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Mitigating the Effects of Transport Infrastructure Development on Ecosystems

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Abstract

Transport infrastructure is one of the most important ways to help a country drive economic growth and alleviate poverty, but it can also have devastating effects on the surrounding ecosystems and wildlife. Habitat fragmentation and degradation, vehicle-wildlife collisions, population and genetic isolation, and loss of ecosystem services are just some of the effects roads can have on ecosystems and wildlife. This synthesis paper seeks to explore these effects and look at different ways to mitigate them to help restore ecosystems and the services they provide. Some ways to mitigate these effects include green infrastructure, corridors, and wildlife crossings. Green infrastructure provides more natural or semi-natural space for various ecosystem services, wildlife, and humans. Corridors connect the natural spaces created by green infrastructure and protected areas and allow movement of wildlife between these areas. Wildlife crossings can be overpasses or underpasses that lessen the barrier effects of transport infrastructure. Collaboration between multiple sectors, including governments, policy makers, transport infrastructure planners, ecologists, and geographers, is needed to create successful and both sustainable transportation networks and green infrastructure that support ecosystem services and functions.

Keywords: transport infrastructure, development, ecosystem services, green infrastructure, corridors, wildlife crossings.

Mitigating the effects of transport infrastructure development on ecosystems

Infrastructure provides the basic framework for moving goods and providing services such as energy, housing, healthcare, and education—essential components for the economic and societal health of a nation (Skorobogatova & Kuzmina-Merlino, 2017). Transport infrastructure, such as road and rail, is a key element that stimulates the growth of modern economies, can ameliorate the health of citizens (Mandle et al, 2015), and reinforces social and cultural relations within and between nations (Gornig, Michelsen, & van Deuverden, 2015, Skorobogatova & Kuzmina-Merlino, 2017). However, these benefits to development often come at a cost to the environment (Reid & Sousa, 2005, Beben, 2012), as interaction between transport infrastructure and the surrounding landscape is inevitable, and most likely negative (Coffin, 2007).

Roads can have adverse effects on biodiversity (Polak, 2014) by increasing wildlife mortality from collisions (Coffin, 2007), fragmenting and degrading habitat (Karlson, Mortberg, & Balfors, 2014), and creating barriers to wildlife movement and migration (van der Grift et al, 2013). This can have long-term effects, including evolutionary changes in wildlife populations (Brady & Richardson, 2017), the introduction of invasive species (Angelstam et al, 2017), and the loss of ecosystem services to surrounding communities (Mandle et al, 2015). Ecosystem services are "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (de Groots, Wilson, & Boumans, 2002). As the human population continues to increase, more transportation infrastructure will become necessary, increasing the negative impact on ecosystems unless informed action is taken (Polak, Rhodes, Jones, & Possingham, 2014). To ameliorate this, infrastructure construction must evaluate impacts from many different angles. One example is this is road ecology, which investigates through ecological, geographical, engineering, and planning lenses the impact of roads upon the surrounding ecosystems (Coffin, 2007).

This paper seeks to present ways in which the negative effects of transport infrastructure, mainly roads, on ecosystems can be lessened. The paper first looks at why transport infrastructure is important to the development of countries. The next section lays out the effects of transport infrastructure on the surrounding ecosystems. We then explore how these effects can be mitigated through green infrastructure, corridors, and wildlife crossings. Finally, this paper emphasizes that collaboration between multiple sectors is the key to successful mitigation of the effects of transport infrastructure on ecosystems.

Need for infrastructure in development

Often considered a prerequisite for economic growth in developing countries (Arima 2016), advancing transport infrastructure can facilitate the growth of urban centers, agricultural and industrial sectors (Skorobogatova & Kuzmina-Merlino, 2017), and international trade (Hopcraft, Bigurube, Lembeli, & Borner, 2015). By 2050, while much of the world's population will inhibit urban areas, anywhere from 45-50% of populations will still reside in rural homes, especially in poorer nations (Chinowsky, Schweikert, Strzepek, & Strzepek, 2015). Often, a lack of connection to urban areas is a driver of poverty. Reliable transport infrastructure can help alleviate rural poverty by offering access to services such as healthcare, education, and food and water supply networks (Chinowsky et al, 2015). In 2008, only 25% of roads in sub-Saharan Africa were paved, compared to 67% of North American roads (Chinowsky et al, 2015). While more research is necessary, the drastic difference in average life expectancy between the two regions (World Health Organization, 2016) indicates a relationship between paved roads and public health. The improvement of transport infrastructure such as useable roads can help ease poverty, increase citizen well-being, and act as a catalyst for economic development (Hopcraft et al., 2015).

Impact of infrastructure on ecological systems

While public well-being and economic growth are important, maintaining healthy ecosystems is a vital factor to potential development and growth. These can reduce risk of flooding and landslides (Mandle et al, 2015) and provide ecosystem services, such as clean water, food, and income from tourist economies (Hopcraft et al, 2015). Ecosystem services (ES) as defined by Coutts and Hahn (2015) "are the benefits that humans obtain from ecosystems." It can be broken down into four categories:

1. regulation functions, such as water and soil regulation;
2. habitat functions, such as suitable living spaces for animals and plants;
3. production functions, such as providing food and raw materials; and
4. information functions, such as aesthetics and recreation (de Groot et al, 2002).

Ignoring ecosystem services during the development of infrastructure can lead to more negative impacts than anticipated, and the benefits may not live up to estimated standards (Mandle et al, 2015).

Roads can be very important to national development, especially in poorer nations, but they also contribute to ecosystem degradation and habitat fragmentation, which can reduce or even eliminate the populations of certain species in the area (Mandle et al, 2015, Snȁll, Lehtomaki, Arponen, Elith, & Moilanen, 2016). The construction and maintenance of transport infrastructure is one of the most significant drivers of deforestation, which in turn negatively impacts biodiversity and carbon sequestration (particularly tropical forests) (Arima, 2016). Additionally, developing new roads that interfere with existing ecosystems could have a devastating impact on the economy of a country through loss of tourism (Hopcraft et al, 2015). For example, tourist revenue from the Serengeti-Ngorongoro ecosystem in Tanzania, a protected area famous for its annual wildebeest migration, brings in over 100 million USD each year (Hopcraft et al, 2015). A road such as the proposed Serengeti Route would bisect the area of wildebeest migration and disrupt the ecosystem. Degradation of this area would reduce tourist economies and foreign capital which, in turn, would have huge repercussions for Tanzania's economy and those who rely on the ecosystem resources (Hopcraft et al, 2015).

Globally, road network length is expected to increase 60% by 2050 (Mandle et al, 2015). Of all types of infrastructure, roads inflict the most damage on surrounding ecosystems (Reid & Sousa, 2005). This ranges from the fragmentation, degradation, and loss of habitat (Clauzel, Xiqing, Gongsheng, Giraudoux, & Li, 2015) to increased mortality rates due to vehicle-wildlife collisions (Coffin, 2007) to noise disturbances, pollution, chemical contamination (Ogden, 2012), and runoff contamination (Brady & Richardson, 2017) to barriers to wildlife movement and migration (van der Grift et al, 2013) and the spread of invasive species (Herzog, 2016) to an increased human carbon footprint (Angelstam et al, 2017) to population and genetic isolation (Beben, 2012) and loss of biodiversity (Karlson et al, 2014).

Habitat fragmentation, generally caused by the construction process and the resulting physical barriers to movement, is a major threat to species, leading to isolation of populations and gene flow restrictions (Clauzel et al, 2015). These effects persist even after the infrastructure is in place (Karlson et al, 2014). Paved roads become a predictor of deforestation in the Peruvian Amazon, one of the most biodiverse areas in the world, by making surrounding zones more accessible; proposed transportation projects could cause an anticipated 1.8 million hectares of deforestation (Arima, 2016, Reid & Sousa, 2005). This damage should be considered while planning such projects in order to minimize these effects (Beben, 2012). One example of this is the National Environmental Policy Act in the United States, which currently mandates that agencies develop Environmental Impact Statements during project proposals. In its 1990 Environmental Policy Statement, the U.S. Federal Highway Administration also recognized the importance of ecological assessment (Southerland, 1994). While this is a good step forward, it is one of only a few exceptions.

More commonly, the failure to consider ecosystem services and the effects of infrastructure on surrounding ecosystems creates disastrous results: eliminating native ecosystems, contributing to floods and landslides, increasing pollution, and creating urban heat islands (Herzog, 2016). When a coastal road, the Clenaga-Barranquilla highway, was built in Columbia, the importance of mangroves was not considered. This resulted in a highway being exposed to erosion, a decline in certain fish populations, and increased poverty among villagers reliant upon fishing (Mandle et al, 2015). Both society and nature can benefit from infrastructure that is developed with an understanding of the services that ecosystems provide to the affected region.

Balancing infrastructure and ecosystems

Green Infrastructure

Green infrastructure (GI) refers to natural or semi-natural areas that are strategically planned to lessen the environmental burden of development (Capotorti, Del Vico, Anzellotti, & Celesti-Grapow, 2017) and provide ecosystem services, such as new habitats, flood management, temperature reduction, and cleaner air and water (Tayouga & Gagne, 2016). Urban areas use GI, such as public parks and green spaces, to counteract the loss of intact natural habitats, reduce urban heat islands, and promote biodiversity and species movement (Garmendia, Apostolopoulou, Adams, & Bormpoudakis, 2016, Kasada et al, 2017). GI can also help maintain and restore ecosystems by giving land developers the tools to balance infrastructure and wildlife habitat conservation (Snȁll et al., 2016, Garmendia et al., 2016). Other GI benefits include water management and regulation (Herzog, 2016), climate change mitigation, and improvements in public health and well-being (Garmendia et al, 2016).

The main goal of GI in the United States is to improve watershed quality, which provides many ecosystem services. One of the most common barriers to implementing GI policy is the difficulty of convincing private landowners to comply (Dhakal & Chevalier, 2017). To counter this, the GI website of the Environmental Protection Agency (EPA) has information on implementing policy for and overcoming barriers to green infrastructure (United States Environmental Protection Agency, 2017). Some U.S. cities have already started using it on public land to help restore ecosystem services that have been depleted by urban density and infrastructure (Snȁll et al, 2016). In Portland, Oregon, GI was implemented to help divert storm-water and to improve watershed functions (Shandas, 2015). This has been realized extensively through the Tabor to River program, which includes planting 3500 trees and creating an extensive network of 500 vegetated storm-water facilities to ameliorate the impermeability of roads and subsequent runoff (Shandas, 2015). GI initiatives in U.S. urban centers such as Portland have improved watershed stability, increased biodiversity, and provided various ecosystem services such as improvement in air quality and noise reduction (Herzog, 2016).

Green infrastructure, which can be as small as an isolated tree or as large as a forest (Capotorti et al, 2017), is only effective if properly planned and maintained (Snȁll et al, 2016). Its aim is to reestablish socio-ecological services and functions (Herzog, 2016); therefore, when planning for green infrastructure, data on distribution of species, habitat types, ecosystem services, and land-use patterns must be taken into account. An analysis of the trade-offs should also be considered (Snȁll et al, 2016). GI deterioration, caused by increased land use or ineffective management, negates its initial benefits (Angelstam et al, 2017). New transport infrastructure should try not to interfere with current green infrastructure initiatives that allow for increased ecosystem services to humans as well as benefits to wildlife (Angelstam et al, 2017).

Corridors

One of the most common ways to implement green infrastructure is with corridors (Snåll et al, 2016). As defined by Van de Perre, Adriaensen, Songorwa, and Leirs (2014), a wildlife corridor is "an unprotected area between two or more protected areas either

(i) through which animals are known or believed to move,
(ii) that are connected by (or can potentially be reconnected by) natural vegetation, or
(iii) both (i) and (ii) together."

Wildlife corridors are frequently used to connect green infrastructure and protected areas (Snåll et al, 2016) to help mitigate the effects of habitat fragmentation from transport infrastructure (Coffin, 2007). Increasing functional movement between protected areas mitigates the effects of climate change on vulnerable species, helps conserve biodiversity, and maintains ecosystem services (Karlson et al, 2014). Corridors should be planned to overcome the barrier effect of nearby transport infrastructure (Karlson et al, 2014), to be useful for a majority of local species (Garmendia et al, 2016), and to account for range distribution changes due to climate change (Snåll et al, 2016).

Corridors can maintain or expand gene pool flow, help facilitate movement, and provide habitat for range shifts, as well as enable other processes that require large spaces (Snåll et al, 2016). Unfortunately, new roads are breaking up wildlife corridors worldwide, creating ecological islands of isolated populations in protected areas and affecting genetic diversity (Van de Perre et al, 2014, Beben, 2012).

To counter this problematic trend, U.S. Representative Don Beyer, Jr (D-VA) introduced the Wildlife Corridors Conservation Act of in December 2016 (HR-6448), which would promote the creation of corridors with a National Wildlife Corridors System to protect and restore native wildlife and plants (Wildlands Network, 2017). As of December 2017, the bill is still in the subcommittee on conservation and forestry (Library of Congress, 2016).

Similarly, in Ukraine there is a plan in place to increase forest coverage, but the rate of habitat gain has been deemed far too low to have a discernable effect (Angelstam et al, 2017). While the creation of corridors after the building of infrastructure is beneficial, natural corridors that are kept intact while building infrastructure seem to have a bigger and more positive effect on species movement (Snåll et al, 2016).

Corridors allow development to occur while addressing conservation needs (Rovero & Jones, 2012). However, the relative success of corridors should not blind governments or policy makers into thinking we no longer need to protect larger reserves or that we should move our attention away from managing ecosystems as a whole (Snȁll et al, 2016).

Wildlife crossings and fences

Wildlife crossings are another way to mitigate the effects of new roads on local species, and they are particularly good at aiding efforts to reduce habitat fragmentation. These crossing structures can be either underpasses – including tunnels, pipes, or even drainage culverts (Karlson et al, 2014) – or overpasses – such as land or rope bridges (van der Grift et al, 2013). They are being globally developed and utilized, including underpasses for various populations in the Roztocze Hills in Poland (Angelstam et al, 2017) and Canadian overpasses for grizzlies in Banff National Park (Ogden, 2012). Well-designed over- and under-passes can be used by many species (Karlson et al, 2014), although it is not always a one size fits all scenario (Ogden, 2012). There are key factors to the design of the wildlife crossing that can improve its viability. These include location, size, openness, habitat cover, and fencing (Ogden, 2012). Smaller animals may need more frequent crossings than larger animals, and it may take some time for the crossings to be used, as in Banff National Park, where it took grizzlies five to six years to start using the overpasses (Ogden, 2012).

Polak et al. (2014), van der Grift et al. (2013), and Beben (2012) all agree that wildlife crossings are most effective when they are paired with fences, although it can be difficult due to the cost of fences, the impact on landscape aesthetics, and the potential for it to cross onto private land (Huijser et al, 2016). It is the combination of wildlife crossings and fences that helps create protected and connected habitats which allow the migration of species over long distances (Beben, 2012). Fences along the road help keep wildlife from trying to cross, therefore reducing mortality, and can also help guide animals to use the wildlife crossings, which can encourage movement of populations and gene flow (Polak et al, 2014). Wildlife crossings and fences also help maintain a steady traffic flow, which is beneficial for humans by making the roadway safer, reducing vehicle-wildlife collisions, and decreasing property damage caused by these collisions (van der Grift et al, 2013).

Working together

Mitigating the effects of transport infrastructure on ecosystems must be a collaborative effort. Many different sectors, including governments, transport infrastructure planners, policy makers, ecologists, geographers, must come together to ensure that all the needs of both ecosystems and human communities are met. Road ecology, for example, is the investigation of the impact of roads upon the surrounding ecosystems. To understand the multifaceted and complex issues, this discipline uses multiple lenses including ecological, geographical, engineering, and planning, among others (Coffin, 2007).

One of the main problems that prevents the effective implementation of green infrastructure is the knowledge gap regarding ecosystem services and biodiversity. This can be clearly observed in many transport infrastructure planning situations (Angelstam et al, 2017). Data showing the benefits of green infrastructure to humans and ecosystems, however, can provide key knowledge and can bolster support from other parties, including community members and decision makers (Lovell & Taylor, 2013). To be sustainable in the long term, transport infrastructure and GI planning should be collaborative, strategic, dynamic, and adaptive (Herzog, 2016).

Conclusion

While building infrastructure is vital to economic development and poverty alleviation, the benefits of natural ecosystems to both the economy of a country and the well-being of its citizens should not be forgotten. Using green infrastructure during development can maintain and support the services provided by a specific ecosystem (Coutts & Hahn, 2015). Wildlife corridors are necessary to connect protected land areas, and wildlife crossings and fences can help connect fragmented habitats. While there are ways to mitigate the negative effects of roads on ecosystems after they are built, a proactive approach that preserves natural corridors will help with long-term sustainability of the transport infrastructure and the ecosystem services of an ecosystem. Successful and sustainable projects require collaboration between governments, policy makers, infrastructure planners, ecologists, and the community. There are ways to balance human needs and ecosystem needs when it comes to building infrastructure, especially roads. It may not be easy, but unless we want to continue to be affected the negative impacts of roads on ecosystems and wildlife, we need to take informed action now.

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