Australia of collisions with medium to large mammals, usually kangaroos, equates to tens of millions of dollars[59]. Eastern grey kangaroos (*Macropus giganteus*) are frequently involved in wildlife-train collisions in Victoria, resulting in costs due to removal of the train from service, inspection, cleaning, repairs, and delays[60].

The severity of vehicle damage and risk of injury and fatality increases with the body-size of the animal involved in the collision. Therefore, increases in the range and abundance of large-bodied feral animals in Australia is of concern.

High rates of WVC also have the potential to negatively affect tourism. For example, Tasmania is renowned for its abundance of fauna, but also for high rates of fauna roadkill[61]. This can negatively affect the experience of tourists and can adversely impact tourism businesses who depend on high density and accessible fauna populations for reliable tourist viewing[62].

6.7 Other direct causes of injury and death

Fauna mortality along transportation infrastructure can occur from electrocution and collision with powerlines, fencing, bridges, as well as light and noise walls[63].

Smaller animals such as turtles, reptiles and amphibians can become trapped between the railway tracks, kerbs, gutters, and other structures, increasing the risk of WVC, predation, starvation, overheating, and desiccation from excessive exposure to the sun[64]. Small species may also be washed into drains and channels during rain events, often drowning or being washed away.

The barbs on barbed wire fencing also pose a major risk of entanglement to gliders such as cassowary (*Petaurus norfolcensis*), sugar gliders (*Petaurus breviceps*), greater gliders (*Petauroides sp.*) and yellow-bellied gliders (*Petaurus australis*), as well as flying foxes (Chapter 10) and microbats[65]. Kangaroos and emus have become entangled and died in the top strands of plain wire fencing and reptiles and other small species can get stuck in mesh fencing and die from predation and

[57] (Jones 2000, Hobday and Minstrell 2008, Dorsey et al. 2017, Visintin et al. 2018, Jasińska et al. 2019)
[58] (Bissonette et al. 2008, Huijser et al. 2009, Visintin et al. 2018)
[59] (Klocker et al. 2006)
[60] (Visintin et al. 2018)
[61] (Magnus et al. 2004, Hobday and Minstrell 2008, Fielding et al. 2021)
[62] (Magnus et al. 2004)
[63] (Dorsey et al. 2015, Santos et al. 2017)
[64] (Kornilev et al. 2006, Budzik and Budzik 2014, Dorsey et al. 2015, Dornas et al. 2019)
[65] (van der Ree 1999)

overheating[66]. There is little quantified data on the rates of entanglement and death from fencing, but it can be high in certain areas[67]. Entanglements are also a major animal welfare concern because entangled animals will invariably undergo a slow and painful death.

Fauna mortality may also occur as a result of WVC with large plant during the construction phase of a project, especially as habitat is being cleared (refer to Chapter 7).

7 Barrier or filter to fauna movement

Transport infrastructure can be complete barriers or partial filters (hereafter simply 'barrier effects') to the movement of fauna[68]. Reductions in movement limit the ability of animals to find food, shelter, and mates. This lowers the survival rate and decreases population size, ultimately increasing the risk of local extinction.

A wide range of Australian and international species are affected to varying degrees, including fish, amphibians[69], terrestrial mammals[70], possums and gliders[71], turtles [72], invertebrates[73], some species of birds[74] and bats[75].

The barrier effect of transport infrastructure is species-specific and occurs because the species is unable or unwilling to cross the road or railway due to one or more of the following factors:

- The gap in habitat exceeds their gap-crossing ability.
- The species avoids disturbance (e.g. vehicles, traffic noise, ALAN, etc.).
- Physical features (e.g. road surface, fencing, railway tracks, rock ballast, cuttings, and retaining walls) prevent animals from crossing.
- Animals die from WVC while attempting to cross (Section 6).
- Additionally, the barrier effect of transport for aquatic fauna occurs if transport crossings are not adequately designed to allow for the movement of aquatic fauna, e.g. increased velocities, reduction in temporal fish passage.

The causes of the barrier effect are described further in Section 7.2. Understanding the causes helps to determine the type of mitigation likely to be successful.

7.1 Consequences of reduced movement

7.1.1 Inability to access food, shelter, and mates as part of movements

Animals need daily and seasonal access to food, shelter, and mates and transport infrastructure may prevent them from accessing all the diverse resources they need to survive. When this occurs, the

[66] (Ferronato et al. 2014)
[67] (van der Ree 1999, Ferronato et al. 2014)
[68] (e.g. van der Grift and Kuijsters 1998, Tremblay and St Clair 2009, Taylor and Goldingay 2010, van der Ree et al. 2015b, Barrientos and Borda-de-Água 2017, Ament et al. 2023)
[69] (Hamer 2016, Hamer 2018)
[70] (Burnett 1992, Rondinini and Doncaster 2002, Riley et al. 2006, Rico et al. 2007)
[71] (Asari et al. 2010, van der Ree et al. 2010)
[72] (Hamer et al. 2016)
[73] (Bhattacharya et al. 2003)
[74] (Belisle and St Clair 2001, Laurance et al. 2004, Jones and Bond 2010)
[75] (Ramalho and Aguiar 2020)

infrastructure has effectively divided a patch of habitat into two smaller patches, with each patch supporting fewer animals and increasing the risk of local extinction.

The time scale at which this restriction occurs varies depending on the needs of the species. For example, a wide road may separate a den tree for yellow-bellied gliders from specific sap trees, which is a resource they need to access on an almost daily basis. Impacts can occur seasonally if trees on the opposite side of the road only flower at certain times of the year and other resources are not available. In both situations, yellow-bellied gliders may experience food shortages and have lower survival rates, produce fewer offspring, and ultimately have lower population sizes when transport infrastructure dissects their habitat. Fish species that spawn in saltwater and grow in freshwater must move seasonally and barriers can disrupt this cycle, leading to local extinctions.

7.1.2 Reduced dispersal, migration, and gene flow

Movements across relatively large spatial scales are important for the survival of many species and populations. Dispersals are typically once-in-a-lifetime events where juveniles leave their areas of birth and establish new territories away from parents and siblings to minimise inbreeding and over-population. Migrations are typically seasonal events where animals track resources across the landscape at certain times of the year. Migrations can occur across relatively small distances, such as few hundred metres for mountain pygmy possums *(Burramys parvus*) in the Australian Alps (Chapter 6, Case Study 6.1) to thousands of kilometres along the east coast of Australia by grey-headed flying-foxes (*Pteropus poliocephalus*)[76]. Some birds also migrate tens of thousands of kilometres annually across the globe, such far eastern curlews (*Numenius madagascariensis)* and red-necked stints (*Calidris ruficollis*). Fish can also migrate vast distances including moving between freshwater and saltwater.

Transport infrastructure can limit or prevent dispersal and migration, increasing population density and competition for resources, reducing gene flow, and causing inbreeding – all ultimately increasing the risk of extinction. If sufficient barriers to movement exist, populations may become extinct[77].

Over the medium- and longer-term time frames, populations of fauna that are isolated by transport infrastructure will have lower rates of gene flow and may eventually experience inbreeding[78]. The speed at which this occurs is influenced by the size of the effective breeding population (i.e. excluding non-breeding adults and those not able to find mates), the mating system (e.g. age at which breeding commences, litter size, number of litters per year, etc.) and the rate of immigration and emigration. For example, a small population with no new arrivals will experience inbreeding quicker than larger populations or those with many immigrants.

Populations that experience reduced gene flow and inbreeding have reduced levels of genetic diversity, which may limit their ability to adapt to new conditions, such as a changing climate or new diseases. In these situations, populations may decline and go extinct if they are unable to adapt to the new conditions. In addition, offspring from highly related individuals may be born with mutations and conditions which reduce survival rate.

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[76] (Welbergen et al. 2020)
[77] (Gadd 2015)
[78] (Sunnucks and Balkenhol 2015)

7.2 *Causes of the barrier effect*

The causes of the barrier effect are often complicated and involve more than one factor. An understanding of the likely cause(s) can assist in designing effective avoidance, minimisation, and mitigation strategies by focussing on the relevant reason(s) for the barrier effect, which are typically either physical or behavioural limitations.

7.2.1 The gap exceeds their gap-crossing ability

There is an increasing body of evidence that gaps in habitat from clearing for infrastructure are a physical limitation to movement for many species. These gaps can range in width from approximately 10 metres for narrow roads to greater than 100 metres for large motorways and multi-track railways. The severity of the barrier effect is related to the size of the gap and the species-specific movement capabilities.

For example, the size of gaps that gliders can cross, and their rate of gap-crossing is strongly influenced by the size of the gap in habitat (Chapter 14, Case Study 14.1). Squirrel gliders crossed the Hume Freeway in central Victoria more frequently when the centre median contained tall trees to break the crossing distance into two[79]. The rate of use of paddock trees by squirrel gliders decreased as gap size increased, with an apparent gap-size threshold of approximately 40 metres[80]. The relative height of launch and landing trees, which includes consideration of whether the road or railway is in a cutting or on fill, also influences the gap-crossing ability of gliders. Gliders can cross wider distances when launching from taller heights. Thus, gliders are unlikely to successfully cross wide clearings when only relatively short trees are present.

Many other studies have inferred that the gap size exceeds the gap-crossing ability of the species they studied, however they did not test this explicitly. Confirming a species' inability to physically cross a gap requires a study of multiple individuals along a gradient in infrastructure width. Nevertheless, the physical ability to cross gaps decreases as gap size increases.

7.2.2 Design effects

The physical design of the transport infrastructure may limit or prevent the movement of some species of fauna or certain age or sex cohorts. For example, some species of turtles in Europe, such as the eastern box turtle (*Terrapene carolina carolina*)[81] and the gopher tortoise (*Gopherus polyphemus*)[82] are physically unable to climb over railway tracks. The same effect probably applies to many Australian turtles, especially juveniles.

Embankments, retaining walls, and cuttings may physically prevent some species from accessing and crossing transport infrastructure. There is anecdotal evidence that large and steep cuttings and embankments prevent cassowaries (*Casuarius casuarius*) from accessing the road. Gutters and kerbs may similarly prevent small animals from accessing the road or railway, but for those that do, they may be unable to escape. Motorbike rub-rails on W-beam guard rails also prevent some small animal species from accessing and exiting the road. Noise and light walls act in similar ways for some species, depending on the design.

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[79] (van der Ree et al. 2010)
[80] (van der Ree et al. 2003)
[81] (Kornilev et al. 2006)
[82] (Rautsaw 2018)

It is important to note that these barriers may, in some situations, provide positive benefits in reducing rates of WVC by preventing animals from accessing the road or railway. The trade-offs or costs and benefits of barriers at reducing connectivity vs reducing rates of WVC must be carefully considered and is discussed further in Chapter 5.

7.2.3 Behavioural avoidance

Many species choose to not cross over transport infrastructure despite being capable of moving distances larger than the width of the infrastructure and clearing. In these cases, the transport infrastructure corridor represents a behavioural barrier to movement, whereby a species can cross the clearing but chooses not to. This behaviour may be a result of:

- Clearing width and/or traffic volume, as demonstrated by studies which translocate animals across the transport infrastructure or entice movement with food or calls[83].
- Species sensitivity to clearings and associated edge effects. Studies in the Brazilian Amazon found that movements of frugivorous birds and birds associated with edges and gaps were not inhibited while forest-dependent insectivores were impacted, except at sites with extensive vegetation cover. The authors concluded that road-crossing movements were inhibited by the clearing itself and the edge-affected vegetation[84].
- Species sensitivity to noise and ALAN. Some species of insectivorous bats which fly many kilometres to avoid crossing relatively narrow transport corridors because of bright street lighting[85]. Sudden transitions from light to dark such dark culverts, can deter fish from moving into the culverts.
- The risk of predation or attack by competitors (e.g. noisy miners, cats, foxes).

8 Habitat degradation or loss

8.1 Direct habitat loss

The construction of transport infrastructure often results in the loss of vegetation and other natural features, such as fallen logs, rocky outcrops, and wetlands that provide habitat for fauna. Importantly, the loss and degradation of habitat specifically for transport infrastructure, pipelines, and transmission lines is a significant threat to at least 465 taxa listed under the EPBC Act[86].

Habitat loss is a significant threat to biodiversity globally and in Australia[87] and results in a wide range of impacts to fauna, ultimately resulting in an increased risk of extinction. These consequences include:

- Reduced population sizes.
- Increased competition and over-consumption of resources.
- Genetic in-breeding.

[83] (Develey and Stouffer 2001, Tremblay and St Clair 2009)
[84] (Laurance et al. 2004)
[85] (Stone et al. 2009, Zeale et al. 2018)
[86] (Kearney et al. 2019)
[87] (Pereira et al. 2010, Rands et al. 2010, Kearney et al. 2019, Ward et al. 2021)

The extent of habitat loss and the ecological consequences will vary by project and by species. For example, a major road through bushland will result in the clearing of more natural vegetation than a road through agricultural areas. However, the significance of those losses for fauna depends on multiple factors, including the:

- Amount of native vegetation and fauna habitat in the area and the relative amount being cleared.
- Value (or use) to fauna of the habitat being cleared.
- Population size or conservation status of the fauna species being impacted by the loss.
- Role of the vegetation or ecological resource as habitat or connectivity pathway.

Habitat loss can be temporary where it is cleared during construction to provide access for the construction process and then rehabilitated after construction is completed. These impacts are discussed in more detail in Chapter 7.

8.2 Degradation and indirect habitat loss

Habitat degradation is the decline in the quality of fauna habitat due to the presence and operation of the transport infrastructure. Habitat degradation can occur due to multiple factors, including weed invasion, altered fire regimes, stock grazing, noise, light, and chemical pollution, altered microclimates and hydrological cycles, increases in feral and pest species, etc. Some of these mechanisms are discussed in Section 10.

Habitat degradation causes indirect habitat loss by reducing the carrying capacity of the habitat. In many situations, the vegetation and other habitat features (e.g. logs, wetlands, hollow-bearing trees etc.) remain but they support fewer animals than occurred prior to construction. For some species of fauna, the degradation may be so severe that they are no longer able to live in the impacted area.

This indirect loss of habitat is one factor that can cause the REZ to can extend many kilometres from the edge of the road or railway (Section 4).

8.2.1 Invasive plants

Linear transport corridors often provide ideal environments for the establishment and spread of invasive plants. Also known as weeds, these species can be native or exotic and are successful because they have a competitive advantage over other species when responding to changes in habitat, disturbance, microclimate, or other processes. Weeds can directly affect biodiversity through displacement and competition or indirectly by reducing habitat quality.

Fauna can be directly and indirectly affected by weeds, including positively through the provision of foraging resources or negatively if the weeds are thick and prevent fauna movement. For example, lantana thickets can be impenetrable to the movement of koalas (Chapter 13), while blackberry (*Rubus fruticosus*) bushes and other thick vegetation can provide important sheltering habitat for bandicoots and small birds. Increased rates of WVC and fauna mortality may also occur if the weeds encourage fauna to move towards or along the road or railway verge, or limit visibility for both fauna and drivers.

Cars and trains are effective long-distance vectors of weed seeds and propagules[88], resulting in the establishment of weeds in new places[89]. Roads and railways can also facilitate weed dispersal by allowing movement through the landscape in ways that were not previously possible. For example, road and railway tunnels can facilitate weed dispersal across mountain ranges which may otherwise have acted as an environmental barrier to its spread.

9 Habitat and corridor function of transport infrastructure

In many human-dominated landscapes across Australia, vegetation in transport infrastructure corridors and on unused reserves can represent a large proportion of remaining native vegetation and habitat for fauna (Figure 9). These linear strips often support remnant vegetation, which in some cases are more representative of pre-European vegetation condition than larger patches[90]. These can occur in rural and agricultural landscapes, areas on the urban-rural fringe and in cities and towns.

The linear strips can potentially provide important functions, including:

- Important habitat for occasional, seasonal, or permanent use by fauna, including numerous threatened species[91].
- The last refuges for rare plants[92] and threatened invertebrates[93].
- Corridors for fauna movement between large patches of habitat.
- Provision of ecosystem services, such as shade, flood mitigation, etc.

Figure 9 – Aerial view of an agricultural landscape in Queensland western downs

Source: *Queensland Imagery includes material © State of Queensland 2023, © Earth-i*

[88] (Lonsdale and Lane 1994, Zwaenepoel et al. 2006, Gangadharan et al. 2017, St. Clair et al. 2019)
[89] (Ascensão and Capinha 2017)
[90] (van der Ree and Bennett 2001)
[91] (van der Ree et al. 2001, van der Ree 2003, van der Ree and Bennett 2003, van der Ree 2010, Vesk et al. 2015)
[92] (Hobbs 1993)
[93] (New et al. 2020)

The value and function of vegetation and habitat features on road and railway verges is threatened by:

- Vegetation clearing associated with road and rail widening and other upgrade projects.
- Vegetation clearing for road safety works where vegetation is within the required clear zone to allow for vehicles to leave the road and come to a stop. Vehicle speeds, horizontal curves and the height difference between the road and adjacent areas affects the minimum clear zones required.
- Grading of unsealed roads and gravel verges that incrementally result in wider roads, less vegetation in the reserve, as well as numerous indirect impacts (Section 8.2).
- Weed invasion and poor species diversity due to harsh conditions.

The transport infrastructure corridors can provide habitat and facilitate movement of fauna in positive ways[94].

- Transport infrastructure is designed to avoid steep inclines and may present an easier parallel movement path for fauna than climbing up and down steep slopes.
- Southern brown bandicoots (*Isoodon obesulus*) utilise blackberry thickets and other weeds along roadsides as habitat[95].
- Common raptors in northern Australia, the black kite (*Milvus migrans*) and whistling kite (*Haliastur sphenurus*), readily scavenged dead cane toads (*Bufo marinus*) and native frogs from roads[96].
- Some bird species benefit from grain spills[97], including the nationally listed regent parrot (*Polytelis anthopeplus monarchoides*) which has been observed feeding on spilt grain on roadsides in northern Victoria[98]. This can sometimes occur in large numbers, with one study recording more than 300 regent parrots along a 3-kilometre section of road[99]. However, such behaviour poses a major risk of WVC and potentially negative outcomes, as was the case in March 1980 when more than 150 regent parrots were killed by vehicles[100].

Many of the structures associated with transport infrastructure can provide important habitats and resources for fauna. Some examples include:

- Street lights can increase the foraging time and/or foraging efficiency for a small group of species. Note that most species are negatively affected (Section 10.2).
- Some fauna species may utilise the road or rail infrastructure for habitat, like Australian white ibis (*Threskiornis molucca*) nesting in roadsides on the Gold Coast[101].
- Some species of microbats can roost and breed in cracks and cavities in bridges and culverts[102] (Chapter 11).
- Roads and railway ballast can provide warm surfaces which reduces energetic demands for both endotherms and ectotherms.

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[94] (Morelli et al. 2014, Morelli 2017)
[95] (e.g. Maclagan et al. 2020)
[96] (Beckmann and Shine 2011)
[97] (Popp 2017)
[98] (Shultz 2006)
[99] (Forshaw and Cooper 1981)
[100] (Higgins 1999)
[101] (Sheehan et al. 2022)
[102] (Gorecki et al. 2019)

- Some bird species construct stick nests on signs, pylons, and bridge structures, and mud nests under bridges and in culverts.
- Drainage ditches along transport infrastructure can provide habitat for frogs and water sources for terrestrial species.
- Owls and other hunting birds use fences, signs, and powerlines along transport infrastructure as perches for resting and hunting.

Transport infrastructure and the vegetation and/or clearings associated with them can be of benefit to fauna and biodiversity conservation[103]. A recent analysis of the international peer-reviewed literature found that the number of negative effects of roads were five times higher than positive effects[104]. The potential positive benefits of such areas for fauna relies on the species-specific ability to avoid the risks associated with vehicles and trains, such as WVC[105].

9.1 Introduced predators and invasive or aggressive fauna

Introduced predators, such as red foxes and feral cats, are significant contributors to the decline and extinction of many species of small- and medium-sized mammals, reptiles, birds, and amphibians in Australia[106]. There is compelling evidence that introduced predators are more abundant and/or more active along transport infrastructure because they use the clearings for hunting and movement[107]. For example, feral cats were detected 60 times more frequently on cameras set along roads than on cameras off-roads in Western Australia[108].

The construction of new transport infrastructure through otherwise intact natural areas can increase the density and activity of introduced predators, potentially threatening the viability of small and medium-sized native species. Studies have also shown that introduced predators can use crossing structures, and care must be taken to ensure they are designed to provide protection to prey species and discourage use by the predators[109] (Chapter 6). Nevertheless, it is important to acknowledge that while crossing structures are used by predators, they do not typically function as prey traps[110]. Chapter 6 provides numerous ways to mitigate this risk.

Invasion of natural ecosystems by introduced species is a significant threat to biodiversity conservation. In northern Australia, the cane toad actively selected and used roads and fence lines to rapidly expand their range at an invasion front, rather than move through dense vegetation[111].

Aggressive native fauna can also be advantaged by the breaking up of contiguous habitats into smaller patches and the creation of boundaries between natural ecosystems and clearings. These species, such as the noisy miner, benefit from changes to the structure of the habitat and can outcompete other species of birds that are smaller in size, less aggressive, or those which avoid such ecotones.

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103 (Morelli 2017)
104 (Fahrig and Rytwinski 2009)
105 (Fahrig and Rytwinski 2009)
106 (Fisher et al. 2013, Lawes et al. 2015)
107 (Wysong et al. 2020)
108 (Wysong et al. 2020)
109 (e.g. Harris et al. 2010)
110 (Little et al. 2002, Mata et al. 2015, Soanes et al. 2017)
111 (Brown et al. 2006)

10 Disturbance

10.1 Noise and vibration

Noise pollution is the 'elevation of natural ambient noise levels due to sound-generating human activities, which may have detrimental consequences for humans and fauna alike[112]. The effects of anthropogenic (human-caused) noise can occur both during the construction and throughout the operational phases of a road or railway[113]. Construction noise often occurs at a high intensity but for relatively short periods of time, while traffic noise typically occurs at lower intensities and is more persistent over time, with peaks in volume occurring during the morning and evening peak travel times[114]. Noise pollution currently affects vast areas of natural habitat across the globe, with most affected areas situated along major transport links[115].

There is a rapidly growing body of evidence which has unequivocally demonstrated that anthropogenic noise can have significant impacts on a range of fauna including birds, amphibians, reptiles, terrestrial and marine mammals, arthropods, and molluscs[116]. A 2019 meta-analysis of over 464 data points from 102 studies that investigated impacts on 101 species concluded that the significant response by fauna to anthropogenic noise 'can be explained by most species responding to noise, rather than a few species being particularly sensitive to noise'[117].

Noise can have both direct and indirect impacts on fauna, including:

- Reduced ability of species to hear prey, predators, and mates[118].
- Reduced breeding success[119].
- Increased stress levels.
- Alterations in the timing, volume, and/or frequency of calling or activity, with potential energy costs associated with these changes[120].
- Modified development, physiology, and behaviour of species in aquatic systems[121].
- Hearing damage, which may be temporary or permanent.
- Lower survival rates.
- Reduced density, richness, and/or activity of affected fauna species in noisy habitats[122].

Studies have reported animals communicating at higher pitches to overcome the 'masking' of their usual call by the low-frequency noise of the urban environment[123], including for birds and frogs in Australia[124]. The severity of the impact 'masking' has on birds largely depends on the temporal and

112 (Slabbekoorn 2019)
113 (Slabbekoorn 2019)
114 (Parris 2015)
115 (Forman 2000)
116 (Kunc et al. 2016, Shannon et al. 2016, Kunc and Schmidt 2019)
117 (Kunc and Schmidt 2019)
118 (Schaub et al. 2008, Siemers and Schaub 2011)
119 (e.g. Reijnen and Foppen 1994, Halfwerk et al. 2011)
120 (Slabbekoorn and Peet 2003, Brumm 2004, Parris and Schneider 2009, Parris et al. 2009a)
121 (Kunc et al. 2016)
122 (Hoskin and Goosem 2010, Arevalo and Newhard 2011, Bhardwaj et al. 2021)
123 (Slabbekoorn and Peet 2003)
124 (Parris and Schneider 2009, Parris et al. 2009a)

frequency (Hz) overlap between their call and the traffic noise[125]. For example, most birds call to defend territory and attract mates, with much of this occurring around dawn. Therefore, the impacts of traffic noise on birds can be particularly acute if this dawn ‘chorus’ of their calling coincides with morning peaks in traffic[126]. The impacts of traffic noise on birds, frogs, and bats are described further in the respective species profiles.

Noise amplitude (or loudness) is measured in pressure or intensity, which is expressed in decibels (dB). The decibel (dB) is a logarithmic scale that allows a wide range of values to be compressed into a more comprehensible range, typically 0 dB to 120 dB, and is scaled for human hearing. While there are numerous challenges in identifying relevant sound pressure levels which impact different species, the following has been observed:

- An upper limit of 93 – 110 dB(A) for continuous traffic noise has been recommended to prevent temporary hearing loss in birds and pulses (presumably equivalent to L_{maxT}) to not exceed 125 dB(A) to prevent permanent damage to hearing in birds[127].
- Maximum noise levels from roads should not exceed 50 – 60 dB(A) to prevent masking and other similar effects[128] while a more recent study suggested the threshold was 49 dB(A)[129].
- Two studies found a significant effect of propagated road noise at 55 dB(A)Leq within a road-free landscape with a background noise level of 41 dB(A), demonstrating a maximum threshold (i.e. 55 dB(A)) that should be avoided[130]. Unfortunately, they didn’t test different noise levels between the background (i.e. 41 dB(A)) and their test (55 dB(A)Leq), so a threshold was not determined, but is likely less than 55 dB(A)Leq.
- Studies in The Netherlands identified thresholds of 42 – 52 dB(A)) in woodland and (47 dB(A)) in open grassland in The Netherlands[131].
- A study of wetland birds in Finland found a negative effect where noise levels exceeded 56 dB, implying that this SPL may represent a threshold[132].

These studies and reviews suggest that to minimise impacts on birds, traffic noise should ideally be kept below 55 – 60 dBA(18 hr exposure), especially during the morning chorus.

[125] (Brumm and Slabbekoorn 2005, Coffin 2007)
[126] (Halfwerk et al. 2011)
[127] (Dooling and Popper 2007)
[128] (Dooling and Popper 2007)
[129] (Wiacek et al. 2015)
[130] (McClure et al. 2013, Ware et al. 2015)
[131] (Reijnen et al. 1997)
[132] (Hirvonen 2001)

Case Study 4.1 – Effects of traffic noise on birdsong

One study of the effect of traffic noise on birdsong was conducted on the Mornington Peninsula in Victoria, where the calls of the grey fantail (*Rhipidura fuliginosa*) and grey shrike thrush (*Colluricincla harmonica*) were recorded adjacent to 58 different roads of varying size and traffic volume[133]. The lower-singing grey shrike thrush sang at a higher frequency in traffic noise, while the higher-singing grey fantail did not appear to alter its call. However, the increased pitch of the grey shrike thrush was still unlikely to fully compensate for the acoustic interference experienced, thereby causing a reduction in the distance over which their calls can be heard by other individuals in the population.

Some species of frog will also attempt to call louder or change their pitch in areas with lots of anthropogenic noise[134]. These changes may come with additional costs, such as increased energetic demands associated with changes in call volume or pitch. In other studies, species that remain exposed to the noise have reportedly experienced reduced breeding success and lower survival rates[135].

Figure 10.1 – Barking frog (Limnodynastes fletcheri) (left) and Greenstripe frog (Cyclorana alboguttata) (right)

Source: © Matt Head

Transport infrastructure also emits vibrations which move through various substrates such as rocks, soil, water, and vegetation, rather than air, and are felt rather than heard. Even species without hearing capacity can be impacted by vibration disturbance, and some species have appendages or organs specifically designed to detect vibrations. Many species use vibration for communication and predator and prey detection similarly to noise. The impact of anthropogenic vibration on fauna is scarcely studied, but from the few studies completed, is expected to have similar effects and intensity to noise[136].

The impacts of vibration will vary depending on a species' relationship with vibrational cues. For example, the European garden spider relies on vibration in its web to detect prey. In an experiment, the spiders' prey detection thresholds were impacted by vibrational noise[137]. In another example, red-eyed treefrogs hatched earlier when exposed to vibration, likely because the vibration mimics the cue

133 (Parris and Schneider 2009)
134 (Parris et al. 2009b)
135 (Reijnen and Foppen 1994, Halfwerk et al. 2011)
136 (Roberts and Howard 2022)
137 (Wu and Elias 2014)

for predator presence[138]. It is likely that species which spend time underground – such as burrowing frogs, lizards, and invertebrates—will be more impacted by ground-borne vibrations, as the ground is where the vibrations occur most strongly, and these species rely on ground vibration cues to estimate the above-ground conditions that they cannot see. For example, *Diplocardia* earthworms emerge from soil after exposure to vibrational noise likely because the vibration mimics the cue for rainfall[139].

Impacts will also depend on the type and level of vibration and its overlap with environmental and behavioural cues. Importantly, the same disturbance source can produce different frequencies of noise and vibration. For example, a study in Sri Lanka found that most trains studied produce airborne noise in the range of 40Hz to 60Hz, while the ground-borne vibration ranged from 8Hz to 36Hz[140].

It is likely that many species are impacted by vibration and further studies are required to quantify the severity of impacts on most species groups. Consequently, it's likely that understanding and mitigating vibration impacts will increasingly be required for approvals of transport projects. Consideration of noise does not also automatically consider vibration. Efforts to understand the relationship between potentially impacted species and vibration and the levels of impact caused by transport infrastructure should be key focus areas of future research.

10.2 Artificial light at night

Light functions as a natural stimulus that influences circadian rhythms and a variety of daily and seasonal physiology and behavioural patterns such as foraging, breeding, dispersal, and migration[141]. ALAN, also known as ecological light pollution, alters the natural patterns of light and dark and is 'one of the most visible and pervasive anthropogenic stressors on the planet'[142].

The Australian Federal Government has declared that 'natural darkness has a conservation value in the same way that clean water, air, and soil has intrinsic value'[143] in their *National Light Pollution Guidelines for Wildlife*. Hence, best practice design requires consideration of the impacts of ALAN for all future transportation projects and, where possible, on existing transportation infrastructure.

The impacts of ALAN are species-specific, primarily because of the variation in the visual physiology of different species of fauna. The timing, brightness, wavelength (or colour), design, placement, and orientation of lighting fixtures all influence the severity of the impacts[144]. Vehicle lighting also contributes to ALAN, however, there has been little study of these impacts.

The portion of light that is visible to most fauna has wavelengths between 400 nanometres (nm) and 700 nm as highlighted in Figure 10.2. Some species of fauna have capacity to detect wavelengths in the near ultraviolet (300–400 nm). Warmer colours (reds to yellows) generally have lower impacts than 'cooler' colours (i.e. blues), which include low-energy LED fixtures currently being deployed[145].

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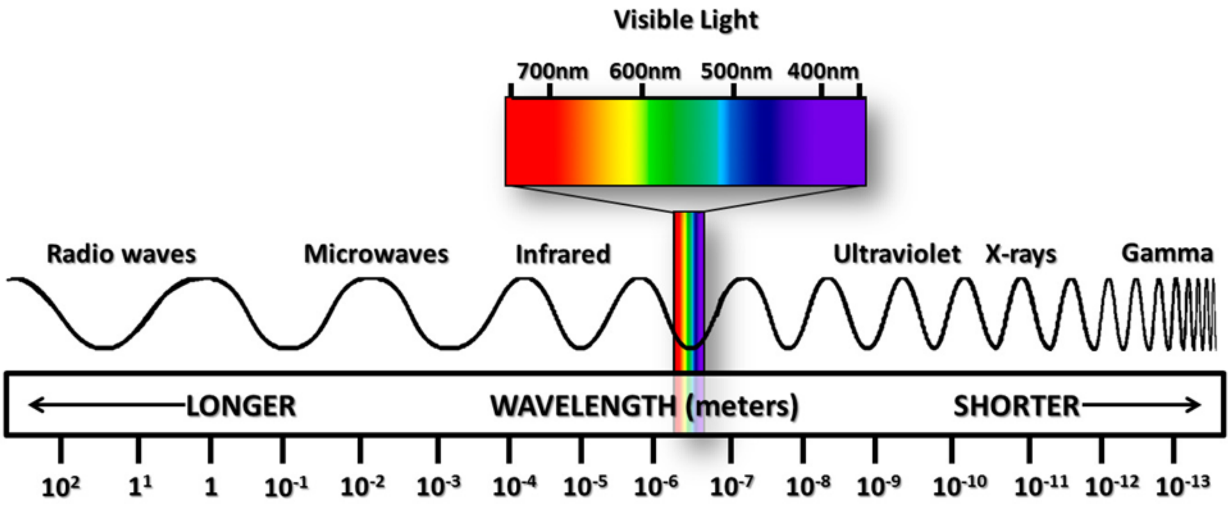
[138] (Warkentin 2005)
[139] (Mitra et al. 2009)
[140] (Palpita et al. 2020)
[141] (Blackwell et al. 2015)
[142] (Longcore and Rich 2004, Gaston et al. 2015, Falchi et al. 2016, Lockett et al. 2021)
[143] (DCCEEW 2023)
[144] (Longcore and Rich 2004, van Langevelde et al. 2011, Ikeno et al. 2014, Blackwell et al. 2015)
[145] (Blackwell et al. 2015)

Figure 10.2 – The electromagnetic spectrum



Source: *The Electromagnetic Spectrum (thinglink.com)*

Artificial light from transport infrastructure includes headlights and street lighting, both of which can have numerous direct and indirect impacts on fauna, including:

- Attraction and/or disorientation of birds, bats, and insects due to high-glare or bright lights. Some birds that migrate at night are attracted to the lighting and can die from collision with light fixtures or from exhaustion.
- Displacement of some species away from well-lit areas, presumably due to an increased risk of predation[146]. Depending on where the displaced animals move to, this may cause higher rates of WVC and/or predation[147].
- Attracting some types of insects, with a subsequent attraction of predators and higher rates of predation, as well as higher rates of mortality of species attracted to the lights[148].
- Changes to community structure, such as an increased number of predatory and scavenging ground-dwelling invertebrates in brightly lit areas[149].
- Changes to species composition, such as favouring wading bird species that feed using visual cues and decreasing foraging success by waders that feed using tactile cues[150].
- Changes in growth rates and hormone production and expression, with consequences for immune responses, circadian rhythms, sleep patterns, reproductive output, and timing of dispersal[151]. In simple terms, ALAN can extend activity of diurnal species into periods of darkness, reducing quantity and quality of sleep and increasing competition with nocturnal species.

[146] (Longcore and Rich 2004)
[147] (e.g. Bhardwaj et al. 2020)
[148] (van Langevelde et al. 2011)
[149] (Davies et al. 2012)
[150] (Santos et al. 2010)
[151] (Riley et al. 2013, Ikeno et al. 2014)

Street lighting on the bridge connecting Phillip Island to San Remo in Victoria attracted short-tailed shearwaters (*Ardenna tenuirostris*) which caused increased mortality because the birds were disorientated, and many juveniles were found weak or dead on adjacent beaches. This was solved by turning the bridge street lights off during the chick fledging period, resulting in almost zero deaths of juvenile birds[152].

10.3 Environmental pollution

Environmental pollution is the introduction and accumulation of chemicals and particulates from transport infrastructure at levels that exceed natural conditions. Pollutants from transportation can accumulate in the air, water, and soil, with engine exhaust emissions from trains and road vehicles being one of the most obvious examples[153]. Pollution can also occur because of chemical spills, vehicle accidents, brake and tyre wear, leaking fluids, and littering. Even maintenance activities can cause pollution through the use of weed sprays, pesticides, and insecticides[154].

Despite being relatively understudied in Australia and globally[155], there is evidence that environmental pollution from transport infrastructure can have a range of direct and indirect impacts on fauna. Impacts from pollution can contribute to the severity of the REZ.

High levels of heavy metal pollutants have been reported in waterways that bisect or border railways[156] and metal concentrations are typically highest near transport infrastructure.

Water run-off from transport infrastructure can flush pollutants into the surrounding environment[157] Once in the ecosystem, pollutants are deposited in the soil which can affect the growth of plants[158]. Heavy metals and toxins may accumulate in the bodies of herbivores that feed on this vegetation as well as predators that feed on the herbivores, potentially resulting in heavy metal poisoning and death. Similarly, in waterways pollutants and sediment can reduce the diversity of macroinvertebrates, alter food-web structures, and reduce aquatic ecosystem services[159]. Amphibians are especially vulnerable because their permeable skin can absorb chemicals, leading to lethal or sub-lethal effects[160].

Some forms of pollution can be transported vast distances by wind, the distance of which is dependent on factors such as seasonality and wind speed and direction[161]. Therefore, habitat degradation from environmental pollutants can extend much further than the linear networks themselves.

[152] (Rodríguez et al. 2014, Rodríguez et al. 2017a, Rodríguez et al. 2017b, Rodríguez et al. 2017c)
[153] (Lucas et al. 2017, St. Clair et al. 2019, White et al. 2023)
[154] (Coffin 2007, Schuler and Relyea 2018)
[155] (Leonard and Hochuli 2017, White et al. 2023)
[156] (Levengood et al. 2015)
[157] (White et al. 2023)
[158] (Lucas et al. 2017)
[159] (Schuler and Relyea 2018)
[160] (Hayes et al. 2010, White et al. 2023)
[161] (Coffin 2007, Schuler and Relyea 2018)

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