

Chapter 45

Beyond the Right-of-Way: Integrating Fence and Road Ecology



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Abstract Fences are ubiquitous across the world's landscapes. As a result, fence ecology—the empirical study of interactions between fences, organisms, ecosystems, and societal needs—is gaining more attention among researchers and practitioners. While road ecologists often incorporate fences along roads as tools to reduce wildlife–vehicle collisions, fence ecology views all fences from a broad landscape perspective. Road ecology can benefit from fence ecology by considering wildlife mitigation along transportation corridors in concert with fence networks in the surrounding landscape. Understanding how fences affect animal movements and wildlife–vehicle collisions, impact the efficacy of safe wildlife crossing opportunities, and contribute to the cumulative effects of infrastructure on ecosystems, can improve road planning, design, and mitigation. Here, we explore the intersection of fence ecology with road ecology and advocate for use of a context-sensitive design (CSD; also termed context-sensitive solutions, CSS) approach to merge the principles of these disciplines by using a broad landscape perspective. By integrating fence and road ecology through CSD or CSS, we can design appropriate fence systems and road mitigation measures that benefit human economic needs, social values, and restore, maintain, or improve the function and resiliency of ecosystems.

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45.1 Synthesis

45.1.1 *What Is Fence Ecology?*

Fences are ubiquitous across the world's landscapes. Globally, the extent of fence networks far exceeds roads and is rapidly increasing (Jakes et al. 2018; McInturff et al. 2020). A growing body of research is uncovering the profound effects of fences on wildlife, vegetation, hydrology, soils, and ecological processes (Jakes et al. 2018; McInturff et al. 2020; Wilkinson et al. 2023). As a result, fence ecology—the empirical study of interactions between fences, organisms, ecosystems, and societal needs—is gaining more attention among researchers and practitioners.

The ever-widening webs of fences and roads contribute to habitat loss, habitat fragmentation, reduced habitat quality, and a decline in biodiversity. While road ecologists often incorporate fences along roads as tools to reduce wildlife–vehicle collisions, fence ecology views all fences from a broad landscape perspective. However, road ecology can benefit from fence ecology by considering wildlife mitigation along transportation corridors in concert with fence networks in the surrounding landscape. Understanding how fences affect animal movements (Chap. 23) and wildlife–vehicle collisions (Chap. 1), impact the efficacy of safe wildlife crossing opportunities (Chaps. 33 and 34), and contribute to the cumulative effects of infrastructure on ecosystems, can improve road planning, design, and mitigation (Jakes et al. 2018; Lee et al. 2023). In this chapter, we explore the intersection of fence ecology with road ecology and advocate for a landscape perspective for the study and mitigation of fences and roads.

45.1.2 *The Function of Fences*

Fences are used as management tools to control human and animal movement and demarcate property boundaries (Jakes et al. 2018). Fences are also used as conservation tools in the management of wildlife and habitat and to control the spread of disease between wildlife and domestic livestock. The invention of barbed wire in 1874 made it economical to fence vast areas and led to the proliferation of fences around the globe (Jakes et al. 2018). Today, the rapid spread of fences globally is driven by accelerating human demands and land-use change (Løvschal et al. 2017; Xu and Huntsinger 2022).

Fences are often erected to reduce wildlife and livestock incursions onto roads. When properly designed and maintained, they can reduce wildlife–vehicle collisions by at least 80% (Huijsers et al. 2016). However, wildlife exclusionary fences along roads result in near-impermeable barriers to wildlife in the landscape (Chap. 4).

Wildlife crossing structures over and under roadways can help maintain and even improve ecological connectivity, especially when combined with fences that guide animals to crossings (Huijser et al. 2016; Seidler et al. 2018). Yet the planning of wildlife crossings often overlooks the influence of fence networks beyond the transportation corridor and how this may hinder or assist wildlife movements across linear infrastructure (Chap. 33). Further, fences as well as roads create impacts on ecological processes and function at every scale. Broadening our perspective to incorporate fence ecology in the practice and science of road ecology can result in more effective mitigations for ecological connectivity and integrity.

45.1.3 Spatiotemporal Footprint

Fences are so pervasive and familiar that they easily recede from people's consciousness and stir little consideration of their purpose or effect. Despite their prevalence, we do not know the full spatial extent of fences across landscapes because they are difficult to map (Jakes et al. 2018). Fences are narrow linear features that are difficult to detect via imagery, are undetectable under tree cover, and often can only be inferred from vegetation differences. Additionally, imagery gives us no ability to determine fence purpose, type, design, height, permeability, or condition—all variables that must be verified on the ground.

Fences also have different temporal considerations than roads in terms of their effects on fauna and flora. To cross roads, wildlife may adapt their movements to time when traffic volume is lowest (Chaps. 2 and 3). In contrast, fences are vertical and static, and the ability of animals to cross fences may be affected by seasonal snow or floods, or the age and condition of animals throughout the year (e.g., pregnancy or stress; Segar and Keane 2020). While the spread of roads can outpace the ability of species and ecosystems to adapt, fences are even faster to construct and their proliferation accompanies rapid changes in land tenure and land use, which leads to serious issues for wildlife and the ecosystems that they depend on (Løvschal et al. 2017; McInturff et al. 2020).

Fences require regular maintenance to ensure effectiveness, with associated costs in material and labor (Knight et al. 2011). When fences are allowed to deteriorate, gaps negate their purpose and loose wires create an entanglement hazard for wildlife (Paige 2020). Lastly, fences may have a long temporal “shadow” even after they are removed. Dupuis-Desormeaux and others (2018) documented wildlife continuing to cross at a known fence opening even after most of the fence was removed or reconfigured to allow multiple areas for crossing. Such fences have been termed “ghost fences.”

45.1.4 Ownership and Management

Fences have a wide variety of ownerships and management, ranging from government (national, state/provincial, or local) to private (individual or corporate) entities. The management of public fences is typically the responsibility of public entities. In some cases, both private and public entities may be involved: in the USA, for example, grazing allotment fences on public lands may be owned by the government but maintained by allotment lessees. In most areas, fences and wildlife crossing structures along highways are owned, constructed, and maintained by a government transportation agency. Fences on private land are usually owned, constructed, and maintained by the private landowner. Private fences may be subject to no or few regulations, but owners often rely on materials that are readily available and designs that are common in their region. Any fence removal or modifications to private fences that benefit wildlife are usually at the discretion of the owner. This complicates the coordination of such efforts on a landscape level.

The technical side of fence modifications for wildlife can be relatively simple, as a wide variety of wildlife-friendlier fence designs have been developed (Paige 2020). However, in a given landscape, conservationists are often faced with an array of fence types and purposes as well as social reluctance to try new designs. This leads to complex negotiations with numerous stakeholders when planning for both human needs and habitat connectivity on a landscape level.

45.1.5 Ecological Consequences

Fences and roads both have direct and indirect effects on ecosystem processes and functions, but the effects of fences are largely understudied and poorly understood (Jakes et al. 2018; McInturff et al. 2020). The impact of a fence is a result of structure (i.e., fence type, material, height, wire spacing) and spatial extent. While traffic volume and speed impact wildlife permeability of roads, fences add a physical impediment that slows or completely bars wildlife passage.

Direct effects of fences include changes to habitat or individual mortality, whereas indirect effects result in changes in habitat quality and accessibility or changes to wildlife behavior (Jakes et al. 2018; Jones et al. 2019)—both can create “winners” and “losers” depending on the ecological process or species involved (Jakes et al. 2018; McInturff et al. 2020). For example, many wildlife species, particularly ungulates, birds, and bats, collide with fences or become entangled and either die on impact, suffer a slow death as they try to escape, or gradually decline from injuries (Harrington and Conover 2006). Note that while an animal killed in a fence “loses,” there may be a secondary “winner” if a scavenger feeds on the remains or a predator incorporates fences in their hunting strategy (Davies-Mostert et al. 2013).

Habitat loss or alteration along fence lines occurs from changes in soil and moisture regimes associated with fences (such as where snowdrifts build up along fence lines) and changes in herbivore grazing pressure. However, habitat loss can also be measured in terms of the number of animals unable to navigate past a fence (Segar and Keane 2020). Fences that exclude wildlife on a large scale can generate a cascade of changes throughout ecological communities (Smith et al. 2020).

Indirect effects of fences are predominantly related to changes in species presence, numbers, and behaviors and can be subtle or drastic. For example, fence posts are used as perches by avian predators in landscapes with few trees, resulting in increased predation, including on threatened species (Cutting et al. 2019). Fences often block ungulate movements, sometimes leading to severe population declines (Van Moorter et al. 2020). Even if a fence is semi-permeable, there may be subtle impacts in use of available habitat if there is an avoidance of the fence and a reluctance to cross (Jones et al. 2019). Fences can increase energy expenditure if animals must cross many fences or travel along a fence line to find places permeable enough to cross (Sawyer et al. 2016; Jones et al. 2020). Beyond direct effects to wildlife, fences can alter nutrient dispersal, spread invasive weeds, change plant and soil structure through altered herbivory, and in turn modify soil absorption of rain and snow, all of which subsequently influence where and how humans interact with and depend on landscapes (Bradby et al. 2014; Løvschal et al. 2017). At multiple scales, fences influence ecological function and resiliency. Hence, societies must thoughtfully integrate fences and roads with landscape contexts and the cultures that are supported by them.

45.2 Perspectives

45.2.1 *Integrating Fence and Road Ecology Objectives via Context-Sensitive Design and Solutions*

The expansion of roads and fences continues at a breathtaking pace. Of specific concern to road ecology, fence networks can affect animal movement and wildlife–vehicle collisions, impact the efficacy of wildlife road crossings and mitigations, and add to the cumulative effects of transportation infrastructure to ecosystems.

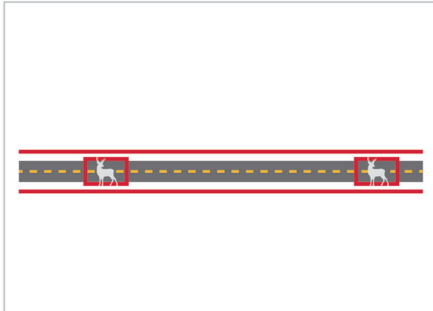
To avert the accumulating impacts of these infrastructure networks, we urgently need a shift in perspective that takes a landscape-level view and sets social–ecological planning objectives to address the needs of people, nature, and wildlife more holistically (Xu and Huntsinger 2022). Such an approach asks that we adopt a view of natural communities as first-level “infrastructure” that is as essential to human well-being as are commerce, agriculture, and transportation. This means not merely saving patches of nature, carving out greenways and parks as a nod to open space, or secondarily installing crossings in road and fence networks for ecological connectivity and passage of mobile organisms. Rather, it asks us to value the flows and fluxes of nature’s processes and diversity of organisms as fundamental to human health.

This perspective is not new. In transportation planning, “context-sensitive design” (CSD) is a “collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation infrastructure that integrates social and ecological values” (FHWA 2001). Though there is no formal definition, the term “context-sensitive solutions” (CSS) is now used more commonly to emphasize that the stakeholders and the social and ecological values are not only involved during the design phase, but that they are present in all stages of a project: from the earliest planning through the construction (Neuman et al. 2002; Sipes and Sipes 2013). CSS not only involves stakeholders, but it uses interdisciplinary teams, integrates social and ecological values, seeks broad-based public involvement, aims to achieve consensus on the purpose and need of a project, addresses alternatives, includes all modes of transportation, and is seen as having added a lasting value to community (Neuman et al. 2002, Sipes and Sipes 2013). In the case of the integration of road and fence ecology, CSD or CSS should include measures that reduce direct wildlife mortality and that allow for better wildlife connectivity, both along roads and in the surrounding landscape (Fig. 45.1). By incorporating both human and ecological infrastructure in the planning process, CSD or CSS can produce designs that work with nature to meet ecological and societal needs. Ultimately, such an approach can result in faster project delivery, better relationships among the stakeholders (including the public), and a more sustainable landscape that works better for people and wildlife (Neuman et al. 2002; Sipes and Sipes 2013). An example of such high-level efforts at a landscape level, or even national scale, comes from The Netherlands, where a multi-decade habitat defragmentation program resulted in coordinated mitigation measures along highways, railroads, canals, and changes in land use to increase core habitat and establish or strengthen corridors between them (MJPO 2020). Connecting small tracts of natural habitat via several crossing structures along transportation corridors has created a large, integrated, and permeable network of habitat that can support larger populations of diverse species.

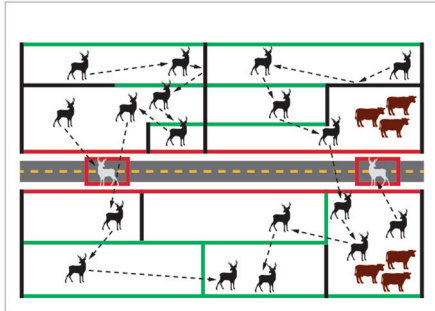
Road systems and fence networks are managed as separate entities, yet they interact and both affect wildlife movement and human and wildlife safety (Jones et al. 2022). Traditionally, road engineers aim to provide safe and efficient transportation (Stamatiadis 2004), but do not necessarily address ecological or other social impacts (Lee et al. 2020). Transportation agencies have historically been aware of the danger of wildlife–vehicle collisions (Fig. 45.1A) but may not consider the presence and necessity of wildlife movements across the road as a significant impact to wildlife distribution and movements throughout the landscape. With advances in technology (e.g., GPS tracking and mapping; Chap. 42), biologists are gaining a detailed understanding of how certain species interact with and navigate obstacles encountered during daily and seasonal movements. Yet while fences are a common impediment to wildlife movement (Fig. 45.1B), reducing or eliminating these barriers is often piecemeal, whether along roadways or in the broader landscape (Jakes et al. 2018).

By using CSD or CSS as an integral part of the decision process to plan or modify infrastructure within a landscape context (i.e., from “ridgetop to ridgetop,” across watersheds, or across other natural units), there is an opportunity to avoid the most

A) Road Management



B) Fence Management



C) Fence and Road Ecology

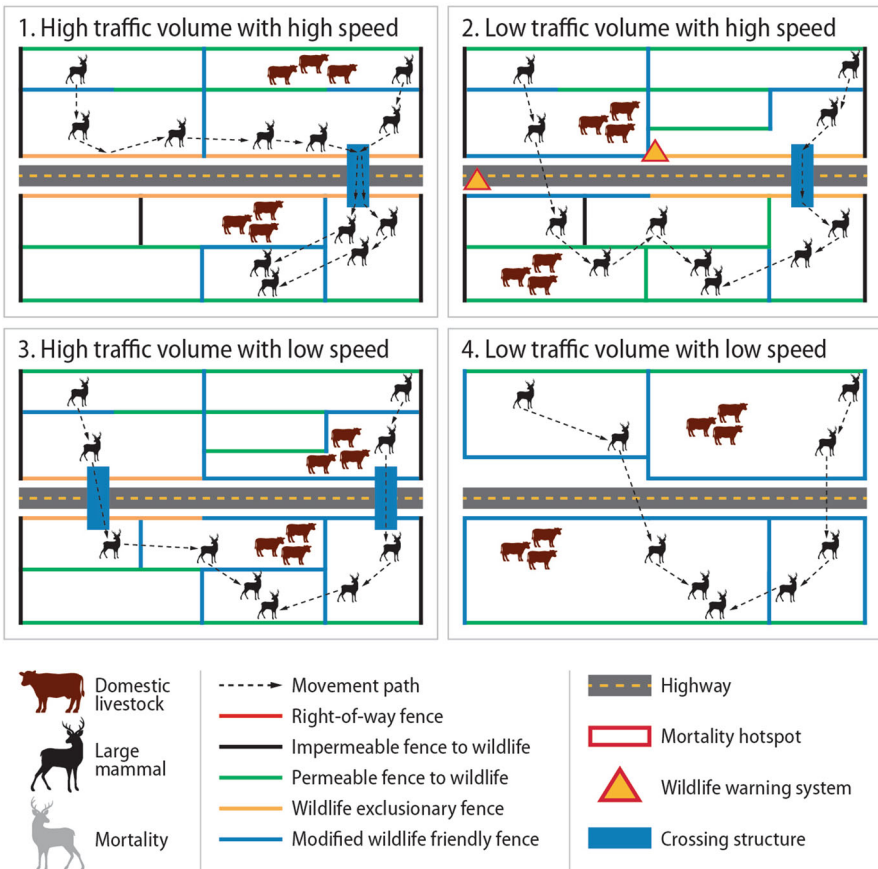


Fig. 45.1 How can we merge fence ecology with road ecology using context-sensitive design or context-sensitive solutions? This graphic illustrates some basic examples for wildlife movement and connectivity. Conventionally, roads are managed with a focus on traffic efficiency and human safety. Road right-of-way fences may be installed to prevent livestock or human trespass onto roadways, but these fences are often permeable to wildlife (A) resulting in wildlife–vehicle collisions (WVC, red boxes). Fence ecology examines how fences dictate or hinder where wildlife

severe impacts on ecosystems. This inherently requires more coordination with other stakeholders and deft balance of varied and competing interests, compounding the road agencies' task. Yet CSD or CSS can lead to practical solutions that sustain natural processes while also addressing transportation and other community needs. Initially, we can consider whether a road or fence project is worth the ecological and social cost. We can strive to assure that vehicle route design, construction, and expansion accommodate wildlife movements and ecological function appropriately. We can also address whether fence systems in the broader landscape can allow for improved wildlife movement in concert with safe road crossings (Fig. 45.1C). This approach can have practical safety and economic benefits for transportation agencies. For example, if a roadway is re-routed away from sensitive habitat and wildlife movement areas, wildlife may be less likely to breach right-of-way fences, which in turn reduces wildlife–vehicle collisions and the need for mitigation measures aimed at improving human safety. However, there may still be a need for widespread adoption of mitigation measures and restoration practices along road sections where impacts remain. Traffic volume and speed influence the type of measures that are most needed (Fig 45.1C).



Fig. 45.1 (continued) moves across the landscape in the context of topography, land use, and other infrastructure such as transportation corridors and developments. In **(B)**, fences are modified to be safer, more permeable, and direct movement in a landscape, but there is yet no alliance with road ecology. The four scenarios under **(C)** combine the interests of road ecology and fence ecology in the context of traffic volume, traffic speed, and the broader landscape. Here, we see how ecologists might reduce WVCs and enhance wildlife movement to maintain or restore wildlife connectivity. This framework can be used as a guide for prioritizing mitigation, though structure design and placement will also be influenced by socioeconomic considerations. Working with adjacent landholders to reduce fence density and create wildlife-friendlier fences in the surrounding landscape can influence where animals move and interact with the transportation corridor. Fewer and more permeable fences are especially important where animals approach crossing structures (underpasses and overpasses) or where we want to encourage animals to cross the road at grade. High traffic speed (C1 and C2) results in more severe collisions and increased human injury and fatality. This warrants substantial measures to reduce WVCs, such as warning systems and crossing structures. High traffic volume, whether at high or low speed (C1 and C3), creates a greater safety hazard and barrier to wildlife. Traffic at high volume and high speed calls for physically separating wildlife and traffic by constructing exclusion fences to funnel animals to safe wildlife crossing structures (C1). Note that crossing structures installed without exclusion fences do not necessarily reduce WVCs but is one approach for increasing wildlife connectivity at low speeds when the traffic volume itself may prevent at-grade crossings by wildlife (C3). Installing exclusion fences to guide animals to crossing structures is the ideal mitigation strategy as it reduces collisions and increases wildlife use of crossings. Roads with low traffic volume (C2 and C4) are less of a barrier to wildlife and have less risk of collisions. With low traffic, we can allow wildlife to cross on the road surface if we identify and mitigate problem areas (e.g., blind curves and hills, preferred wildlife crossing areas). On low traffic high-speed roads (C2), WVC mitigations would be appropriate at high-frequency crossing sites, including warning systems and crossing structures. On roads with both low traffic volume and low speeds (C4), there is far less risk to human safety and less barrier potential to wildlife movement. Here, permeable wildlife-friendlier fences along the roadway allow wildlife to cross fences easily and move quickly out of the right-of-way. (Figure graphics produced by Alberta Conservation Association)

45.2.2 Opportunities to Plan Fences at a Landscape Scale

The application of CSD or CSS principles with the aim to reduce wildlife–vehicle collisions and improve ecological connectivity can enhance human safety and allow for more natural processes in perpetuity. For example, wildlife exclusionary fences along roads keep the animals off the road, reduce wildlife–vehicle collisions, and guide the animals toward safe crossing opportunities. Concurrently, removing unneeded fences in the surrounding landscape, and rendering the remaining fences more permeable, are important habitat restoration and improvement projects, and are especially important strategies that provide wildlife safe crossing opportunities while navigating to or from transportation corridors.

Efforts to reduce the impacts of fences require the adoption of criteria for placement and design that are sensitive to purpose and context (e.g., Paige 2020). The first need is to understand where fences are on the landscape (sensu Poor et al. 2014), what the purpose is or was, the type and condition of the fences, and to track where changes to fences occur. Fence effects on wildlife movement and habitat use should be evaluated (Jones et al. 2019; Xu et al. 2021). At a finer level, the interactions of fencing with ecological processes can also be investigated, such as effects on soils, hydrology, community composition and diversity, and invertebrate behavior (Fukuda et al. 2011; Jakes et al. 2018).

Once fence network characteristics are known, options to remove or modify fences can be explored. This level of planning is a social enterprise influenced by local values, perception, traditions, economics, and the sheer number of stakeholders, which often makes landscape-level planning conflict-laden and messy. However, it is essential to incorporate community voices early on in any large-scale and meaningful planning. Identifying community influencers and early adopters, addressing points of resistance, and providing opportunities for public collaboration throughout the planning and design phases can accelerate long-term acceptance and implementation.

Wildlife is more likely to navigate road crossings successfully if the resistance of the surrounding landscape is low. Removing obsolete fences and modifying necessary fences with wildlife permeable designs (Paige 2020) in the larger landscape can enhance wildlife movement and the effectiveness of wildlife highway crossings. Wildlife-friendlier fencing is gaining traction among resource agencies, landholders, and conservationists. Wildlife-friendlier designs are more likely to be embraced when landholders are presented with multiple design options, cost-share opportunities, and incentives based on economic interest or values, such as reducing the cost of fence maintenance or programs that reward conservation. Fence alternatives are also possible, such as hedgerows or stakes to delineate property boundaries or “virtual fences” that manage livestock movement with electronic collars. Further, the need to fence properties to identify boundaries or for decorative purposes only should be reconsidered, where unconventional or multipurpose markers could be viable options.

By integrating fence ecology into roadway planning, fence design, placement, and removal become prudent tools to improve the effectiveness of roadway mitigation measures in terms of human safety and biological conservation (Fig. 45.1C).

45.2.3 Conclusions

The footprint of both fences and roadways continues to increase. However, by integrating fence and road ecology, we can improve human safety and allow for more natural ecological processes, both across roads and through the surrounding landscape. Although wildlife mitigation measures along transportation corridors can be expensive, applying CSD or CSS principles can be helpful to reduce both the societal and ecological costs and maximize the benefits on a project-by-project basis. While it is a complicated process and agreement among stakeholders can be arduous to achieve, an integrated approach can result in more sustainable and durable landscapes through tangible activities that put people to work, in which communities can support, and that uphold or improve ecological processes.

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