Chapter 1

THE ECOLOGICAL EFFECTS OF LINEAR INFRASTRUCTURE AND TRAFFIC: CHALLENGES AND OPPORTUNITIES OF RAPID GLOBAL GROWTH

Rodney van der Ree[1], *Daniel J. Smith*[2] *and Clara Grilo*[3]

[1]Australian Research Centre for Urban Ecology, Royal Botanic Gardens Melbourne, and School of BioSciences, The University of Melbourne, Melbourne, Victoria, Australia
[2]Department of Biology, University of Central Florida, Orlando, FL, USA
[3]Departamento de Biologia & CESAM, Universidade de Aveiro, Aveiro, Portugal

SUMMARY

Roads, railways and utility easements are integral components of human society, allowing for the safe and efficient transport of people and goods. There are few places on earth that are not currently traversed or impacted by the vast networks of linear infrastructure. The ecological impacts of linear infrastructure and vehicles are numerous, diverse and, in most cases, deleterious. Recognition and amelioration of these impacts is becoming widespread around the world, and new roads and other linear infrastructure are increasingly planned to avoid high-quality areas and designed to minimise or mitigate the deleterious effects. Importantly, the negative effects of the existing infrastructure are also being reduced during routine maintenance and upgrade projects, as well as targeted retrofits to fix specific problem areas.

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1.1 Global road length, number of vehicles and rate of per capita travel are high and predicted to increase significantly over the next few decades.
1.2 The 'road-effect zone' is a useful conceptual framework to quantify the negative ecological and environmental impacts of roads and traffic.
1.3 The effects of roads and traffic on wildlife are numerous, varied and typically deleterious.
1.4 The density and configuration of road networks are important considerations in road planning.
1.5 The costs to society of wildlife-vehicle collisions can be high.
1.6 The strategies of avoidance, minimisation, mitigation and offsetting are increasingly being adopted around the world – but it must be recognised that some impacts are unavoidable and unmitigable.
1.7 Road ecology is an applied science which underpins the quantification and mitigation of road impacts.

The global rates of road construction and private vehicle ownership as well as travel demand will continue to rise for the foreseeable future, including at a rapid rate in many developing countries. The challenge currently facing society is to build a more efficient transportation system that facilitates economic growth and development, reduces environmental impacts and protects biodiversity and ecosystem functions. The legacy of the decisions we make today and the roads and railways we construct tomorrow will be with us for many years to come.

INTRODUCTION

Since ancient times, trails and roads have connected settlements and facilitated the movement of goods and people around the world. The Appian Way (over 500 km long), built in the second and third centuries BC in Italy for military and trade purposes, was one of the first improved (hard-surfaced) highways. Portions of this road still remain today, a testament to the high-quality engineering and construction practices of the Roman Empire and the importance of roads to human society. Up until the early 1900s, the majority of the roads linking cities and towns were mostly unimproved, and paving with brick, concrete or asphalt only became common when mass production of vehicles began and the demand for better quality roads and more efficient routes increased. Depression-era public work programs designed to provide employment opportunities and stimulate economies also facilitated a significant increase in paved roads. Today, road construction is still an important driver of economic growth, both during construction and for its long-term effects. Roads are now conspicuous components of almost all landscapes globally, and set to expand even further into the future (Lesson 1.1).

Transportation infrastructure and roads, in particular, are pivotal to economic and social development by providing access to markets, places of employment, businesses, health and family care, leisure activities and education. Governments and international development banks see the construction of new roads and improvement of existing roads as priorities to improve livelihoods. However, the benefits of improved access vary regionally and by road type (e.g. Fan & Chan-Kang 2005), and not all rural road projects result equally in increased agricultural productivity and/or poverty reduction (Laurance et al. 2014; Chapter 2), and in some cases the costs outweigh the benefits. Once built, roads are nearly permanent elements in the landscape, and the wrong road (e.g. motorway/expressway vs. unpaved road) in the wrong place (e.g. roadless wilderness vs. agricultural landscape) can have long-term consequences for both society and the environment. Planning and impact assessment processes must properly account for all the costs, benefits and environmental impacts to ensure that the future road network is as sustainable as possible, particularly in regions where the rate of road construction is currently high or set to increase (see Chapter 5).

The broad aim of this chapter is to provide the necessary background and context for the many topics covered in this book. While primarily focused on roads and vehicles, the lessons in this chapter and book can be applied to all types of linear infrastructure.

LESSONS

1.1 Global road length, number of vehicles and rate of per capita travel are high and predicted to increase significantly over the next few decades

The total length of paved and unpaved roads on earth currently exceeds 64 million km; enough for 83 round-trips to the moon (CIA 2013). Roads dominate most landscapes worldwide – for example, 83% of the continental United States is now within 1 km of the nearest road of any type (Riitters & Wickham 2003). There is approximately 5 million km of road across the 27 countries of the European Union (EFR 2011). The emerging economies of China, India and Brazil are already among the top five countries in road length (4.1, 4.7 and 1.6 millions km, respectively) (CIA 2013) and they have ambitious plans to further increase the capacity of their transportation networks (Chapters 50, 52 and 57). Globally, an additional 25 million lane-kilometre of paved road are to be built by 2050, 90% of which will be in non-Organisation for Economic Co-operation and Development (OECD) countries (Dulac 2013). The 870 million vehicles around the world in 2009 are expected to more than double by 2050 to between 1.7 and 2.8 billion (WEC 2011; Meyer et al. 2012). The majority of these cars will still be in developed countries (with a 33% increase from 2000 to 2050), even though non-OECD countries will have a five-fold increase in vehicles by 2050 (Fulton & Eads 2004). In 2000, the total vehicular travel worldwide was estimated at 32 trillion passenger kilometre per year (up from 2.8 trillion in 1950), and by 2050 is predicted to be 105 trillion passenger kilometre per year, of which about 42% will be by car, the remainder by bus, rail and air (Schafer & Victor 2000).

The predictions of growth in road length, per capita travel and car ownership are based on models with a range of assumptions and will ultimately be influenced by fuel availability and pricing, climate change limits, a desire for increased mobility and other technological, economic, environmental and social priorities and constraints. While the magnitude of the predictions may be debated, all models predict a massive increase in the number of vehicles, road length and travel distances. The challenge for society is to acknowledge this potential rate of growth and decide (i) if it is necessary or desired; (ii) where it should occur; (iii) the preferred mode of transport (e.g. cars, high-speed trains or air travel); and (iv) the design and management of the transport network (e.g. road design and type of mitigation). Importantly, the impacts and solutions proposed in this book and the wider road ecology literature are based on the scale and extent of the current road network. The predictions of growth, even if only partially correct, require urgent and effective actions now.

1.2 The 'road-effect zone' is a useful conceptual framework to quantify the negative ecological and environmental impacts of roads and traffic

The 'road-effect zone' is defined as the area over which the ecological effects of roads and traffic extend into the adjacent landscape (Forman & Deblinger 2000), including noise, light and chemical pollution; disturbance effects; and habitat modification (Fig. 1.1). The size of the road-effect zone is determined by the characteristics of the (i) road (width, surface type, elevation relative to adjacent landscape); (ii) traffic (volume, speed); (iii) adjacent landscape (topography, hydrography, vegetation type, habitat quality); (iv) prevailing wind speed and direction; and (v) species traits and their sensitivity to the impact. Road effects have been observed many hundreds to thousands of metres from the road itself (Reijnen et al. 1995; Forman & Deblinger 2000; Boarman & Sazaki 2006; Eigenbrod et al. 2009; Benítez-López et al. 2010; Shanley & Pyare 2011). The impacts are usually greatest closer to the road and either diminish gradually with increasing distance from the road or exhibit thresholds with steep changes in responses (Eigenbrod et al. 2009). The road-effect zone is a useful approach to quantify and mitigate the negative effects of roads and traffic because it helps regional planners calculate the extent of the area impacted by existing roads (e.g. 15–22% of continental United States) (Forman 2000) or likely to be impacted by proposed roads (e.g. Williams et al. 2001).

1.3 The effects of roads and traffic on wildlife are numerous, varied and typically deleterious

Roads and traffic can significantly affect individual wildlife, populations and communities, and landscapes (Figs 1.1 and 1.2). These impacts can begin during construction and may continue as long as the road

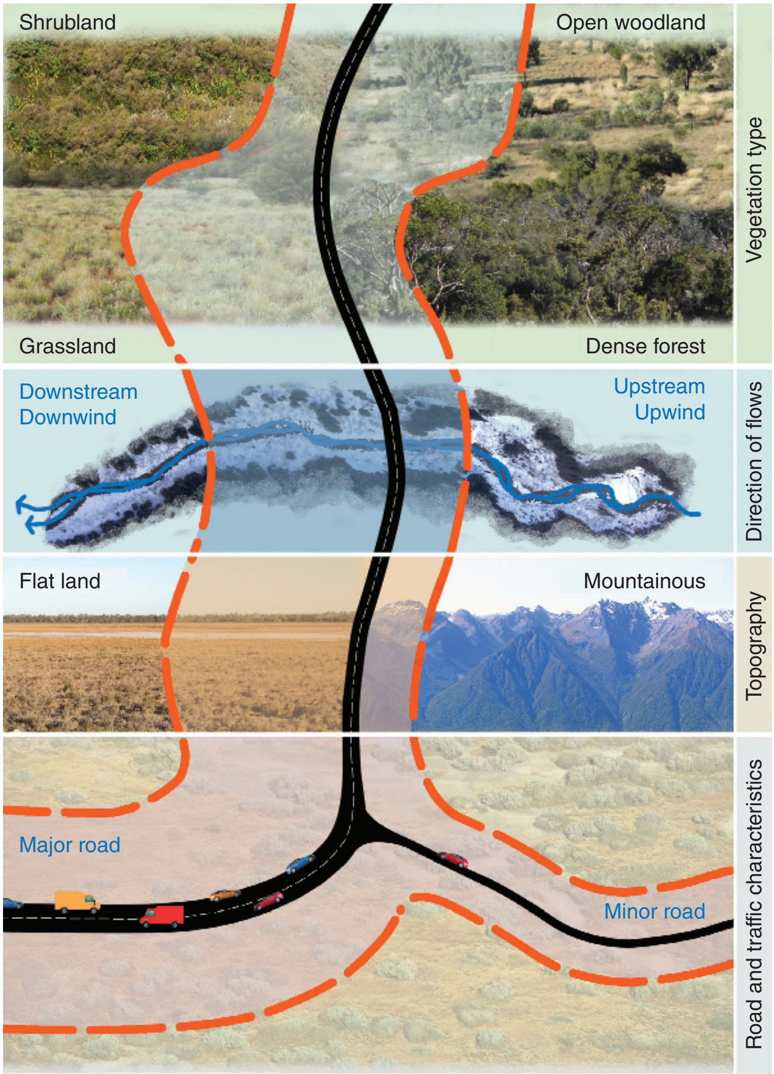

Figure 1.1 The road-effect zone, showing the area over which the ecological impacts of roads and traffic extend. The size of the road-effect zone is affected by a range of parameters – here we show four: (1) vegetation type; (2) direction of flows such as wind and water; (3) topography; and (4) road and traffic characteristics. The relative size of the road-effect zone for each parameter is illustrative only and not indicative; for example, the road-effect zone is not necessarily three times larger in flat than mountainous terrain. Source: Photograph by Zoe Metherell. Reproduced with permission of Zoe Metherell.

remains operational or until the impacts are mitigated. The majority of impacts are typically deleterious, and if severe enough, can reduce the size of populations of wildlife, with a concomitant increase in the risk of local extinction. These impacts are summarised here, and expanded on in subsequent chapters:

• **Habitat loss**: The construction and expansion of transportation corridors results in the clearing of vegetation and a loss of habitat at and adjacent to the road (Figs 1.2 and 2.1). Roads attract people and encourage further development, often resulting in further clearing of vegetation after road construction. Indirect loss of habitat also occurs through degradation, and this can exceed the amount of habitat directly cleared for the road.

• **Habitat degradation**: Due to a range of interacting biotic and abiotic effects, habitat quality often declines

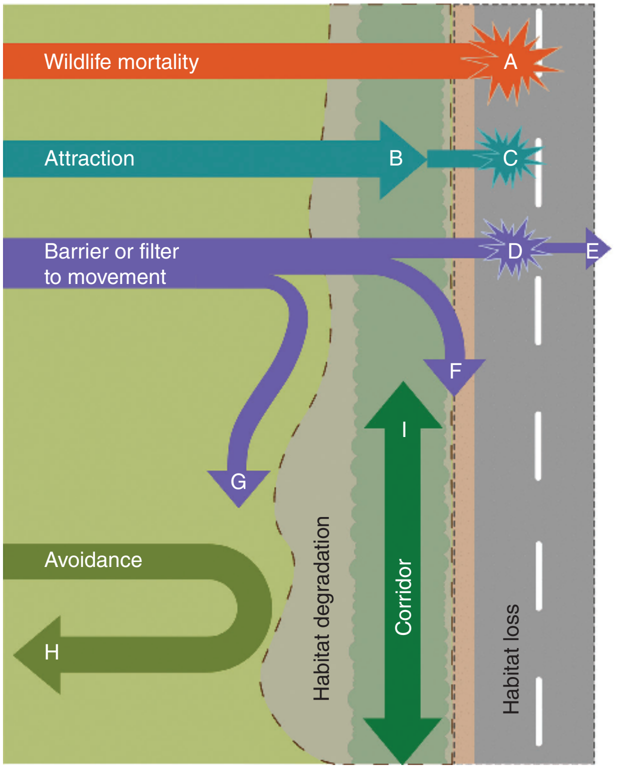

Figure 1.2 Impacts of roads on individual wildlife, populations and ecosystems. Habitat is lost to build the road and habitat adjacent to the road is degraded. The most obvious impact of roads and traffic on wildlife is mortality due to Wildlife-vehicle collisions WVC (A). Some species are attracted to resources (e.g. carrion, spilled grain or heat for basking) on the road or roadside (B) which, depending on the animals ability to avoid traffic, may result in death due to WVC (C). The barrier or filter effect reduces the movement of animals across the road and a proportion of individuals that attempt to cross are killed due to WVC (D) and some make it across (E), while others are deterred from crossing by the road (F) or degraded roadside habitat (G). Other species actively avoid the road or degraded habitat (H). By contrast, some species use the roadside vegetation as habitat and/or as a corridor for movement (I). Source: Illustration by Zoe Metherell. Reproduced with permission of Zoe Metherell.

adjacent to linear infrastructure. For example, the abrupt edges along linear clearings modify microclimatic conditions and encourage weed invasion, and specialist 'habitat interior' species of plants and animals are often outcompeted by 'edge-adapted' generalist species. Edge effects are particularly pronounced in tropical ecosystems (Chapter 49).

• **Barrier or filter to movement**: The creation of gaps in habitat can prevent or restrict the movement of wildlife that avoid clearings, and the noise, light, and chemical pollution and disturbance from vehicles will exacerbate these effects. Road width, whether it is paved or unpaved, and traffic volume affect the severity of the barrier effect (Riley et al. 2006) and species-specific thresholds exist. The type of movement affected varies, including (i) individuals' daily access to important resources; (ii) seasonal migrations of entire populations; and (iii) once-in-a-lifetime dispersal events, all of which can have significant consequences for individual survival, gene flow and population persistence.

• **Wildlife mortality** due to wildlife-vehicle collisions or WVC: Animals that attempt to cross roads or are attracted to the road surface have an increased risk of being involved in WVC and being killed or injured (e.g. Figs 26.2A, 32.2, 32.3, 33.1, 35.1, 38.2).

• **Avoidance**: Some species of wildlife avoid the road-effect zone due to traffic disturbance and/or habitat degradation, resulting in a reduction of habitat or a barrier to movement.

• **Attraction**: Roads and roadsides can attract some species by providing resources or enhanced opportunities. For example, reptiles may bask on the warm surface of the road, herbivores may forage on the enhanced plant growth on roadsides and scavengers can be attracted to feed on roadkill (e.g. Figs 26.2B, 26.3A, 26.4, 46.6).

• **Habitat and/or corridor for movement**: In some highly modified landscapes, roadside strips can provide the majority of habitat for wildlife (e.g. Fig. 46.3). Many adaptable species of wildlife, including invasive species (Seabrook & Dettmann 1996), use the cleared roadways and railways to efficiently move around the landscape (Fig. 26.3B).

The nature and severity of these effects vary among species because of their different morphological, ecological and behavioural traits. Importantly, most effects rarely operate in isolation (e.g. Farji-Brener & Ghermadi 2008), and many act synergistically. For example, animals that avoid roads have low rates of mortality due to WVC because they rarely attempt to cross, but barrier to movement effects may be high, potentially subdividing the population into smaller sub-populations. This arrangement is often called a metapopulation – a set of discrete populations of the same species occurring within the same area that exchange individuals through dispersal, migration or human-assisted movement (after Hanski & Simberloff 1997). The persistence of the metapopulation depends on the number and size of the sub-populations and the level of connectivity among them, and the risk of extinction increases as sub-populations become fewer, smaller and/or less connected. Species that are attracted to roads may suffer high rates of mortality due to WVC if they are unable to avoid oncoming vehicles, or conversely, low rates of mortality if they avoid oncoming vehicles (e.g. low-mobility species such as amphibians versus high-mobility species such as scavenging carnivores).

A recent review demonstrated that roads and traffic have had detectable population-level effects by reducing the size or density of populations near roads for many species (Fahrig & Rytwinski 2009; Chapter 28). These included frogs and toads (Fahrig et al. 1995; Hels & Buchwald 2001), salamanders (Gibbs & Shriver 2005), turtles (Steen & Gibbs 2004), birds (Erritzoe et al. 2003), European hares (Roedenbeck & Voser 2008), badgers (Clarke et al. 1998), bobcats and coyotes (Riley et al. 2006), Iberian lynx (Ferreras et al. 1992) and bighorn sheep (Epps et al. 2005). Roads and traffic can also alter population structure by affecting specific groups of animals, resulting in populations with skewed age or sex ratios (e.g. Aresco 2005; Nafus et al. 2013). These impacts are of particular concern when roads pass through protected areas or ranges of rare and threatened species or sever access to important breeding areas.

1.4 The density and configuration of road networks are important considerations in road planning

The density and configuration of the road network across the landscape are important drivers of the scale and intensity of road impacts on wildlife. Road density is a measure of the abundance of roads within a region, and is measured as the length of road per unit area. Thresholds in road density have been identified for populations of a number of species, including gray wolves in the Great Lakes region, USA which generally avoided landscapes when road density exceeded approximately 0.6 km per km^2 (Thiel 1985). The configuration of the network describes how roads and other linear infrastructure are arranged – such as bundled together or spread out across the landscape. Road networks are typically (i) rectangular/block/grid patterns that decrease in density from urban to rural areas; (ii) radial spokes and concentric rings that form around a city or other central feature; or (iii) linear configuration typically following natural features in the landscape. Road configuration has an enormous bearing on the scale of road impacts across the landscape, and bundling them together and having fewer roads with higher traffic volume is almost always preferred to having them spread out (Jaeger et al. 2006; Rhodes et al. 2014; Chapter 3).

1.5 The costs to society of wildlife-vehicle collisions can be high

The cost to society of WVC with large animals is high, primarily from human injury and loss of life, as well as costs associated with damage and repair of vehicles. There are approximately two million WVC with large mammals in the United States every year, injuring 29,000 people and killing 200 more (Conover et al. 1995), and there were an estimated 500,000 WVC with ungulates in Europe during 1995 (Groot Bruinderink & Hazebroek 1996). The likely rates of collisions are undoubtedly much higher because (i) collisions resulting in minor or negligible damage remain unreported, and (ii) the cause of single-vehicle collisions with roadside objects (e.g. trees) that result in human death may be due to swerving to avoid collisions with wildlife, which remain unreported. The death of wildlife due to WVC will also reduce the size of animal populations, which in some regions are an important source of food for people or income via tourism or hunting. Reduced populations of other species due to WVC may also impact people if such species are important pollinators or perform other critical ecosystem services (e.g. insectivorous bats and birds that help control populations of mosquitoes and other flying insect pests).

1.6 The strategies of avoidance, minimisation, mitigation and offsetting are increasingly being adopted around the world – but it must be recognised that some impacts are unavoidable and unmitigable

The impacts of roads and traffic have been recognised globally as significant threats to the persistence of species and functioning of healthy ecosystems. The principles of the hierarchy of avoiding, minimising, mitigating and offsetting these impacts have also been widely adopted and increasingly practised (Chapter 7). Many governments and communities around the world have accepted the challenge and additional cost of building an efficient transportation network that is safe for wildlife and people. In some regions, priority has shifted to retrofitting the existing network to reduce its impacts on biodiversity. The global proliferation of numerous professional networks (Chapter 61) and non-government organisations with the intent to improve best-practice road mitigation and the membership that includes planners, designers, regulators, ecologists and engineering/construction firms is a testament to this.

However, not all impacts can be fully mitigated, and not all mitigation measures are equally effective. For example, it is difficult and likely impossible in some locations to control the effects of human activities after roads are built, such as increased land clearing and development, the migration and movement of people, and increased hunting or poaching (Chapters 2 and 51). Similarly, the inclusion of mitigation measures in a proposed road project does not automatically mean that all effects have been mitigated and the project should proceed. For example, the likelihood of crossing structures effectively permitting the annual migration of hundreds of thousands of mammals in the Serengeti is extremely low (Chapter 56). Therefore, it is essential to include a 'no-road' option when ranking different route options during the planning of new roads or expansion of existing roads in remote and/or intact ecosystems (Selva et al. 2011; Chapter 3).

1.7 Road ecology is an applied science which underpins the quantification and mitigation of road impacts

The accurate quantification and effective mitigation of road impacts relies on scientifically rigorous research and monitoring (Chapter 10). The first published road ecology studies reported rates of WVC, the most visible ecological effect of roads and traffic (e.g. Stoner 1925; DeVos 1949; Fitch 1949). As road networks expanded and traffic volumes increased in the latter half of the 20th century, research began to focus on quantifying and reducing rates of WVC with large herbivores to save human lives and reduce societal costs. More recently, attention has expanded to include smaller species and encompass a range of biological and ecological parameters such as species distribution, abundance, reproductive rate, behaviour and dispersal (e.g. Legagneux & Ducatez 2013). There have also been recent calls to understand effects at larger spatial and temporal scales and to focus on populations, communities of species and ecosystems (van der Ree et al. 2011). However, quantifying the full breadth of impacts and the effectiveness of mitigation measures as well as reporting practical issues associated with road planning and management are still scarce in research findings (Roedenbeck et al. 2007). Consequently, a large proportion of published road ecology studies appear to have little influence on road planning and design. In moving forward, road agencies should recognise and support good-quality research, scientists and practitioners should collaborate more effectively and researchers should ask applied questions that provide relevant information which road agencies need (Chapter 10).

CONCLUSIONS

The global network of roads, railways, artificial waterways, trails and utility easements is extensive in its length and spread. The total number of vehicles in use is escalating and already difficult to comprehend, and the total distances travelled annually even more so. However, these statistics are to be dwarfed over the next 20–40 years, even if the predictions in growth of road length, number of vehicles and travel distances are only partially met. The impacts of linear infrastructure and vehicles on many species and ecosystems are sufficiently well known to allow the development of effective strategies to avoid, minimise, mitigate and offset most negative effects. The challenge facing society is to identify and retrofit the worst parts of the existing network and build and manage a network for tomorrow that is as good for biodiversity as it is for people.

FURTHER READING

Beckman et al. (2010): An edited volume focussing on North America that aims to collate and integrate information and approaches from various disciplines, as well as a series of case studies that demonstrate effective innovations in planning and mitigation.

Benítez-López et al. (2010): A meta-analysis of almost 50 studies, demonstrating that populations of many species of wildlife declined in close proximity to infrastructure, including up to about 1 km for birds and 5 km for mammals.

Forman et al. (2003): A seminal and comprehensive review and introduction to the field of road ecology, encompassing ecological concepts, planning, wildlife and vegetation, and pollution.

van der Ree et al. (2011): The introduction to a special issue of the open access journal, *Ecology and Society*, which contains 17 articles focussed on the 'Effects of roads and traffic on wildlife populations and landscape function' (http://www.ecologyandsociety.org/issues/view.php/feature/41).

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