YOSEMITE NATIONAL PARK TECHNICAL GUIDANCE FOR MITIGATION OF WILDLIFE-VEHICLE CONFLICT

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Contents

Abstract

Yosemite National Park (Yosemite) is one of the pre-eminent parks of the National Park Service and in California's Sierra Nevada. Visitors love Yosemite's grandeur, geological features, Sierra Nevada ecology, and wildlife. Over 400 wildlife species depend on Yosemite for at least part of the year, where they are vulnerable to impacts from people, including wildlife-vehicle conflict (WVC). Wildlife-vehicle conflict is defined here as any conflict between wildlife and vehicles (e.g., collision, wildlife aversion to traffic). WVC puts both animals and drivers at risk and can be costly in term of dollars and resources. This technical guide provides an overview of methods the Park can use to reduce WVC, followed by examples of each. Methods include structural installations, traffic regulation, and modification of driver behavior through education. When implemented, these methods should reduce the risk and harm to drivers and wildlife alike.

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I. Executive Summary

Wildlife-Vehicle Conflict (WVC) is defined as any negative interaction between wildlife and vehicles and includes collisions, wildlife avoiding traffic, and drivers avoiding wildlife in the road. For humans, incidents of WVC can lead to injury or death. It also leads to property damage to cars and roadsides, damage to ecological systems at the roadside, pressure on emergency response systems, and inconvenience and economic impacts (i.e., caused by traffic jams) to other drivers. For wildlife, incidents of WVC can lead to injuries or death, avoidance or displacement from habitat/corridors, and fragmentation of a population.

A variety of techniques have been used to reduce these negative impacts. We describe the primary attributes of each method, as well as how they vary in efficacy, cost, and difficulty of implementation. We summarize ways to decide which method to use, and ways to include the methods in existing work-flows within Park operations and capital projects.

We first describe approaches that rely on changing driver behavior, traffic patterns, and traffic volumes. We then present structural approaches that require re-engineering the relationship between the roadway and surrounding habitat, to encourage wildlife crossing through safe crossings. We briefly discuss methods that are not effective, but that are still commonly considered. Finally, we present several methods for decision-support that can be used to both prioritize the types of actions needed and to evaluate effectiveness of actions after they have been deployed.

II. Background

Road networks have detrimental effects on wildlife populations. Globally, roughly 6% of adult vertebrates are being killed by vehicle collisions, with this percent increasing over time (Hill et al 2019). In North America, the direct effects of vehicles on wildlife populations are substantial, with estimates amounting to 340 million birds killed annually on US roads (Loss et al., 2014), and 13.8 million birds annually in Canada (Bishop and Brogan 2013).

In addition to the impact of WVC on individual species, road networks may also cause an unraveling of trophic interactions and other ecosystem processes. For example, apex predators are particularly vulnerable to mortality from traffic owing to their high mobility and range size. The loss of apex predators can cause unintended top-down effects, such as causing meso-predators to flourish, threatening smaller prey species, as well as causing populations of herbivores to expand, which can in turn threaten plant communities (Beschta and Ripple, 2009).

Within US national parks, >12,500 WVC incidents were reported between 1989 and 2006. A myriad of mitigation approaches that include ecological, sociological, and engineering solutions are effective for reducing WVC, yet only 36% of 106 National Park Service units use any mitigation measure to prevent WVC (Ament et al., 2008). Recognition and mitigation of road and traffic impacts on wildlife is one of the most important conservation actions that protected areas can take. Because roads provide access to visitors, it can also be one of the most challenging.

Yosemite has 214 miles of roads that visitors and staff use to access the 748,000 acres of the Park. Up to 5 million visitors in hundreds of thousands of vehicles visit the Park every year, which can equate to an average of ~19,000 vehicles per day (2017 values) on the three primary access highways (120, 41, 140). Such a high number of vehicles in a concentrated area can impact tourist safety and tourist experience within the park (Hobday and Minstrell 2008). For instance currently, there are as many as 600 motor vehicle collisions with animals per year (all statistics from NPS Park Statistics website: https://www.nps.gov/yose/learn/management/statistics.htm). At the same time, Yosemite is home to several iconic species that are vulnerable to traffic and sometimes to the road structure itself: i. great gray owl (*Strix nebulosa*, California Endangered Species); ii. California spotted owl (*Strix occidentalis*, Species of Special Concern); iii. Pacific fisher (*Pekania pennanti*, Species of Special Concern); iv. Sierra Nevada yellow-legged frog (*Rana sierrae*, Federally Endangered Species); v. California red-legged frog (*Rana draytonii*, Federally Threatened Species); vi. Yosemite toad (*Anaxyrus canorus*, Federally Threatened Species); vii. American Black Bear (*Ursus americanus*); viii. ringtail (*Bassariscus astutus*); gray fox (*Urocyon cinereoargenteus*); and ix. mule deer (*Odocoileus hemionus*). Although Yosemite does not keep regular statistics on WVC, between 2007 and 2017, collisions with 270 black bears were reported to or by Park staff.

The primary causes of WVC are animal interactions with roadways and vehicle speed (Shilling et al., 2020). Wildlife-vehicle collisions can result in injury or death to the animal, injury or death to drivers, and significant property damage. Although fencing can be used to reduce or eliminate animals appearing on roads (Rytwinski et al., 2016), in un-fenced areas, it is virtually impossible to predict when and where animals might appear in front of a vehicle. Educating drivers about speed and WVC, enforcing speed limits, and warning drivers when animals are present are all cost-effective ways to reduce WVC. Wildlife will sometimes use under- and over-crossing structures with and without associated fencing. However, crossing stuctures are more effective when paired with wildlife-resistant fencing (Rytwinski et al., 2016). Further, animal detection systems, combined with fencing, can warn drivers when wildlife are present in crossing areas.

The goal of this report is to present a distillation of the technical and scientific literature to inform managers of the most effective approaches to reduce WVC that reduce overall costs and increase acceptance by managers, visitors, employees, and others. The following sections provide detailed descriptions of different types of mitigation actions that can be taken to reduce WVC, and maintain tourism satisfaction within the park. These include educating the public, using speed limits and vehicle entry controls to modify traffic patterns and speed, installing systems to detect animals and then warn drivers of their presence, the installation of fencing and/or wildlife crossing structures. Finally, we provide recommendations for the data collection, and decision-making process which play a key role pre- and post-mitigation strategy.

1. Citations

Ament, R, Clevenger, AP, Yu, O, Hardy, A (2008) An Assessment of Road Impacts on Wildlife Populations in U.S. National Parks. Environmental Management (2008) 42:480–496

Beschta, RL, Ripple, WJ (2009) Large predators and trophic cascades in terrestrial ecosystems of the western United States. Biol. Conserv. doi:10.1016/j.biocon.2009.06.015

Bishop CA, Brogan JM (2013) Estimates of avian mortality attributed to vehicle collisions in Canada. Avian Conserv Ecol 8:2. https://doi.org/10.5751/ACE-00604-080202

Hill, JE, DeVault, TL, Belant, JL (2019) Cause-specific mortality of the world's terrestrial vertebrates. Global Ecol Biogeogr. 28:680–689. DOI: 10.1111/geb.12881

Loss SR, Will T, Marra PP (2014) Estimation of bird-vehicle collision mortality on U.S. roads. J Wildl Manag 78:763–771. https://doi.org/10.1002/jwmg.721

Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig L, Findlay C.S., Houlahan J., et al. (2016) How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS ONE, 11(11): e0166941. doi:10.1371/journal.pone.0166941

Shilling, F, Wendy Collinson, Michal Bil, Diemer Vercayie, Florian Heig, Sarah E. Perkins, Sandra MacDougall (2020) Designing wildlife-vehicle conflict observation systems to inform ecology and transportation studies. Biol. Cons., 251 (2020) 108797. https://doi.org/10.1016/j.biocon.2020.108797

B. Public Education and Speed Control

The first methods we describe are intended to change driver behavior. In theory, changing our own behavior should be easier than trying to change what wildlife do.

1. Public education, handout, interpretative centers

Park visitors are accustomed to changing their behavior in response to direction and education by staff, signs, and handout materials. However, visitors with entrenched beliefs and habits may not respond to this type of approach (Hughes et al., 2009). Permanent roadside signs warning of animals in the vicinity are common (Forman et al., 2003), however, their effectiveness is rarely studied and when evaluated usually found to be ineffective at reducing collisions (Romin and Bissonette, 1996; Al-Kaisy et al., 2008; Rytwinski et al., 2016). Roadside signs are intended to change driver behavior, but their effectiveness is dependent on characteristics of the signs, driver familiarity with the problem, ease of responding, and driver's knowledge of appropriate responses (Meis and Kashima, 2017). When surveyed, drivers indicated that static (unchanging) signs would not be effective at changing their behavior (Bond and Jones, 2013). In addition, in driving-simulation tests, the presence of static wildlife-warning signs do not result in significant reductions in driving speed (Jagerbrand and Antonson, 2016; Jagerbrand et al., 2018). In contrast, drivers may change their behavior in response to static signs if these provide clear direction (Meis and Kashima, 2017), and are accompanied by multiple outreach mechanisms, such as printed educational material, or radio messages (Jagerbrand et al., 2018). In a limited study in Sequioa & Kings Canyon National Parks (Winter, 2008), visitors responded to negative direction ("please don't …") more than positively-worded direction ("please stay on the path…"). In one elaborate investigation, drivers were asked to review a range of (primarily) static signs related to WVC and predict how they would respond to them (Bond and Jones, 2013). One key finding from this study is that including a changing tally of number of killed animals over some preceding time provides

Box 1. Watch out for Wildlife!

Park visitors are accustomed to receiving warnings and instructions while walking and driving through the Park. This receptivity can be harnessed to constantly remind them that driving fast through wildlife habitat is a recipe for collisions. Typically, signs that simply warn of animals in the road are not effective at reducing speed, or collisions. However, combining more dynamic and attention-grabbing signs with public education at other locations in the Park may get through to visitors, who would not want to be involved in a collision with an animal.

evidence of roadkilled animals to drivers which increases their receptivity to signage. Therefore combining signage with outreach and education may be most effective at reducing WVC – this includes directive handouts, signs at kiosks and along roads, and communication with visitors through social media, clear descriptions of desired or prohibited behavior, and clear enforcement of regulations.

Public education recommendation: Signs and educational materials that provide clear instructions and are dynamic (i.e. frequently moved, flashing and containing changeable messages) are most effective at changing driver behavior. Making signs more dynamic (see section 2) and engaging and combining this with outreach through informational booths and materials, visitor apps, and websites will tend to increase general effectiveness.

2. Dynamic signs/messages

Dynamic signs (defined as flashing, alternating between messages, or temporarily-placed) are more likely to change driver behavior including increased driver vigilance and decreased speed than static signs. Dynamic signs warn of conditions that the driver is headed towards, such as construction, or an accident, which drivers may respond to by reducing speed or changing their path. In contrast, static signs are more like street signs – familiar, not usually tied to approaching problems, and possibly taken for granted by the driver. Dynamic signs are most effective when selectively applied in certain hotspot areas, such as where there have recently been high rates of roadkill. For example in rural areas, drivers will respond to information about animals (including physical models of animals) as part of their risk-perception, but this may depend on how the information is delivered and received (Cox et al., 2017).

Dynamic signs warning of animals and the potential for WVC can be effective at reducing collisions, however, their effectiveness may depend on how much they are moved around, and their message changed to reduce familiarity (Sullivan et al., 2004). For example, in places where rain and seasonal conditions are likely to result in amphibians crossing a road, a large flashing sign that turns on under those conditions will alert drivers to toads crossing. In addition, their effectiveness may be enhanced when used in conjunction with a public-education campaign (Rea, 2013). A critical difference between dynamic and static signs is that dynamic signs can give the impression of updated warning information, including information about recent WVC, the short distance over which the warning is relevant, and the types of animals the driver should be aware of (Bond and Jones, 2013). In addition, if there are "hot-times" for WVC (e.g., after first rain, or dusk and dawn), then the signs can be placed and/or activated during those times. Even though dynamic signs have been shown to sometimes be effective and certainly more than static signs, there have only been a few studies of whether or not speed and WVC-reduction accompanied the signs. Interestingly, radio-warning messages can be effective at reducing driver speeds and when combined with signs have a greater combined effectiveness than either approach alone, including having an effect that extends well beyond the warning location (Jagerbrand and Antonson, 2016; Jagerbrand et al., 2018).

Box 2. Caution, owl crossing

Great gray owls hunt by perching on the edge of meadows and diving down to catch their prey. In Yosemite, roads often bisect meadows. When owls focus on their prey and dive, they are oblivious to passing vehicles. Great gray owls are listed as endangered in California because of a small breeding population. Therefore, every roadkilled owl can have an impact on the population success. Using attention-grabbing signs to warn drivers about the possibility of owls flying across the road could reduce these collisions.

Dynamic signs recommendation: Dynamic warning signs are more effective at changing driver behavior and reducing WVC than static signs. Examples of effective dynamic signage include: changing the position of signs, including flashing lights, briefly describing the desired driver behavior, and providing information about prior WVC.

3. Speed control

When drivers are traveling at higher speeds, they are more likely to collide with animals, and collisions are more likely to have severe consequences, with increased rate and severity of accidents in proportion to increase in speed (Muller et al., 2014; Valero et al., 2015; Tejera et al., 2018). Speed limits and comprehensive enforcement have been proven to be very effective at dramatically reducing the risk of all collisions, including those with animals in roadways. Slower vehicles are much less likely to collide with animals, and when collisions occur with larger animals, are less likely to cause fatality or injury to driver or animal. The traffic safety literature is replete with studies of traffic speed and every traffic agency in the US emphasizes the role that speed plays in collisions. At the same time, there is substantial pressure to maintain or even raise speed limits. For example, a CA senator introduced legislation on 2/20/2019 to remove speed limits from stretches of I-5 and SR 99 in California. These stark contrasts – between the role that speed reduction plays in collision reduction and the US drivers' desire to go fast, makes speed control a challenging solution. However, protected areas have a very special place in the public's heart, and it seems likely that speed control that protect wildlife and drivers from collisions could be readily supported, assuming the justification is clear.

Internationally, managers of protected areas have used speed control to reduce the rate of WVC, primarily to protect wildlife. For example, in late 2017, the National Parks, Wildlife and Plants Conservation Department of Thailand instructed national park staff to enforce a speed limit of 60 kph (37 mph) as part of a multi-pronged effort to reduce wildlife mortality due to human activity (http://englishnews.thaipbs.or.th/strict-speed-limits-national-parks-prevent-wild-animals-road-accidents/). In certain Australian parks and natural areas, reducing traffic speed limits to protect wildlife resulted in a significant reduction in WVC. For one road-expansion project through a forested area in Queensland, Australia, enforced speed reductions (to the limit of 50 kph) resulted in 3-fold lower roadkill rates compared to areas of the same road without enforced speed reduction (Jones et al., 2014). Speed controls to benefit animals are especially important during periods of reduced visibility (Hobday and Minstrell, 2008; Hobday, 2010).

Box 3. Closing for butterflies

In Taiwan, highway officials have partially closed national highways in response to a mass migration of the purple butterfly (https://udn.com/news/story/7266/3719532). As many as 1,200 butterflies/min crossed the highway on the 26th March 2019. The butterflies are now directed to fly above vehicles by barriers placed alongside the highway. In addition, the highway administration can restrict traffic when the butterfly passage standard of 250/minute is exceeded, ensuring protection during migration. Vehicle strikes have been estimated to kill 3% of monarch butterflies during their migration through the US (Kantola et al., 2019). Road closure and traffic speed restriction could reduce mortality of butterflies (and other animals) during migration.

Traditionally, driver speed is controlled using speed limit signs and on-road enforcement. These approaches are most effective when enforcement is frequent, and drivers perceive the need for speed reduction. Speed control is most effective when combined with other approaches such as those described in earlier sections. For example, in a driving simulation study, drivers reduced their speed by 8 kph, from ~90 kph, in response to a warning delivered through their radio about animals in the roadway (Jagerbrand et al., 2018). This warning was even more effective when combined with a sign warning of animals' presence (Jagerbrand and Antonson, 2016).

Speed control recommendation: Traffic speed plays such a critical role in WVC that it should be evaluated as a mitigation measure. Speed limits that are appropriate for line of sight and stopping distances, especially in wildlife-containing areas, are likely to be one of the least costly and most effective WVC mitigation measures.Speed limits are most effective when combined with increased driver education, dynamic signs, and visible enforcement of speed limits.

4. Citations

Al-Kaisy, A., Hardy, A., and Nemfakos, C. (2008) Static warning signs of occasional hazards: Do they work? ITE J. 2008, 78, 38–42.

Bond, A.R.F. and Jones, D.N. (2013) Wildlife warning signs: public assessment of components, placement and designs to optimise driver response. Animals 3, 1142-1161; doi:10.3390/ani3041142

Cox, J.A., Beanland, V. and Filtness, A.J. (2017) Risk and safety perception on urban and rural roads: effects of environmental features, driver age and risk sensitivity. Traffic Injury Prevention, 18(7), pp.703-710.

Dique, D.S. (2003) Koala mortality in south-east Queensland: the koala speed-zone trial. Wildlife Research, 30: 419–426.

Fahrig, L., Pedlar, J.H., Pope, S.E., Taylor, D. and Wegner, J.F. (1995) Effect of road traffic on amphibian density. Biological Conservation, 73: 177–182.

Forman, R.T.; Sperling, D.; Bissonette, J.A.; Clevenger, A.P.; Cutshall, C.D.; Dale, V.H.; Fahrig, L.; France, R.; Goldman, C.R.; Heanue, K.; Jones, J.A.; Swanson, F.J.; Turrentine, T.; Winter, T.C. (2003) Road Ecology: Science and Solutions; Island Press: Washington, DC, USA, pp. 113–167.

Hobday, A.J. (2010) Nighttime driver detection distances for Tasmanian fauna: informing speed limits to reduce roadkill. Wildlife Research, 37: 265–272.

Hobday, A.J and Minstrell, M.L. (2008) Distribution and abundance of roadkill on Tasmanian highways: human management options. Wildlife Research, 35: 712–726.

Hughes, M., Ham, S.H. and Brown, T. (2009) Influencing park visitor behavior: A belief-based approach. Journal of Park and Recreation Administration, 27(4): 38-53

Jagerbrand, A.K. and Antonson, H. (2016) Driving behaviour responses to a moose encounter, automatic speed camera, wildlife warning sign and radio message determined in a factorial simulator study. Accident Analysis and Prevention, 86: 229–238; http://dx.doi.org/10.1016/j.aap.2015.11.004

Jagerbrand, A.K., Antonson, H. and Ahlstrom, C. (2018) Speed reduction effects over distance of animal-vehicle collision countermeasures – a driving simulator study. European Transport Research Review, 10:40; https://doi.org/10.1186/s12544-018-0314-8

Jones D.N., Griffiths, M.R. , Griffiths, J.R., Hacker, J.L.F. and Hacker, J.B. (2014) Implications of upgrading a minor forest road on traffic and road-kill in southeast Queensland. Australasian Journal of Environmental Management, 21(4): 429–440, http://dx.doi.org/10.1080/14486563.2014.944590

Kantola, T., Tracy, J.L., Baum, K.A., Quinn, M.A., and Coulson, R.N. (2019) Spatial risk assessment of eastern monarch butterfly road mortality during autumn migration within the southern corridor. Biological Conservation, 231: 150-160 https://doi.org/10.1016/j.biocon.2019.01.008

Meis J. and Kashima Y. (2017) Signage as a tool for behavioral change: Direct and indirect routes to understanding the meaning of a sign. *PLoS ONE* 12(8): e0182975. https://doi.org/10.1371/journal.pone.0182975

Muller, L.I., Hackworth, A.M., Giffen, N.R., Evans, J.W., Henning, J., Hickling, G.J., and Allen, P. (2014) Spatial and temporal relationships between deer harvest and deer–vehicle collisions at Oak Ridge Reservation, Tennessee. Wildlife Society Bulletin, 38(4):812–820; DOI: 10.1002/wsb.446

Rea, R.V. (2012) Road safety implications of moose inhabiting an urban-rural interface. Urban Habitats, 7. Available online: http://www.urbanhabitats.org/v07n01/moose_full.html

Romin, L.A. and Bissonette, J.A. (1996) Deer-vehicle collisions: Status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin, 24: 276–283.

Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig L, Findlay C.S., Houlahan J., et al. (2016) How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS ONE, 11(11): e0166941. doi:10.1371/journal.pone.0166941

Sullivan, T.L.; Williams, A.F.; Messmer, T.A.; Hellinga, L.A. and Kyrychenko, S.Y. (2004) Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. Wildlife Society Bulletin. 32: 907–915.

Tejera G., RodrõÂguez, B., Armas, C., RodrõÂguez A. (2018) Wildlife-vehicle collisions in Lanzarote Biosphere Reserve, Canary Islands. *PLoS ONE* 13(3): e0192731. https://doi.org/10.1371/journal.pone.0192731

Valero, E.., Picos, J., and Álvarez, X. (2015) Road and traffic factors correlated to wildlife–vehicle collisions in Galicia (Spain). Wildlife Research, 42: 25–34; http://dx.doi.org/10.1071/WR14060

Winter, P.I. (2008) Park signs and visitor behavior: A research summary. Park Science, 25(1); 34-35.

C. Traffic Timing

1. Daily "hot-times"

In areas where human activity is common, animals that are naturally diurnal are more active at night to avoid human interactions (Gaynor et al., 2018). In California, most WVC on moderate to busy roadways occur after dark and before dawn (Shilling, unpublished observations). Within Yosemite, black bear collisions were highest between 3-4pm and 6-8pm (Rodriguez, 2015). These observations about time of day can be used to adjust how much driving is permitted in certain areas, speed limits/reductions, and even closure of certain roads at certain times. In South African protected areas, nighttime road closures are a common strategy used to reduce WVC with nocturnal and nighttime-active wildlife.

Daily hot times recommendation: Restrict driving into and within the park after dark (30 minutes after sunset). If driving is permitted, then suggest strict speed limits (25 mph) and enforcement.

2. Seasonal "hot-times"

For many species, the risk of WVC increases at certain times of day and season. For example, mule deer are more likely to be on roadways during the fall breeding season and subsequent migration (Shilling, unpublished observations). In California, up to 1/3 of vehicle conflict with deer is during two fall months (mid-September to November), however, collisions with other animals (e.g., skunks) often peak in spring (Shilling, unpublished observations), when many animals are moving around more, and young are emerging from dens. In Yosemite, the highest number of bear collisions occur between June – September, coinciding with peak number of visitors and high levels of bear activity in the park (Rodriguez, 2015).

Seasonal hot times recommendation: During times of the year, times of day, or during early rains, limit driving or speed limits. This may be especially important for stretches of road where amphibians are migrating as they will tend to freeze when under threat or move slowly on the road.

Box 4. Toad alert

When the first rains of the wet season arrive, amphibians will migrate toward breeding ponds, which may send them across roads. During these times, the more vehicles on the road, the more likely amphibians are to be killed (Fahrig et al., 1995; Mazerolle, 2004). It is possible to place signs seasonally, or use dynamic signs activated by rain to warn drivers that amphibians may be on the road. In certain cases of mass migration, roads can be closed, and traffic diverted to protect crossing animals.

3. Citations

Fahrig, L., Pedlar, J.H., Pope, S.E., Taylor, P.D., and Wegner, J.F. (1995) Effect of road traffic on amphibian density. Biological Conservation, 73:177–182.

Gaynor, K.M., Hojnowski1, C.E., Carter, N.H., and Brashares , J.S. (2018) The influence of human disturbance on wildlife nocturnality. Science, 360: 1232–1235

Mazerolle, M.J. (2004) Amphibian road mortality in response to nightly variations in traffic intensity. Herpetologica, 60(1):45-53. http://dx.doi.org/10.1655/02-109

Rodriguez, K E. 2015. Identification and modelling of black-bear vehicle collision zones on Yosemite National Park, California. MSc thesis, San José State University.

D. Traffic Types and Volumes

In Yosemite, there is increased concern about the number of visitors and vehicles accessing the Park. This has led to discussion of remote parking and expanded shuttle service, especially during the busiest parts of the season. Traffic volume can have a direct effect on the likelihood of WVC, with increases in volume generally leading to greater rates of WVC for road-tolerant species (Valero et al., 2015). Further, for more sensitive species, increases in traffic may cause changes in movement behavior (wolverine, Scrafford et al., 2018), or greater road avoidance (Mount. Graham red squirrel, Chen and Koprowski, 2016), which can genetically separate sub-populations from each other.

1. Single-Occupancy Vehicles vs. Shuttles

All other things being equal, the more vehicles on a road, the greater the chance that an animal attempting to cross could be hit by a vehicle (Valero et al., 2015). For example, in Tennessee, as traffic volumes increased, there was a significantly greater rate of collisions with deer (Muller et al., 2014). This means that a shuttle service would not only reduce traffic and emissions on Park roadways, but it would be easier to enforce shuttle speeds and would also reduce the potential for collision with wildlife.

Vehicle recommendation: Concentrate visitors into fewer vehicles to reduce the likelihood of collisions with wildlife. Because fewer vehicles on the road may tempt drivers to speed, enforcement of speed limits for remaining drivers, including shuttle/bus drivers would be necessary.

2. Visitor-Traffic Restriction

There is likely to remain a strong correlation between the number of visitors and the number of vehicles. Because there is also a strong relationship between the number of vehicles and mortality of wildlife, or wildlife-avoidance of roadways, the more visitors, the more impacts on wildlife. This means that reducing the number of visitors will reduce harm to Park wildlife. It is theoretically possible that this correlation can be affected by the mitigation measures described elsewhere in this document. For example, wildlife mortality would be lower if wildlife-protective and enforced speed limits were in place. Wildlife avoidance of roads would possibly also be lower if vehicles were traveling more slowly and only in the daylight.

Visitor traffic recommendation: Absent broad application of other mitigation measures, the most effective method to reduce vehicle and roadway impacts to wildlife is to limit the number of vehicles to the park, either through use of public transportation, or limits on visitors, or both.

3. Citations

Chen, H.L. and Koprowski, J.L (2016) Differential effects of roads and traffic on space use and movements of native forest-dependent and introduced edge-tolerant species. PLoS ONE, 11(1): e0148121. doi:10.1371/journal.pone.0148121

Matthew, A., Scrafford, M.A., Avgar, T., Heeres, R., and Boycea, M.S. (2018) Roads elicit negative movement and habitat-selection responses by wolverines (Gulo gulo luscus). Behavioral Ecology, 29(3): 534–542. doi:10.1093/beheco/arx182

Valero, E., Picos, J., and Álvare, X. (2015) Road and traffic factors correlated to wildlife–vehicle collisions in Galicia (Spain). Wildlife Research, 42: 25–34; http://dx.doi.org/10.1071/WR14060

E. Driver Warning & Roadside Animal Detection Systems

1. Dynamic signs combined with wildlife crosswalks

Dynamic signs (see section B2 for description) that warn drivers of the imminent risk of WVC can effectively reduce WVC (Hardy et al, 2006). In Arizona, a wildlife-crosswalk is set up to alert approaching drivers with a flashing sign when a large animal is approaching or within the crosswalk (Gagnon et al., 2019). This has led to a >95% reduction in WVC and 100% reduction in human fatalities and injuries in what was previously a dangerous highway.

Dynamic signs & crosswalks recommendation: In short zones where animal crossing can either be easily predicted (e.g., first rains for amphibians) or detected, place a dynamic sign that directs drivers to be alert, slow down, and potentially stop when animals may be or are crossing.

2. Roadside Animal Detection Systems

Several ways of detecting and identifying wildlife have emerged that can be combined with driver-warning systems (Table 1). Some systems sense a signal emitted from a fixed roadside station that is reflected by animals near or on the road, and then use software to interpret that signal. Two technologies rely on passive detection of heat (thermal imagery) or movement of larger animals (buried electrical cable). In all cases, if an animal is detected, a signal is sent to a warning sign directed at drivers to alert them to the potential of an animal in the roadway. The different technologies vary widely in cost, maintenance requirements, effectiveness, and readiness for deployment (Table 1).

Table 1. Range of technologies, costs, and readiness for roadside animal detection systems. Costs are for detection systems only, not the corresponding driver warning signs. (Including information from Drs. Hau Xu and Andrew Alden, University of Nevada Reno and Virginia Tech Transportation Institute, respectively)

Technology	Proven effectiveness	Up-front cost (cost/length)	Maintenance requirements	Readiness
Radar	Limited	$100,000/mile	$$, maintain station	Research-grade
Buried cable	Useful for deer or larger	$100,000/mile	$$, maintain station	Research-grade
LiDAR	Useful for deer or larger	$30,000/100 m	$$, maintain station	Research-grade
Thermal camera	Useful for medium to large mammals	$30,000/100 m	$$, maintain station	Field-implemented

Roadside animal detection system recommendation: In stretches of roadway where collisions are common, position roadside detection systems to detect animals moving into the roadside and connect detection to dynamic signs warning drivers.

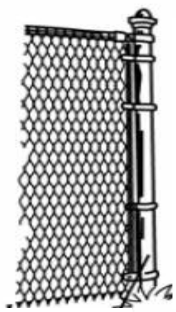
1. Citations

Gagnon, J.W., Dodd, N.L., Sprague, S.C., Ogren, K.S., Loberger, C.D. and Schweinsburg, R.E. (2019) Animal-activated highway crosswalk: long term impact on elk-vehicle collisions, vehicle speeds, and motorist braking response, Human Dimensions of Wildlife, 24(2): 132-147, DOI: 10.1080/10871209.2019.1551586

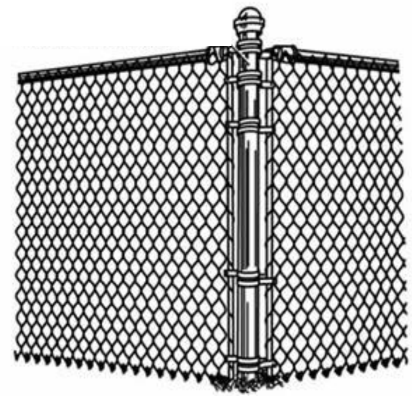
Hardy, A., Lee, S. and Al-Kaisy, A.F. (2006) Effectiveness of animal advisory messages on dynamic message signs as a speed reduction tool case study in rural Montana. Transportation Research Record: Journal of the Transportation Research Board, 1973: 64–72.

F. Wildlife Fencing

Fencing works particularly well for deer. Research within and outside the US has demonstrated an up to 80% decline in roadkill-related mortality in ungulates for fenced roadways. Fencing designed with a V-shaped fence-end to direct animals away from the roadway (Figure 1), and/or in conjunction with wildlife crossing structures can be especially effective. Placement can be modified to include a jumpout; an escape ramp that wildlife can use to leave the roadside if they breach the fence and become trapped on the roadside.



A fence end without a V-shape exposes animal to the road



Attach a piece of fencing on the end to create a V. This directs animal away from road

Figure 1. A straight-line fence versus a fence with a V-shaped end. Images courtesy of https://www.chainlinkfencing.org/terminology/index.html

Fencing can serve two purposes: a mitigation tool for road mortality, or “barrier fencing”, and to direct animal movement toward suitable routes of passage such as wildlife crossing structures, known as “funnel fencing” (Van Der Ree et al., 2015). Fencing reduces roadkill by 54% on average for all taxa combined (Rytwinski et al., 2016) and despite the initial financial expenditure, is an economically beneficial strategy over the long term (Huijser et al., 2009).

Fencing design

The structural specifications required for fencing will largely depend on the target species and non-target species that are to remain unaffected (Glista., et al 2009). Designing the fencing for multiple species to use, also known as ‘combination fencing’ can be a useful and cost-effective strategy to employ (Hamer et al., 2015). Another consideration is site condition, for example, a potential site within Yosemite that receives snowfall would require fencing to be positioned such that snow clearing equipment could move through unimpeded. Structural considerations for fencing are mesh size (avoiding animal entanglement), height (avoiding animals jumping over) and aesthetic (visitor enjoyment) (Evans and Wood, 1980, Wright, 1998, Van der Ree et al., 2015).

Wildlife crossing structures positioned at fence ends can prevent wildlife-vehicle collisions concentrating at the fence end point. If fencing is built in conjunction with a wildlife crossing structure, gaps or ‘joins’ between where the crossing structure ends and the fencing begins should be avoided, the length of fencing in relation to the crossing structure should be long, and spatial arrangement on the landscape should be well thought out (Van der Ree et al., 2015).

1. Large Mammal Exclusion

Fencing drastically reduces vehicle collisions with large mammals; for example, Rytwinski et al (2016) observed an 83% reduction in large mammal roadkill post-construction across 39 studies. Fence length >5km is effective for large mammals (Huijser et al., 2015), as are jump-outs, particularly when used with small sections of fencing to direct wildlife. One-way gates are another method of funneling trapped animals off the highway, although consideration of non-target species and gate design is crucial to avoid animals injuring themselves (Van Der Ree et al., 2015).

Box 6. Bear Crossing!

The American black bear roams widely throughout the Sierra Nevada and the Park. This iconic species has to move across large areas to forage, mate and disperse. This behavior means that bears do cross roads, and ~30/year are hit by vehicles in Yosemite. Providing safe passageways and jump-outs (photo below) for bears and other wildlife is effective in other parts of North America (Jensen, 2018) and should be considered to help the populations thrive and survive. Bear-vehicle collisions in the Park are highest in areas with low roadside visibility, therefore removing understory vegetation in certain hotspots would increase visibility for bears and drivers (Rodriguez, 2015).

Bear escaping the highway through a purposefully designed gap in the fence, and a jump out. Photo courtesy of Kootenay National Park Wildlife Crossing Project.

2. Digging and climbing Animal Exclusion

Fences can be circumvented by animals digging underneath or climbing over the top. Constructing additional skirting at the base of the fence or building fencing slightly underground can reduce wildlife escaping underneath. To stop coyotes climbing under fencing installed along the TransCanada Highway in Banff National Park, the fencing was buried 1.5 meters below ground (Clevenger, Chruszcz & Gunson 2001).

Large mammals such as bobcat, cougar and black bear as well as some herpetofauna can climb over fencing. Altering the mesh size, utilizing a smooth non-grip material and building a ‘floppy top' can prevent animals escaping over the top (Klar et al., 2009; Van der Ree et al., 2015). Animals may use vegetation to jump or climb over fences, so clearing vegetation from the base of the fence or laying material down in front of the fence to prevent vegetation establishing is also useful (Hamer et al., 2015).

3. Gliding Animal Barriers

Floppy tops or 'hanging lips' can be added to fencing that is designed to guide flying animals such as the northern flying squirrel (*Glaucomys sabrinus*) above the line of traffic. Barbed wire at the top of fencing must be avoided when built within a gliding animal's habitat range to avoid the animal becoming entangled (Van Der Ree., 1999).

4. Herpetofauna Exclusion

For amphibians, fencing is often placed in areas where basking is prevalent, or within close proximity to breeding sites (D'Amico et al., 2015, Van Der Ree et al., 2015). Fencing color is a key consideration; using an opaque material prevents turtles being able to see the other side, and results in the individual spending less time attempting to cross. If mesh fence is used, mesh size should be no larger than the size of a metamorphizing individual, typically <3mm.

Table 2. Design specifications for effective fencing in Australia and Europe. Adapted from Hamer et al 2015.

	Australia	Europe
Material	Shade cloth	Sheet polythene plastic, shade cloth, plastics, galvanized and stainless steel
Height	1.2m	500mm
Overhang	300mm	-
Underground depth	200mm	-

5. Fencing Maintenance

As discussed above, fencing can be breached by animals. Fencing is also susceptible to wear-and-tear and vandalism, therefore annual maintenance inspections are vital. In addition, regular fence maintenance is much more cost-effective than a large repair project in the future (Jaeger, 2015). The time of year that inspection occurs is important; just before a frog breeding season, or just after a snow drift are good examples of when to schedule an inspection (Hamer et al., 2015). Fencing inspections can also be used as a time to collect monitoring data (see section on data collection).

Wildlife fencing recommendation: Fencing is the primary method for keeping ground- and tree-dwelling animals of various sizes and tree-dwelling animals (e.g., squirrels) from crossing roadways. Fence design should be tailored to specific species to be most effective. Because biological imperatives to crossroads can be very strong, fencing should be combined with wildlife crossing structures and jump-outs. To be effective, fencing must be maintained.

6. Citations

Clevenger, A.P., Chruszcz, B., and Gunson, K.E. (2001) Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin, 29(2): 646-653.

Evans, G.W., and Wood, K.W. (1980) Assessment of environmental aesthetics in scenic highway corridors. Environment and Behavior, 12(2): 255-273.

Glista, D.J., De Vault, T.L., DeWoody J.A. (2009) A review of mitigation measures for reducing wildlife mortality on roadways. Landscape & Urban Planning, 91:1–7.

Hamer, A.J., Langton, T.E.S., Lesbarreres, D. (2015) Making a safe leap forward: Mitigating road impacts on amphibians, In: van der Ree R, Smith D, Grilo C, editors. Handbook of Road Ecology. Oxford: John Wiley & Sons; pp. 261 – 270.

Huijser, M.P., Duffield, J.W., Clevenger, A.P., Ament, R.J., McGowen, P.T. (2009) Cost—benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada; a decision support tool. Ecology and Society. 14. Available: http://www.ecologyandsociety.org/viewissue. Php?sf=41.

Huijser, M.P., Kociolek, A.V., Allen, T.D.H., McGowen, P., Cramer, P.C., Venner, M. (2015) Construction guidelines for wildlife fencing and associated escape and lateral access control measures. NCHRP Project 25–25, Task 84, National Cooperative Highway Research Program. Transportation Research Board of the National Academies, Washington D.C., USA; Available: http://onlinepubs.trb.org/onlinepubs/ nchrp/docs/NCHRP25-25%2884%29_FR.pdf.

Jaeger, J.A.G. (2015) Improving environmental impact assessment and road planning at the landscape scale. In: van der Ree R, Smith D, Grilo C, editors. Handbook of Road Ecology. Oxford: John Wiley & Sons; pp. 32–42.

Jensen, A. J., & Jensen, A. J. (2018). Crossing Corridors: Wildlife use of jumpouts and undercrossings along a highway with wildlife exclusion fencing.

Klar, N., Herrmann, M. and Kramer-Schadt, S. (2009) Effects and mitigation of road impacts on individual movement behavior of wildcats. The Journal of Wildlife Management, 73(5): 631-638.

Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig, L., Findlay, C.S., Houlahan, J., et al. (2016) How effective is road mitigation at reducing road-kill? A meta-analysis. PloS ONE, 11(11): e0166941. Doi:10.1371/journal.pone.0166941

van der Ree, R. (1999) Barbed wire fencing as a hazard for wildlife. Victorian Naturalist, 116(6): 210-217.

Van der Ree R, Jaeger, J.A.G., Rytwinski, T., van der Grift, E. (2015) Good science and experimentation are needed in road ecology. In: van der Ree R, Smith D, Grilo C, editors. Handbook of Road Ecology. Oxford: John Wiley & Sons; pp. 71–81.

Wright, R.G. (1998) A review of the relationships between visitors and ungulates in national parks. Wildlife Society Bulletin, 26(3): 471-476.

G. Wildlife Crossing Structures

Wildlife Crossing Structures (WCS) enable safe passage of wildlife over or under roads and are best constructed in combination with fencing (Rytwinski et al., 2016). Site selection for a new WCS should be based upon wildlife-vehicle collision hotspots as well as practical and logistic feasibility (Smith et al., 2015), for example, availability of appropriate places for associated fencing and using existing low or high-points in the landscape. WCS can become more attractive to wildlife by adding ‘furniture’, or trees, foliage and rocks to the entrance.

1. Wildlife Crossing Structure Designs

The type of crossing structure chosen depends on: i) The target species (and the non-target species). A crossing structure designed for bears will have very different specifications from an amphibian tunnel. Ii) The intended goals of the project. Is this WCS going to provide year-round crossing capability or be temporarily available e.g. during a breeding season? Iii) Cost. Is it more cost-effective to retrofit, or construct a new WCS?

Figure 2 demonstrates the different WCS designs available. A common strategy is to select multi-use crossing structures. Culverts can be modified with additional shelving, removing ‘riprap’ (large rocks that can block access and passage), or adding a second culvert that is higher than the first and above the water table (Box 5; Smith et al., 2015). Predation risk must be considered when retrofitting; small ‘furniture’ (rocks, foliage and other natural features) can provide cover for prey species, but shelving can also provide cover for ambush predators (Mata et al., 2015).

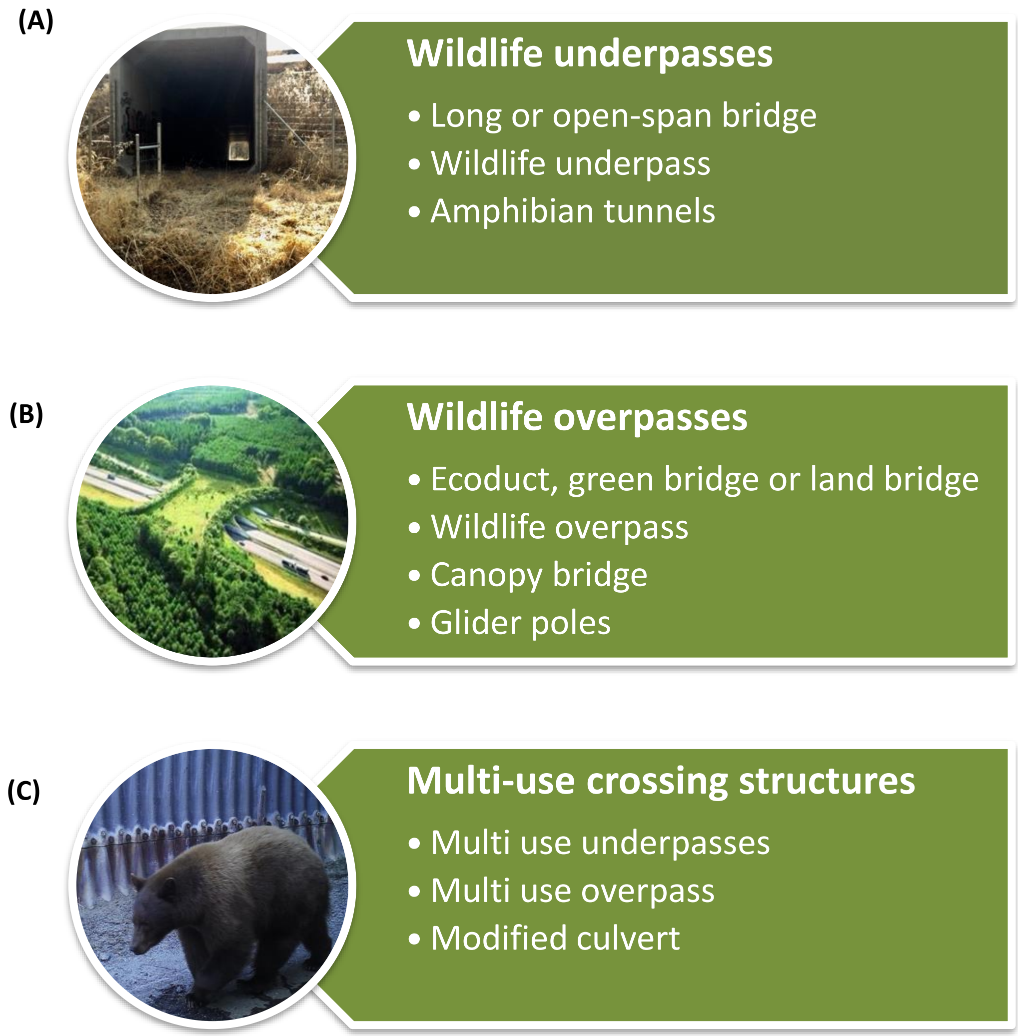


Figure 2. The three categories and sub-categories of wildlife crossing structure. Image A and C courtesy of Amy Collins/Road Ecology Center, image B courtesy of https://unusualplaces.org/wildlife-crossing-in-netherlands/.

Box 5. Reaching new heights

Within Yosemite National Park, vehicle collisions with Pacific fisher are a concern, and between 1993-2012 were most frequent during the denning season (March – June). Camera trap monitoring of twelve culverts between 2011 – 2014 recorded the Pacific fisher using three culverts (Cline, 2014). To combat fisher roadkill, YNP staff and collaborators retrofitted two of the unused culverts that were near roadkill sites with suspended shelving and added dry culverts above existing culverts. Higher, dry culvert additions were the most effective, as wood and debris interfered with culvert shelving.

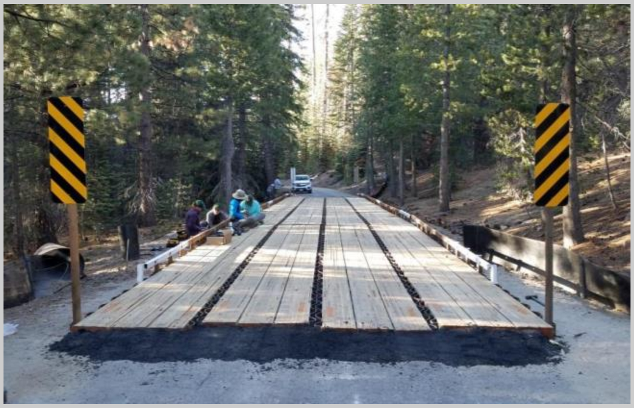
Photos courtesy of Cline 2014.

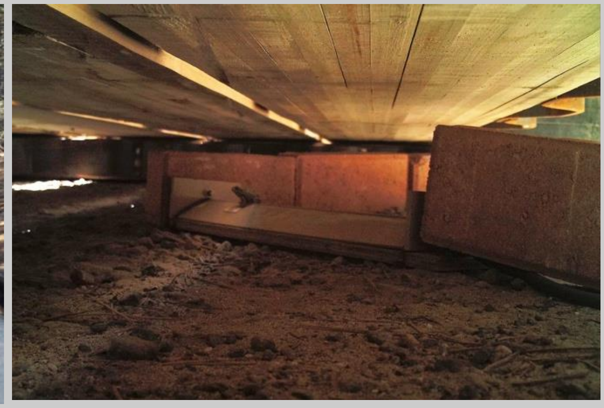
1. Target species for Wildlife Crossing Structures

Use of wildlife crossing structures (WCS) varies by species. WCS can reduce road mortality of carnivores by 50-100% (Clevenger et al., 2009). Cougars, black bears, and deer use crossing structures that are a range of sizes but prefer structures that are quiet (i.e., have traffic noise levels <55 dBA) and free of human use, such as hiking trails. Within Yosemite, species most commonly reported to have used culverts are black bear, gray fox, coyote, mule deer and ringtail, depending on culvert size (Cline, 2014). Culvert retrofitting could be extended to include species that have lower visit rates, such as mountain lion and bobcat.

Amphibians and reptiles are particularly vulnerable to vehicle collisions, as they often bask on roads, and may be too slow-moving to avoid oncoming vehicles. Amphibians are also particularly susceptible as they move from wet to dry habitats. Low bridges could be built in amphibian roadkill hotspots (e.g. Yosemite toad) to facilitate movement, particularly during the breeding season (Box 6). When building mitigation for amphibians, avoid using metal materials, and supplement the area with suitable soils and leaf litter to keep the area cool and damp (Woltz et al., 2008).

Box 6. Toad Crossing ahead!





Photos courtesy of USGS Western Ecological Research Center.

In the Sierra National Forest, CA, two roads identified as roadkill hotspots for the Yosemite toad have had amphibian bridges installed by the USGS and US Forest Service. These bridges enable safe crossing of the toads from the upland habitat to the wetland breeding area. Post-construction monitoring has demonstrated use by the Yosemite toad, and a 100% reduction in mortality (C. Brehme & S. Barnes Pers. Comm). Camera traps set at the bridges have also enabled the team to document non-target species movement such as the pine marten, garter snake and spotted skunk. In collaboration with the California Department of Transportation, amphibian fencing with jump outs designed by ERTEC® and Animex® have now been erected to promote movement toward the bridges.

2. Noise and Light Pollution

Noise and light pollution emitted from road traffic can deter wildlife from using WCS (Barber et al., 2010). If wildlife chooses to use the WCS, noise and light may alter individual behavior, or cause physical damage– e.g. a high-intensity short burst of noise can injure the cochlea (Blickley et al., 2012; Parris, 2015). To avoid such impacts, these secondary effects should be considered when in the planning phase of the mitigation. Physical barriers at the roadside, and vegetation at the structure entrance can be installed to dampen traffic noise and light. Although WCS are less effective if used by people, if this use is intended then red or yellow light can be installed as alternatives to white light, that are activated at certain hours (Blackwell et al., 2015). This impact can also be mitigated by providing fencing or a physical barrier that separates the recreational area from the wildlife area.

Wildlife crossing structures recommendation: WCS are standard ways to improve wildlife crossing of roadways and when combined with fencing can be very effective. If WCS are built, or existing structures improved for wildlife use, ensure that the approaches to the structure are as quiet and dark as possible, primarily by building or growing barriers to traffic disturbance.

3. Wildlife Crossing Structures and Fencing

Providing safe passageways for wildlife to cross roads is a common, effective, and low-cost way to reduce WVC. This approach is most effective for species willing to approach roadways and pass over or under them via an artificial structure. Often the cost of building crossing structures outweighs the cost of collisions (Shilling, unpublished observations and Rytwinski et al., 2016). In the vast majority of cases, crossing structures built for wildlife are accompanied by fencing that blocks wildlife entry into the roadway and in theory directs the animals to the crossing. For large mammals, WCS in concert with fencing reduces roadkill by 83% (Rytwinski et al., 2016). However, effective fencing is associated with several challenges including aesthetic impact of roadside fencing, engineering the end of the fence (animals can go around), and maintenance. One feature of fencing that is not well-studied and hard to overcome is that fencing is only effective in the areas where it is placed, and the ends of fences are places where animals can "wrap-around" and enter the roadway. Across the world, there are far more existing structures e.g. culverts that were not built for wildlife but are used opportunistically by wildlife to cross roads and railways. Because of their sheer number, these structures may be the most important structural solution for wildlife safe passage.

4. Citations

Barber, J. R., K. R. Crooks and K. M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology & Evolution **25**:180–189.

Blackwell, B. F., DeVault, T. L., & Seamans, T. W. (2015). Understanding and mitigating the negative effects of road lighting on ecosystems. *Handbook of road ecology*, 143-150.

Blickley, J. L., K. Word, A. H. Krakauer, J. L. Phillips, S. Sells, C. C. Taff, J. C. Wingfield and G. L. Patricelli. 2012. The effect of experimental exposure to chronic noise on fecal corticosteroid metabolites in lekking male greater sage- grouse (*Centrocercus urophasianus*). PLoS One **7**:e50462.

Clevenger, A. P., Ford, A. T., & Sawaya, M. A. (2009). Banff wildlife crossings project: integrating science and education in restoring population connectivity across transportation corridors.

Cline, L. (2014). Mitigating Fisher Road-kill in Yosemite National Park with Wildlife Crossing Structures 2011-2014 Final Report. Internal report to the National Park Service, U.S. Department of the Interior, Resources Management and Science, Yosemite National Park, CA, USA.

Mata, C., Bencini, R., Chambers, B. K., & Malo, J. E. (2015). Predator-prey interactions at wildlife crossing structures: between myth and reality. *Handbook of Road Ecology*, 190.

Parris, K. M. (2015). Ecological impacts of road noise and options for mitigation. *Handbook of road ecology*, 151-158.

Rodriguez, K E. 2015. Identification and modelling of black-bear vehicle collision zones on Yosemite National Park, California. MSc thesis, San José State University.

Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig, L., Findlay, C.S., Houlahan, J., et al. (2016) How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS ONE 11(11): e0166941. doi:10.1371/journal.pone.0166941

Smith, D J., van der Ree, R., Rosell, C. (2015) Wildlife crossing structures: An effective strategy to restore or maintain wildlife connectivity across roads In: van der Ree R, Smith D, Grilo C, editors. Handbook of Road Ecology. Oxford: John Wiley & Sons. pp. 172–183.

Woltz, H. W., J. P. Gibb and P. K. Ducey. (2008). Road crossing structures for amphibians and reptiles: Informing design through behavioral analysis. Biological Conservation **141**: 2745–2750.

H. Less- or Ineffective Approaches

Some techniques employed to reduce WVC are common despite proven ineffectiveness.

1. Passive signs

The most common ineffective technique in the US is the use of static warning signs, for example the common animal crossing sign. These have no effect on driver speed or rates of WVC. See section III.A.1 above.

2. Reflectors

Common in parts of Europe, roadside reflectors reflect light from traffic into the surrounding habitat presumably to scare animals away from the road. There is no evidence that these reduce WVC rates.

3. Deer Whistles

Finally, “deer whistles” are still sold, but have never been demonstrated to have any effect on deer behavior or rates of WVC.

III. Decision-Process

Whether intentional and formal or not, mitigating WVC to benefit wildlife, ecosystems and drivers usually involves a certain sequence of steps, shown in Figure 3 below. The authors are not aware of the existence of such a formal decision-process in management or legislative direction and literature. Usually this type of decision-process exists in the minds and intentions of staff and managers who are attempting to reduce WVC and follow most or all of the steps below, though typically without direction or a programmatic process. As for most environmental and transportation processes, the first step is usually to measure and

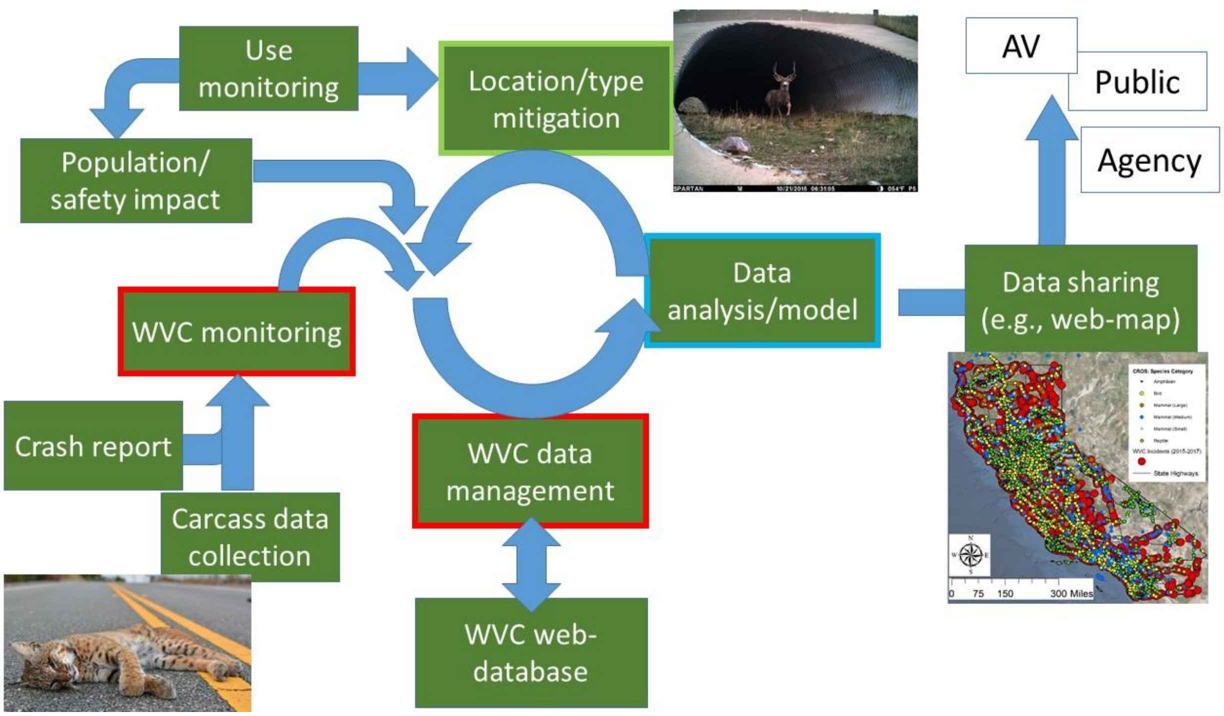


Figure 3. WVC mitigation workflow. Green boxes indicate different types of objects or actions. Outlines indicate primary steps in the process. The white boxes indicate different information recipients (“AV” = automated vehicles, including driver-assist programs).

characterize the problem. For WVC, this typically involves evaluating collision events – where, when, and how often they occur. It is also important to examine where and when WVC doesn’t occur and which species are more or less affected. After evaluating WVC, the next step is to decide on an appropriate mitigation action. This could include any of the effective methods described in preceding sections (or something else). Typically, mitigation for WVC in transportation projects is only considered when a transportation project is proposed. This opportunistic approach is useful, but may not address the extent, nature, or severity of the WVC impacts which occur on most roads, regardless of whether or not they are being “improved”. After the action is implemented, it should be immediately monitored for effectiveness to both find out if adjustments need to be made and to contribute to the NPS and wider community's understanding of the effectiveness of different actions. This monitoring information can then be fed back into the decision-process, completing the loop.

I. WVC and Use Monitoring

Regardless of which mitigation measure(s) are employed, it is vital that systematic data collection occur throughout all phases of the project (Van der Ree et al., 2015, Roberts and Sjolund, 2015). Rytwinski et al (2016) suggest that monitoring occurs at least 4 years pre and post-construction and/or across >4 study sites. By developing a robust Before After Control Impact (BACI) design, efficacy of the mitigation measure can be properly evaluated, and inform future mitigation projects. Where possible, results acquired from monitoring projects should be published. Specific information on what to include in such published work are listed in the table below (table 3).

Table 3. Data that should be included in published results from monitoring mitigation measures. Adapted from Rytwinski et al., 2016.

Information to include in publication	Example
Study design	Method and frequency of monitoring
Mitigation measure	Structural dimensions (e.g. mesh size of fencing, openness ratio of crossing structure), spacing of measures, material
Environmental variables	Surrounding vegetation type, vehicle count, proximity to humans etc.
Test statistics	Sample size, statistical test, and summary statistics

1. Methods

Specific methods of monitoring will depend on the type of mitigation and funding available, but below are a few suggested methods for data collection.

A. **Roadkill data.** Collection of roadkill data by agency staff or volunteers/visitors can occur through online systems such as the California Roadkill Observation System (CROS, https://wildlifecrossing.net/ca). Social media, such as twitter, is another easily accessible platform that visitors can post roadkill information to, assuming there is a mechanism to collect and manage the data. Including volunteers in this kind of science can be an effective tool to increase spatial coverage and reporting. Gather data in areas that are unmitigated as well as mitigated.
B. **Vehicle counts.** The amount of traffic in an area is often a critical determining factor for level of traffic disturbance and rates of WVC. Caltrans provides traffic counts (traffic

volume) for highways leading to Yosemite National Park (http://www.dot.ca.gov/trafficops/census/), however, these data are often not continuously collected.

C. **Camera trapping.** Particularly effective when monitoring mitigation measures aimed at increasing wildlife passage, e.g. wildlife crossing structures. Cameras utilized for this purpose must be placed at either side of the highway to enable confirmation of wildlife crossings. Cameras may also document animal behavior, enabling questions to be addressed on disturbance effects of highways and traffic. For this purpose, cameras that possess invisible night-time IR flash are recommended. See the CamWON website (https://wildlifeobserver.net) for examples of camera trap projects.

D. **Wildlife tracking and telemetry.** To understand the broader impact of the mitigation on population viability and dispersal, Passive Integrated Transponder (PIT) tags or GPS radio collars can be used for monitoring wildlife (Roedenbeck et al., 2007).

E. **Coordinated Distributed Experiments (CDEs).** Partnering with state agencies within Yosemite and beyond can increase study sites and allow for stronger quantitative analyses of data (Rodriguez, 2016).

J. Choosing Mitigation Actions

One of the challenges of mitigating WVC is deciding which solution to employ in a given situation, especially when multiple taxa of species are affected. The matrix below (table 4) shows example combinations of solutions and species/species-groups that have been demonstrated to be effective, or that are highly likely to be effective.

Table 4. Specific mitigation solutions appropriate for different species or groups in YNP.

		Species/Species-Group					
Solution	**Section**	Amphibians	GGOW/Birds	RT	GF	BB	MD
Traffic Speed	II.A	✓	✓	✓	✓	✓	✓
Traffic Timing	II.B	✓	✓	✓	✓	✓	✓
Traffic Volume	II.C	✓	✓	✓	✓	✓	✓
Driver-Warning	II.D	(✓)	-	?	?	✓	✓
Fencing	II.E	✓	-	✓	✓	✓	✓
Crossing Structure	II.F	✓	-	✓	✓	✓	✓
Data Collection	III.A	✓	✓	✓	✓	✓	✓

Legend: Species/Species-Group: GGOW = Great grey owl; RT = Ringtail; GF = Grey fox; BB = Black bear; MD = Mule deer. ✓ indicates effective, (✓) indicates partially effective, - indicates ineffective, and ? indicates unknown effectiveness.

Traffic conditions (speed, volume) are generally effective for any WVC because reduced speed reduces risk of collision and fewer cars means lower risk of collision for any animal crossing a road. Although crossing structures are often thought to be generally effective, their actual effectiveness will depend on their placement, construction materials, continuity with adjacent habitats, species sensitivity/tolerance to the structure, and low level of disturbance from the roadway above (or below). Similarly, many people think that fencing will have a "funneling effect" on wildlife, pushing them toward a crossing structure. However, there is little evidence for this understandable optimism; fence effectiveness will also depend on context, materials and the species involved.

1. Citations

Roedenbeck, I., et al. (2007) The Rauischholzhausen agenda for road ecology. Ecology and society, 12(1): 11. http://www.ecologyandsociety.org/vol12/iss1/art11/

Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig, L., Findlay, C.S., Houlahan, J., et al. (2016) How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS ONE, 11(11): e0166941. doi:10.1371/journal.pone.0166941

Roberts, K., Sjolund, A. (2015) Incorporating biodiversity issues into road design: The road agency perspective. In: van der Ree R, Smith D, Grilo C, editors. Handbook of Road Ecology. Oxford: John Wiley & Sons; pp. 27-32.

van der Ree R, Jaeger, J.A.G., Rytwinski, T., van der Grift, E. (2015) Good science and experimentation are needed in road ecology. In: van der Ree R, Smith D, Grilo C, editors. Handbook of Road Ecology. Oxford: John Wiley & Sons; pp. 71–81.

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III. Additional Resources

https://roadecology.ucdavis.edu/research/projects/wildlife-crossing-manuals-and-wildlife-vehicle-conflict-data-collection