Potential Future Mitigation Measures for Large Wild Mammals, along US Hwy 20, between Burns and Ontario, Oregon

by

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FINAL REPORT

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DISCLAIMER

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16. Abstract
US Hwy 20 between Burns and Ontario, Oregon, bisects important winter and migration habitat for mule deer. The number of collisions with mule deer has been a human safety and a conservation concern for the declining mule deer population that winters along both sides of the road adjacent to the Malheur River and further south. This report explores the potential for mitigation measures aimed at substantially reducing wildlife-vehicle collisions with large wild mammals and measures that are likely to provide substantial safe crossing opportunities for large wild mammals. The effort is specifically directed at mule deer. The road section of interest is between Juntura, Oregon and Harper, Oregon. To achieve a substantial (>80%) reduction in collisions with mule deer, the entire road section should be fenced. If these fences are tied into existing bridges and culverts, originally built for other purposes, many of the road sections between the individual crossing structures would have very low permeability for mule deer as the structures are too far apart based on the size of the winter home range of mule deer. Therefore, additional designated wildlife crossing structures are recommended. For the road sections to be 50% permeable to wintering mule deer, suitable crossing structures would have to be 1.04 mile apart.

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SUMMARY

US Hwy 20 between Burns and Ontario, Oregon, bisects important winter habitat for mule deer. The number of collisions with mule deer has been a human safety and a conservation concern for the declining mule deer population that winters along both sides of the road and the adjacent Malheur River and that migrates through the area. To reduce collisions with large wild mammals, especially mule deer, wildlife fences have been suggested. These fences would be tied into existing structures, mostly bridges across rivers or creeks to maintain a certain degree of habitat connectivity. Designated wildlife crossing structures have been suggested as well. This report explores the potential for mitigation measures aimed at substantially reducing wildlife-vehicle collisions with large wild mammals, and mule deer in specific, and measures that are likely to provide safe crossing opportunities for large wild mammals, and mule deer in specific. The road section of interest is between Juntura, Oregon and Harper, Oregon.

Wildlife fences are the most effective and robust measure to reduce collisions with large wild mammals. However, fenced road sections that are shorter than 3 miles in length are far less effective (about 50% on average) in reducing collisions than long sections (almost always at least 80%), and the effectiveness of the individual short fenced road sections is extremely variable. While collisions in mitigated road sections can be substantially reduced (>80%), they may still result in "moving" collisions to adjacent road sections. Therefore, the scale at which mitigation measures should be implemented for large wild mammals is much larger than just a few miles. In this case, the entire road section between Juntura and Harper can be considered important winter habitat and a migration route for mule deer. Therefore, for mitigation measures to be effective in substantially reducing collisions, fences should be implemented along the entire road section.

Wildlife fences alone would result in a near absolute barrier for the target species, as well as other species for which the fences act as a barrier. Therefore, wildlife fences are almost always combined with crossing structures that allow wildlife to safely cross under or over the road. Along US Hwy 20, there are existing structures in place, originally built for other purposes. These are mostly bridges and culverts for the Malheur River and side streams to pass under the road. The permeability of the road for mule deer was calculated for each road section between these existing crossing structures. These calculations assumed that all of the existing crossing structures are suitable for mule deer, or that these structures can be modified to become suitable for mule deer. Based on the location and spacing of the structures, and the size of the home ranges of mule deer wintering along both sides of US Hwy 20, the permeability of the road sections between the individual existing crossing structures varied between less than 1% and 100%. Overall, many of the structures were so far apart that the permeability for mule deer, based on the size of their winter home ranges, was below 10% or even below 5% for most of the road. This suggests that relying solely on existing structures for connectivity would substantially impact the permeability of the road for mule deer, potentially reducing access to important winter habitat, water from the Malheur River, and cutting off migration routes. Therefore, additional designated wildlife crossing structures are recommended. For the road sections to be 50% permeable to wintering mule deer, suitable crossing structures would have to be 1.04 mile apart. Note that depending on how many or how few wildlife crossing structures are provided, connectivity for mule deer across US Hwy 20 may or may not be improved. It can even be reduced compared to an unmitigated road with relatively low traffic volume such as US Hwy 20.

1. INTRODUCTION

1.1. Background

US Hwy 20 in Harney and Malheur Counties, between Burns and Ontario, Oregon (mile reference posts 83-263), bisects important winter habitat and migration routes for mule deer (Burns Paiute Tribe 2016, ICF 2021). The number of collisions with mule deer has been a human safety and a conservation concern for the declining mule deer population (Burns Paiute Tribe 2016, ICF 2021). Other medium and large wild mammal species in the area include elk, pronghorn, bobcat, mountain lion, red fox, coyote, and porcupine (ICF 2021). Most collisions with large mammals involved mule deer (95%), followed by elk (2%), livestock (1%), other domesticated mammal species (1%), and other wild mammal species including pronghorn and mountain lion (combined less than 1%) (ICF 2021). In Malheur County, most collisions occur in fall and winter (especially October through January), whereas in Harney County the collisions are more evenly distributed across the seasons (ICF 2021). Most crossings occur at night and in the morning, especially between midnight and 1 pm (Burns Paiute Tribe 2016). The road sections between mile reference posts 124-137, and 185-249 have the highest number of reported collisions (ICF 2021). The traffic volume between Juntura and Harper is <2,000 vehicles per day (AADT (ICF 2021). To reduce collisions with large wild mammals, especially mule deer wildlife fences have been suggested (Hagle et al. 2017, ICF 2021). These fences would be tied into existing structures, mostly bridges across the Malheur River and side streams, to maintain a certain degree of habitat connectivity (Hagle et al. 2017, ICF 2021). Designated wildlife crossing structures have been suggested as well (ICF 2021).

1.2. Problem statement

This report is at the request of Oregon Department of Fish and Wildlife. This report contains advise on potential wildlife fences in combination with existing crossing structures, designated wildlife crossing structures, animal detection systems if feasible, or other alternatives that would be aimed at reducing collisions with large wild ungulates (particularly mule deer), and at improving or maintaining connectivity for all large wild mammals (e.g. mule deer, elk, pronghorn, mountain lion).

1.3. Goals, objectives, and tasks

The goal of this report is to contribute to having a viable population of mule deer and safer travel for people.

The objectives of this project are to:

1. Provide advice on measures that are likely to substantially reduce wildlife-vehicle collisions with large wild mammals, and mule deer in specific.
2. Provide advice on measures that are likely to provide safe crossing opportunities for large wild mammals, and mule deer in specific.

The tasks for this project include:

Task 1. Conduct a site visit to US Hwy 20 between Burns and Ontario, Oregon. More specifically, the road section between Juntura and Harper (Figure 1).

Figure 1: US Hwy 20 between Juntura (west) and Harper (east), Oregon.

Task 2. Meet with representatives from Burns Paiute Tribe, Oregon Department of Transportation, and Oregon Department of Fish and Wildlife. The meeting will be combined with the field visit. Discuss the definition of the problems associated with large wild mammals and US Hwy 20, the proposed solutions (e.g., connect wildlife fences to existing crossing structures), and expectations about effectiveness for large wild mammal - vehicle collisions and connectivity for large wild mammals.

Task 3. Given the information obtained through task 1 and 2, and given the suggested mitigation measures (i.e. wildlife fences, modifying existing crossing structures, new designated wildlife crossing structures, and associated measures such as wildlife jump-outs and barriers at fence-ends and access roads, and potentially also animal detection systems (ICF 2021), evaluate whether the objectives for collision reduction and habitat connectivity for large wild mammals are likely to be met. All collision and connectivity data used will be from other sources; this effort does not include the collection of new data or the (re-)analyses of existing data.

Task 4. Formulate mitigation measures (short and long term, if feasible) that are likely to meet the objectives associated with human safety (substantially reduce collisions with large wild mammals) and habitat connectivity (maintain or improve habitat connectivity for large wild mammals while minimizing impacts to, or improving connectivity for, other species). A recommendation on pre- and post-mitigation monitoring to evaluate the effectiveness of mitigation measures will be included.

Task 5. Document the findings in a report. The report will indicate the design specifications for wildlife fences, crossing structures, wildlife jump-outs, measures at fence-ends and access roads, and a spatially explicit configuration of the mitigation measures. Note that the measures may also include a discussion on animal detection systems. Note: No GIS work or maps are included in this effort. Rather, the suggested location of mitigation measures may be indicated on satellite images.

Task 6. Present the findings in a presentation to Oregon Department of Fish and Wildlife and other stakeholders (at the invitation of Oregon Department of Fish and Wildlife).

2. EFFECTS OF ROADS AND TRAFFIC ON WILDLIFE

Roads and vehicles can affect wildlife in several ways. In general, not specific for large wild mammals, there are five different categories of the effects of roads and traffic on wildlife (Figure 2) (e.g. van der Ree et al. 2015):

- Habitat loss: e.g., the paved road surface, heavily altered environment through the road-bed with non-native substrate, altered hydrology, vegetation removal, seeded species and mowing in the clear zone.
- Direct wildlife road mortality because of collisions with vehicles.
- Barrier to wildlife movements: e.g., animals do not cross the road as often as they cross natural terrain and only a portion of the crossing attempts is successful.
- Decrease in habitat quality in a zone adjacent to the road: e.g., noise and light disturbance, air and water pollution, increased access to the areas adjacent to the highways for humans and associated disturbance.
- Right-of-way habitat and corridor: Depending on the surrounding landscape, the right-of-way can promote the spread of non-native or invasive species (surrounding landscape largely natural or semi-natural) or it can be a refugium for native species (surrounding landscape heavily impacted by humans).

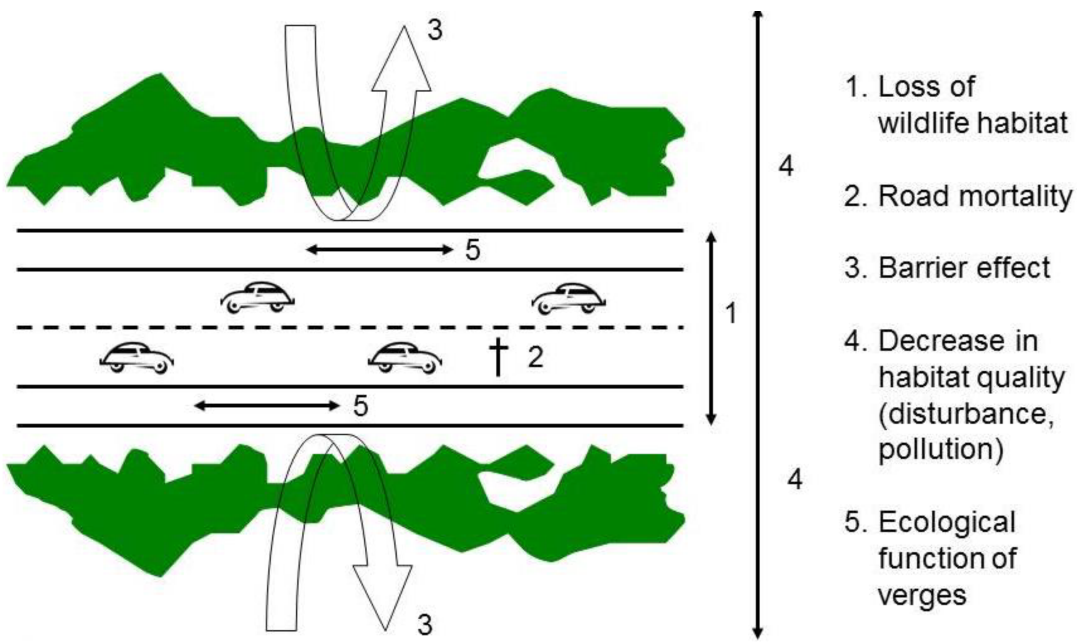


Figure 2: The effects of roads and traffic on wildlife.

While the effects of roads and traffic are varied, direct road mortality, either for the purpose of human safety or biological conservation, and the barrier effect are most commonly addressed effects. Habitat loss, a decrease in habitat quality in a zone adjacent to a road, and the spread of non-native invasive species are acknowledged and dealt with less often.

3. AVOIDANCE, MITIGATION, AND COMPENSATION STRATEGIES

While mitigation (reducing the severity of an impact) is common, avoidance is better and should generally be considered first (Cuperus et al. 1999). For example, the negative effects of roads and traffic may be avoided if a road is not constructed, or the most severe negative effects may be avoided by re-routing away from the most sensitive areas (Figure 3). If the effects cannot be avoided, mitigation is a logical second step. Mitigation is typically done in the road-effect zone (Figure 3) and may include measures aimed at reducing wildlife-vehicle collisions and reducing the barrier effect (e.g., through providing for safe wildlife crossing opportunities) (Clevenger & Huijser 2011, Huijser et al. 2021). However, mitigation may not always be possible, or the mitigation may not be sufficient. In such situations, a third approach may be considered: compensation or off-site mitigation. Compensation may include increasing the size existing habitat patches, creating new habitat patches, or improving the connectivity between the habitat patches that would allow for larger, more connected, and more viable network of populations. Finally, in some situations, a combination of avoidance, mitigation, and compensation may be implemented.

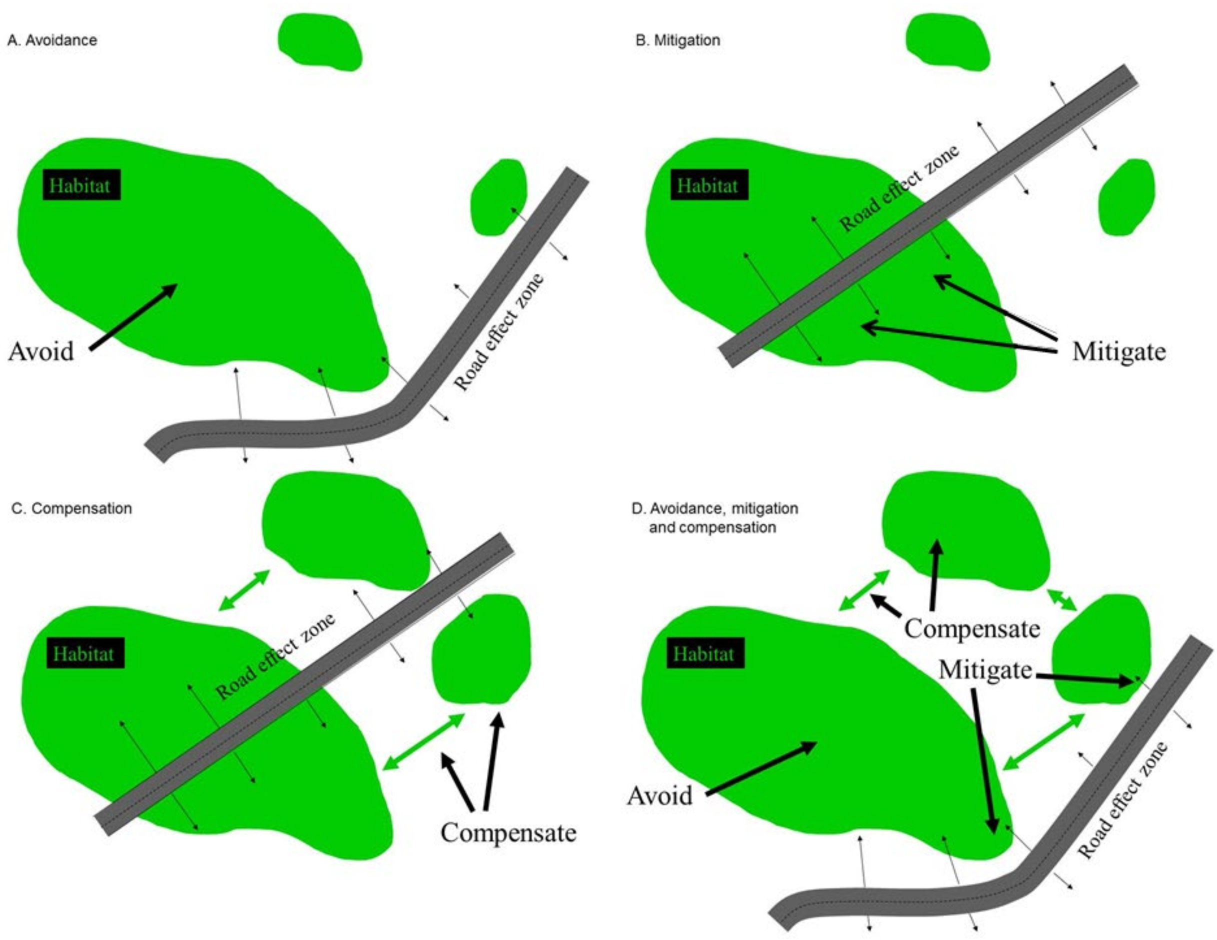


Figure 3: A three step approach: A. Avoidance, B. Mitigation, C. Compensation, D. Combination of avoidance, mitigation and compensation strategies.

4. LARGE MAMMAL PRECENCE ALONG US HWIGHWAY 20

4.1. Mule deer

Mule deer are by far the most common large mammal in the area (ICF 2021, Personal communication Tom Segal, Wildlife Habitat Biologist, Oregon Department of Fish and Wildlife). The areas adjacent to US Hwy 20 between Juntura and Harper are important winter habitat for mule deer that have their summer habitat further north (Figure 4). During the winter, these animals cross the highway regularly (Figure 4). However, some mule deer winter further south, and these animals may only cross US Hwy 20 twice per year, once during spring migration, and once during fall migration (Figure 4).

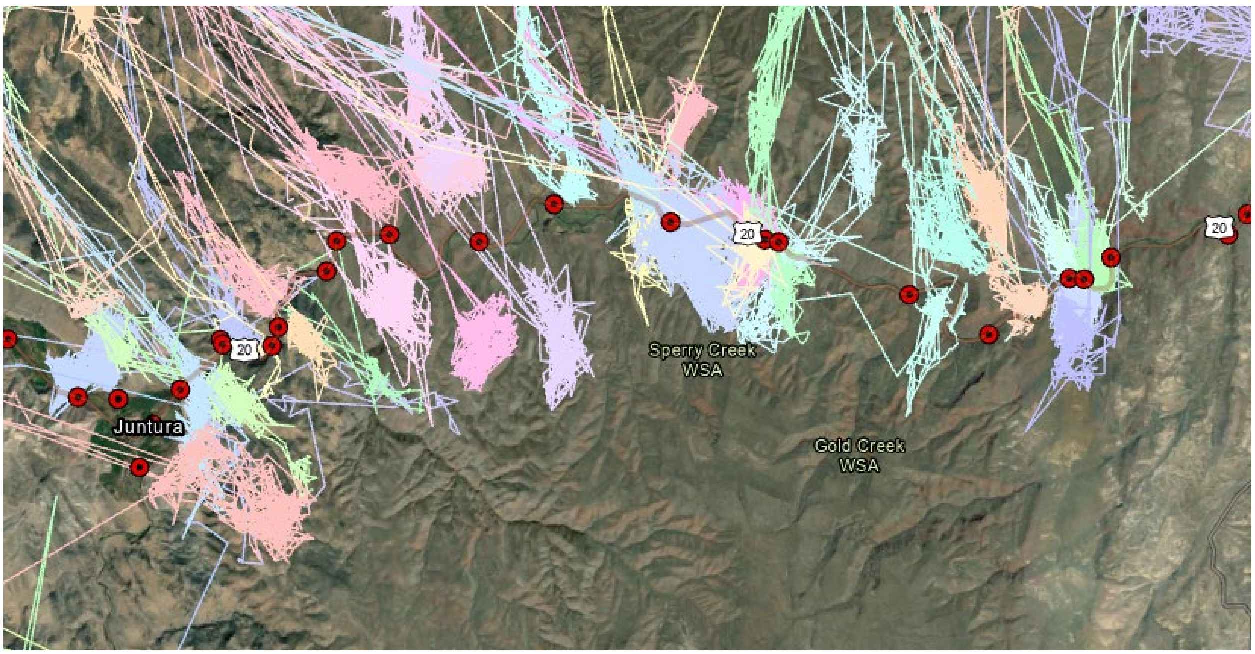


Figure 4: Movements of individual GPS-collared mule deer along US Hwy 20 between Juntura and Harper (Figure provided by Tom Segal, Wildlife Habitat Biologist, Oregon Department of Fish and Wildlife). Each red dot represents an existing structure (bridge or culvert) originally constructed for non-wildlife purposes (mostly for the Malheur River or side streams).

4.2. Other large mammal species

Other large wild mammal species (larger than a coyote) in the area include pronghorn, elk, and mountain lion (Hagle et al. 2017, ICF 2021). Bighorn sheep have been extirpated, but future reintroduction is a possibility (Personal communication Tom Segal, Wildlife Habitat Biologist, Oregon Department of Fish and Wildlife).

5. DESIGN CHARACTERISTICS MITIGATION MEASURES

5.1. Introduction

Large mammal fences or barrier walls in combination with wildlife crossing structures are the most robust and effective mitigation measure to both reduce collisions with large wildlife species and maintain or improve connectivity for wildlife. However, it is important to be aware of the different functions of fences vs. the function of crossing structures and how that relates to the "departure point" of a mitigation project (based on Huijser et al. 2022).

If human safety and direct road mortality of a species are the primary concern, then:

- Road sections with a high concentration of collisions and dead animals are identified and prioritized (e.g. Spanowicz et al. 2020). The target species may be large common mammals if human safety is the primary concern (e.g. Huijser et al. 2008a). If reducing unnatural mortality for rare species is the concern, the target species can be of any body size (e.g. Kramer-Schadt et al. 2004, Huijser et al. 2008, Boyle 2021).
- From a human safety perspective, it is logical to identify and prioritize road sections that currently have a concentration of collisions. However, from a biological conservation perspective, direct road mortality may have already caused population depletion. This means that the greatest threat to population persistence due to direct road mortality may not always be along the road sections that currently have the highest concentration of dead individuals of the target species (Teixeira et al. 2017).
- Fences or other barrier types are the primary measure, as the primary purpose of fences along roads is to keep animals off the highway and reduce animal-vehicle collisions (Huijser et al. 2016a).
- Since fences alone would result in an absolute or near-absolute barrier for the target species, fences are typically combined with safe crossing opportunities for wildlife, especially wildlife crossing structures (underpasses and overpasses).
- The secondary function of the wildlife fences is to guide or funnel wildlife species to these crossing structures (Dodd et al. 2007, Gagnon et al. 2010).

If habitat connectivity for wildlife is the primary concern, then:

- Road sections where habitat connectivity needs to be maintained or restored are identified and prioritized. This may be based on the connectivity needs (genetic, demographic) for individual species (the "target species"), a wide suite of species or species groups, seasonal migration of certain species (e.g. for ungulates), dispersal to allow for colonization or recolonization of areas nearby or further away, or ecosystem processes in general (biotic and abiotic parameters), including those associated with climate change (e.g. Kramer-Schadt et al. 2004, Clevenger & Huijser 2011, Sawaya et al. 2013, 2014, Lister et al. 2015, Sawyer et al. 2016, Jarvis et al. 2018).
- While it seems logical to identify and prioritize road sections that currently have observations of animals living or moving close to the road and observations of animals crossing the road (both unsuccessfully and successfully), the greatest population level conservation benefit of reducing the barrier effect of a road may not be where most animals are currently. From the perspective of biological conservation at the population

level, areas where most animals are now may have high population viability, potentially despite being isolated because of the barrier effect of transportation infrastructure. In such cases, reducing the barrier effect does not necessarily lead to an increase in population viability. Instead, the greatest population level benefits of reducing the barrier effect can be where small and isolated populations can be made more viable by providing safe crossing opportunities. This may even include road sections that currently isolate unoccupied habitat patches, and that bisect planned habitat corridors rather than existing ones. In other words, crossing structures may also be required or can also be beneficial for population persistence in areas where the target species has low abundance or where it is currently entirely absent.

- Wildlife crossing opportunities, especially wildlife crossing structures, are the primary measure, as the purpose of wildlife crossing structures is to provide safe crossing opportunities.
- Crossing structures as a stand-alone measure, without wildlife fences, do not necessarily reduce collisions (Rytwinski et al. 2016). Therefore, wildlife crossing structures are typically combined with wildlife fences.
- An added benefit of connecting crossing structures to wildlife fences is that it guides or funnels wildlife to the crossing structures and that this increases the use of the structures (Dodd et al. 2007, Gagnon et al. 2010).

In this context, it is also important to be aware of the limitations of existing crossing structures that were not built for wildlife versus designated wildlife crossing structures. While designated wildlife crossing structures should be located where connectivity for wildlife is needed most, existing structures that were not built for wildlife are not necessarily located where connectivity for wildlife is needed most. Nor are such existing crossing structures necessarily of the right type (e.g. overpass vs. underpass) or dimensions given the target species, and there are typically limits to potential modifications to existing structures to improve the suitability for the target species. In conclusion, fences and wildlife crossing structures are almost always implemented together, regardless of whether the primary objective is to reduce animal-vehicle collisions or to reduce the barrier effect of roads and traffic for wildlife. However, the road sections where the measures are implemented are very much dependent on the primary objectives or departure points, and they may include road sections where the target species is not hit or no longer hit, and where the target species may have low population density or where it is currently not present at all.

5.2. Barriers

Wildlife barriers can either be fences or walls, and the latter may be integrated in the roadbed when landscape aesthetics as observed from the road are a concern. However, wildlife fences are far more commonly applied than wildlife walls, especially over long distances.

Effective wildlife fences must be designed with the climbing, digging, and jumping capabilities of the target species in mind, as well as their strength. The primary target species for this project is mule deer. But there are other large wild mammal species in the area too, and one may decide to improve human safety and reduce direct road mortality for those other large mammal species (larger than coyote) with the same fence. Therefore, one may design a wildlife fence to keep multiple species from accessing highways in the area (Table 1).

Table 1: Indicative fence characteristics for selected potential wild large mammal target species along US Hwy 20. Note that fence height may have to be adjusted if the fence is positioned on a slope.

Target species	Fence height	Posts	Fence material	Dig barrier	Overhang	High tensile top wire*1
Mule deer, elk	8 ft	Wood	Mesh-wire	No	No	Yes
Pronghorn*2	5 ft	Wood	Mesh-wire	No	No	No
Bighorn sheep	10 ft	Wood	Mesh-wire	No	Yes	Yes
Mountain lion*3	12 ft	Metal	Chain-link	Yes	Yes	Yes

*1 Especially recommended in areas with trees where a tree may fall on the fence.
*2 Pronghorn almost never jump fences, but they will try to crawl under or through a fence.
*3 Mountain lions are good climbers and jumpers. Very tall fence, metal posts, small mesh sizes, and overhang is recommended
*5 Wolves are very good diggers; a dig barrier is recommended.
Note: Strands of electrified wire can further increase functionality of the barrier.

Mule deer are the primary target species, supplemented by elk and pronghorn. Based on these species, a wildlife fence should be 8 ft tall, have wooden posts (except where rocky soil may dictate metal posts), have mesh-wire fence material (mesh size about 6 x 9 inch), and have no dog barrier or overhang (see Figure 5 for most of these characteristics). Since the landscape is mostly treeless, a high tensile top wire may not be needed. However, if bighorn sheep and mountain lions are also among the target species, then the barrier should be designed differently. Also note that species that dig (e.g. red fox, coyote) will be able to access the fenced road corridor if the fence does not include a dig barrier.

Although it is good practice to identify the target species when designing a wildlife fence, it is also good practice to take a step back and look at the presence of other species in the area and how the proposed mitigation measures may positively or negatively impact them and make adjustments that go beyond the minimum design that is required for the target species. For example, medium-sized mammal species (e.g. red fox, coyote, bobcat), or reptiles and amphibians may also among the target species and they require different barrier designs, or additions to designs primarily targeted at large wild mammals (Gunson & Huijser 2019). Note that the design characteristics summarized in Table 1 are indicative only; they are not necessarily prescriptive, and the practices – effective or not - are varied (Huijser et al. 2015a) The main purpose of this table is to illustrate how the biological characteristics of a target species have consequences for the design specification of a fence or other barrier.

Figure 5. Typical large ungulate fence in North America, 8 ft tall, wooden posts and mesh-wire fence material, US Hwy 93 North, Montana, USA. Note that there is a dig barrier attached to the main fence material (e.g. for canids).

When designing wildlife fencing (in combination with safe crossing opportunities for wildlife consider implementing fencing over at least 3 miles (5 kilometers) of road length rather than at shorter road sections (Huijser et al. 2016a). Fenced road sections that are at least 3 miles long almost always reduce collisions within the fenced section by 80% or more (Huijser et al. 2016a). Fenced road sections that are shorter than 3 miles long have reduced effectiveness, 50% reduction on average, and the effectiveness is extremely variable (Huijser et al. 2016a). Fences should at least cover the full length of the road section with a concentration of collisions and an adjacent buffer zone that is “far” compared to the distances over which the target species moves. Regardless of how effective a fenced road section may be in reducing collisions, there is a danger of moving the collisions to adjacent road sections rather than truly reducing them (Huijser & Begley 2022). Therefore, basing the fence length on the habitat, the distribution of the target species, and how far they may regularly move along the fence is recommended. This all points towards long or very long mitigated road sections (many miles, perhaps dozens of miles) rather than just a few miles or less.

Almost always, include wildlife crossing opportunities that are suitable for the target species. Also consider the needs of other species in the area, especially those that are not a target species but for which the fence may also result in a barrier. Solving one problem (direct road mortality, human safety) should not cause another problem (barrier effect for wildlife) (Moore et al. 2021).

Make sure no gaps or other weak points in the fence occur, e.g. because of installation errors or challenges because of the terrain. Gaps are especially common where the fence connects to the wingwalls of underpasses or the walls of jump-outs, or to gaps in the fence at access roads (Figures 6-7). The fence not only needs to have the end-post have a tight connection with the wingwall of an underpass or the wall of a jump-out, but if the fence runs parallel to the wingwall, it must also have a tight connection with the wingwall everywhere they run parallel. A “wedge” or “funnel” between the wingwall and the fence can encourage animals that want to escape the fenced right-of-way to enter the wedge or funnel and get trapped, potentially resulting in injury or death. Alternatively, the fence comes in at an angle that is more perpendicular to the wingwall of the structure, and then the danger of animals getting trapped between the wingwall and the fence is also addressed. The end-post of a fence should be located where the wall is at least as high as the fence itself. If the end-post is located where the wall is lower than the fence, the “exclusion system” falls below the design specifications.

Figure 6. Tight connection (no gap) between last fence post and wall of the wildlife underpass, Hwy 331, Hwy 83 near Freeport, Florida, USA. The angle at which the fence comes in does not result in a dangerous wedge or funnel that could lead to animals getting trapped.

Figure 7. Mule deer got stuck between wildlife fence and the wing wall associated with a wildlife underpass and died, Montana, USA. The fence should be snug up to the wing wall. Here the last fence post was close enough to the wing wall but the second to last post allowed for a funnel or wedge like configuration making the deer believe it could potentially pass in between the wall and the fence. When it realized it could not go forward anymore it tried to turn itself around and then got stuck and died. It is important that both the post and the fence are positioned such that no space is left between the wing wall and the fence.

5.3. Crossing structures

One can distinguish among the following types of crossing structures:

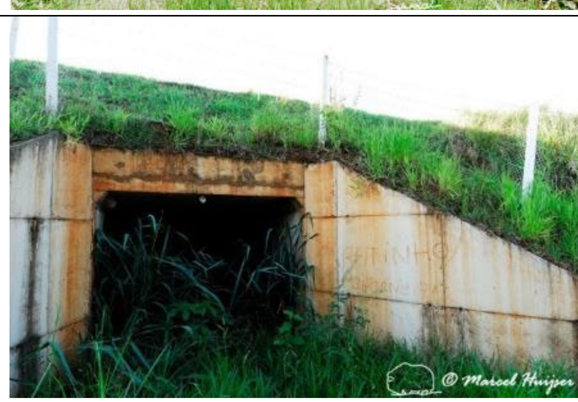
- **Existing structures built for other purposes without modifications for wildlife.** The primary purpose of crossing structures that were not originally constructed for wildlife is often to allow for people (including e.g., vehicles), livestock, or water to cross under (underpasses) or over (overpasses) the road. Their location, type, dimensions, and the distance between them is dictated by their primary - non-wildlife - function. No modifications have been made to encourage use by wildlife species.
- **Modified structures.** These structures are similar to the previous category. However, modifications have been made to enhance use by wildlife species. Modifications can make existing structures, originally built for other purposes, more suitable, or somewhat suitable, for some wildlife species. For a modified structure to be considered successful, it should at least result in enhanced use by wildlife, compared to unmodified structures. However, the location and dimensions of the structures are not influenced by the need or goal to provide safe crossing opportunities for wildlife.
- **Multifunctional structures.** Structures that are truly multifunctional would have their location and design influenced by the different functions, in this case including functions related to wildlife movement. For example, a multifunctional structure could be a structure in a drainage, stream or river that is located and designed to pass both water and aquatic, riparian and terrestrial species that are associated with water. Both the hydrological function and the movement by wildlife species influence the location, design, construction, and maintenance. For a multifunctional structure to be considered successful, it should achieve certain stated objectives, including those related to wildlife movements.
- **Designated wildlife crossing structures.** Designated wildlife crossing structures have their location and design primarily informed by goals related to wildlife movement of certain target species. For example, the location, design, construction and maintenance of a crossing structure, or set of crossing structures, is optimized for the movement of one or more wildlife species. For a designated wildlife crossing structure to be considered successful, it should achieve certain stated objectives related to wildlife movements.

Modified crossing structures, multifunctional crossing structures, and designated wildlife crossing structures should all allow for safe passage by wildlife under or over a road. However, stand-alone crossing structures that are not connected to wildlife fences or other barriers do not necessarily reduce direct road mortality (Rytwinski et al. 2016). In addition, structures that are tied into wildlife fences or other barriers have higher use by wildlife as the fences guide the animals towards the structure (Dodd et al. 2007, Gagnon et al. 2010). Therefore, as a general rule, crossing structures for wildlife should be combined with wildlife fences or other barriers.

The type (underpass vs. overpass), the approach slope of the structure, the dimensions (width, height) and the associated habitat inside or on top of the crossing structure should be based on the biological requirements and behavior of the target species as well as the surrounding landscape (Table 2-3). Different species are more or less likely to use certain types and dimensions of wildlife crossing structures. For a crossing structure type and dimension to be considered suitable for a species, the likelihood that the structure will be used by an animal that approaches the structure should be "high". While there are no established minimum norms for acceptance, selecting a structure type and dimensions that have a high acceptance rate (perhaps at least 70-80%) for the target species is logical. In this context it is important to remember that having observed "use" by a species does not mean that it is defensible to claim that that that structure type and its associated dimensions are "suitable"; even a structure with a very low acceptance rate still has some "use". By definition, a crossing structure that is "suitable" for the target species is much more likely to be found effective in reaching objectives related to the connectivity than a crossing structure that may be "used" but that may not have a high acceptance rate.

Data on acceptance (and thus suitability) are not common (but see e.g. Purdum 2013, Huijser et al. 2019, Denneboom et al. 2021), and they are not available for all large mammal species in the project area of the report. Therefore, published data on structure types and their acceptance by the large wild mammal species in the area (i.e., larger than coyote) were supplemented by "use" data (Table 3).

Table 2: Crossing structure types and dimensions.

Safe Crossing Opportunity type	Indicative dimensions (as seen by the animals)	Image
Wildlife overpass	50-70 m wide	
Open span bridge	12-30 m wide, ≥5 m high	
Large mammal underpass	7-8 m wide, 4-5 m high	
Medium mammal underpasses	0.8-3 m wide, 0.5-2.5 m high	

Safe Crossing Opportunity type	Indicative dimensions (as seen by the animals)	Image
Small-medium mammal pipes	0.3-0.6 m in diameter	

Table 3. Suitability of different types of mitigation measures for selected large mammal species (for 2-3 lane highways [25-35 m (82-115 ft)] wide road without median).
● Recommended/Optimum solution; (●) Likely, but no data, ○ Likely marginal or somewhat possible if adapted to species' specific needs; ⊗ Not recommended; ? Unknown, more data required; — Not applicable (Clevenger & Huijser 2011, O'Brien et al. 2013, Ford et al. 2017, Huijser et al., preliminary data; Clevenger, unpublished data).

Species	Wildlife overpass	Open span bridge	Large mammal underpass	Medium mammal underpass	Small-medium mammal pipes
Mountain lion	●	●	●	⊗	⊗
Deer spp.	●	●	●	⊗	⊗
Elk	●	●	○	⊗	⊗
Pronghorn	●	○	⊗	⊗	⊗
Bighorn sheep	●	●	●/○	⊗	⊗

The type and dimensions of most of the existing structures along US Hwy 20 (see Hagle et al. 2017, ICF 2021) are likely suitable for mule deer and mountain lions, and potentially also for bighorn sheep. However, elk, and especially pronghorn need very large underpasses (open span bridges), or wildlife overpasses. A very gradual approach to an underpass and overpass (perhaps 10-15% at a maximum) is recommended. This may be especially relevant in open and flat landscapes compared to landscapes with lots of cover and topography. Gradual approaches may impact natural vegetation beyond the right-of-way boundary. However, the vegetation on the approaches may be restored after construction, and the disturbance is only once. The structure itself may only have a lifespan of 75-80 years (Huijser et al. 2009). Therefore, while the soil and vegetation on top of an overpass or at an underpass may be disturbed each time the structure is replaced, the soil and vegetation on the approaches may only be disturbed once.

Most data on the suitability of different types and dimensions of crossing structures is based on the movements of residential animals. Animals that live in the vicinity of a crossing structure have time to learn about the location of a structure and that it is safe to use it. This is illustrated by the "learning curve" phenomenon; wildlife use increases with the age of the structures (Clevenger & Barrueto 2014, Huijser et al. 2016b). However, animals that may only encounter structures twice per year on their seasonal migration between their summer and winter habitat have less opportunity to become familiar with the location of a crossing structure and feel comfortable with its type and dimensions. However, both resident and migrating mule deer have reasonable or good acceptance rates for large mammal underpasses (i.e. underpasses that are 8-7 m wide and 3-5 m high): 67-92% (Table 4). However, acceptance in the first few years may be lower. Overpasses can have higher acceptance rates immediately and have these rates stay high (89-99%) (Table 4).

Table 4. Use and acceptance of crossing structures by resident and migratory mule deer.

Location	Measures	Main species	Habitat use	Collision reduction	Use	Acceptance / passage rate	Use by other species	Source
US Hwy 93, Flathead Indian Reservation, Montana	14.01 km road fenced with wildlife crossing structures at 39 locations. The underpasses studied for acceptance rate: about 7 m wide, about 4 m high	Wide variety of large wild mammal species	Resident	71-80%	334 crossings by mule deer	Mule deer: 67%	Black bear, bobcat, coyote, and white-tailed deer: acceptance rate ≥80%	Purdum 2013, Huijser et al. 2016b
US Hwy 30, Nugget Canyon, Wyoming	21 km road fenced with 7 underpasses (about 6.0 m wide, 3.0-3.5 m high, 18.0 m long)	Mule deer	Winter habitat and migration routes	81% (some gates were left open, cattle guards filled with snow)	49,146 mule deer passed through the 7 structures during a 3-year period, and 83% of those animals were in the process of migrating	1st year: 54% 2nd year: 72% 3rd yr: 92%	1,953 elk, 201 pronghorn, 13 coyotes, 77 bobcats, 9 badgers, 13 moose, 3 raccoons, 1 mountain lion	Sawyer et al. 2012
U.S. Highway 191, Wyoming,	20 km road fenced with 6 underpasses (bridges, about 20 m wide, 4 m high, 13 m long) and 2 overpasses (45 m wide)	Mule deer, pronghorn	Migration route	1st year: 64% 2nd year: 72% 3rd year: 81%	40,251 mule deer and 19,290 pronghorn used the structures during a 3-year period. 79% of the mule deer moved under, whereas 93% of pronghorn moved over the highway	Not reported	Not reported	Sawyer et al. 2016
US Hwy 93, northeastern Nevada	10 Mile Summit: 6.4 km road fenced, 1 overpass (48.8 m wide) and 2 underpasses. HD Summit: 4.8 km road fenced, 1 underpass and 1 overpass (30.5 m wide). Underpasses were 8 m wide, 6 m high, 28 m long)	Mule deer	Migration route	About 80%, effectiveness increased in the first few years	10 Mile Summit: 30,259 mule deer used the crossing structures HD Summit: 5,110 mule deer used the crossing structures 82% of the mule deer crossed using an overpass, 18% crossed using an underpass	Underpasses: increasing, ending in about 64% 70% and 86% after 4 years. Overpasses: high immediately and stayed high (89-99%).	4 elk, 3 of them used an overpass. Other species: Badger, pronghorn, bobcat, coyote, black-tailed jackrabbit, desert cottontail, red fox	Simpson 2012, Simpson et al. 2016

It is often possible to modify existing structures not originally built for wildlife and make them more accessible to wildlife. However, there are limitations to such structures:

- Existing structures that were not built for wildlife are not necessarily located where connectivity for the target species is needed most.
- Existing crossing structures are not necessarily of the right type (e.g. overpass vs. underpass) for the target species.
- Existing structures are not necessarily of the right dimensions for the target species.
- There are typically limits to potential modifications to existing structures to improve the suitability for the target species.

Nonetheless, it is good practice to explore the potential for modifications that could potentially enhance wildlife use by wildlife of structures that were originally built for other purposes. For example, an existing bridge over a river may have riprap (large rocks or boulders) on the banks and slope to reduce erosion (e.g., Hagle et al. 2017). Creating a pathway through the rock or boulders for large wild mammal species may be possible. In addition, removal of debris, or excavating an area may open up the approaches through removing physical barriers and increasing the clearance or height of a structure, and it may result in a better line-of-sight to the other side of the structure.

5.4. Associated measures

Fence-end treatments

"Fence-end runs" are situations where animals cross the road in high numbers at or near fence-ends (Figure 8). Such fence-end runs are best addressed by having the fence-end at appropriate locations, well away from known movement areas or suitable habitat.

Figure 8. Wildlife trail at a fence-end, US Hwy 95, Bonners Ferry, Idaho, USA. This is an indication that there is a concentration of wildlife crossings at the fence-end (a "fence-end run"), potentially resulting in a concentration of collisions at or near the fence-end, just inside or just outside the fenced road section.

Fence-end treatments are especially important if the fenced road length is relatively short (e.g. shorter than 3 mi (5 km) (Huijser et al. 2016a). The effectiveness of short sections of wildlife fencing is substantially reduced by collisions inside the fenced road section at or near fence-ends. While these collisions also take place at fence-ends associated with longer fenced road sections, they have limited consequences for the overall effectiveness of long fenced road sections (Huijser et al., 2016a). Be careful and don't assume that steep rocky slopes or other landscape features are a barrier for the target species; animals will often move over difficult terrain when forced or motivated.

To reduce the likelihood of animals accessing the fenced road corridor at a fence-end, consider bringing the fence-ends close to the edge of the pavement (Figure 9). Note that a split fence-end is possible where the other fence-end angles away from the road. Boulder fields at fence-ends have also been used to discourage ungulates from accessing the fenced road corridor by walking and grazing in the right-of-way (Figure 10). Note that boulder fields are likely less effective for species with paws.

Figure 9. Fence-end brought close to the edge of the pavement, protected by Jersey barriers. Also note that there is a wildlife guard embedded in the travel lanes, Alberta, Canada.

Figure 10. Boulder field at a fence-end, Alberta, Canada.

Consider implementing wildlife guards (similar to cattle guards) or electric mats embedded in the roadway to reduce wildlife intrusions into the fenced road corridor at fence ends and at access roads (Figure 11, 12, 13). Wildlife guards or "cattle guards" may be a substantial barrier to ungulates, but not to species with paws (Allen et al. 2013). For species with paws, including bears, canids and felids, electrified barriers may be required (Huijser & Getty 2022a).

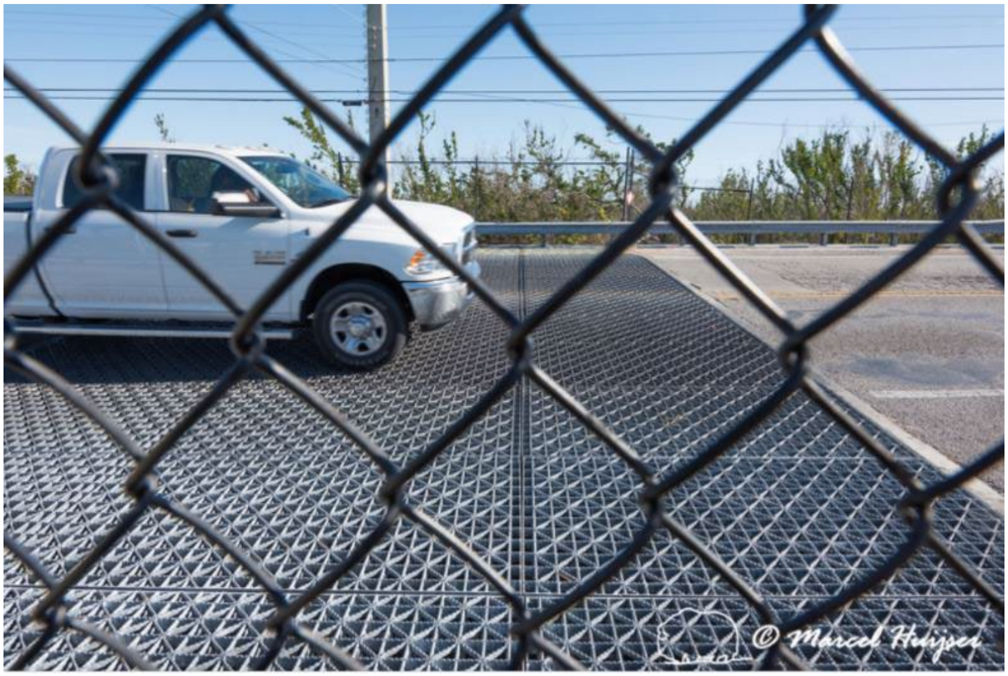


Figure 11. Wildlife guard at a fence-end on US Hwy 1, Big Pine Key, Florida, USA.

Figure 12. Electrified mat associated with an animal detection and driver warning system at a fence-end, S.R. 260 east of Payson, Arizona, USA.

Figure 13. Electrified barrier embedded in travel lanes to keep large mammals, including bighorn sheep, out of fenced road corridor, MT Hwy 200, Thompson Falls, Montana, USA.

To further reduce the likelihood of animals getting on the road at or near a fence-end, consider angling the fence away from the road at the fence-end. This may encourage animals to turn back into the surrounding area, walk back along the fence and potentially find and use a suitable wildlife crossing structure, or it may result in them crossing the road further away from the fence-end. Note that a split fence-end is possible where the other fence-end angles towards the road.

Access roads and trails

Similar to fence-ends, access points result in gaps in the fence. Wildlife guards and electrified barriers can also be used at access roads, but, in contrast to the main travel lanes at fence-ends, they may be designed for lower traffic volume and lower vehicle speed (Figure 14-15). Wildlife guards or “cattle guards” may be a substantial barrier to ungulates, but not to species with paws (Allen et al. 2013). For species with paws, including bears, canids and felids, electrified barriers may be required, sometimes in combination with a wildlife guard (Figure 16) (Huijser & Getty 2022a).

Figure 14. Wildlife guard installed at an access road to the main highway (US Hwy 93S), near Stevensville, Montana, USA. The metal barrier is easy to walk and bike over. Note that the concrete ledge can be used by wildlife to access the fenced road corridor. This concrete ledge should be made inaccessible.

Figure 15. Wildlife guard at an access road to US Hwy 93S, near Victor, Montana, USA. This type of wildlife guard is less suited for pedestrians and cyclists.

Figure 16. Electrified barrier, designed for low traffic volume and low traffic speed, on top of a wildlife guard at an access road to US Hwy 93S, near Ravalli, Montana, USA.

Wildlife should not be able to bypass a wildlife guard or an electrified mat. The fence should run tight along the sides of the barrier. In the image below, the concrete ledge (i.e. the wall of the pit under the barrier), has been made inaccessible to large mammal species (Figure 17).

Figure 17. Blocked concrete edge at side of wildlife guard at access road US Hwy 93, Arizona, USA. Some wildlife species will walk on the narrow concrete edge of the wildlife guard to access the fenced road corridor. The concrete edge is part of a wall for the pit under the metal bars. Here the edge is made inaccessible to large mammals through an extra piece of wildlife fence.

Allow small animal species that fall in the pit under a wildlife guard to escape (Figure 18-19). Exits may be provided at the sides, or through an escape ramp, although the effectiveness of escape ramps is not known.

Figure 18. Combined drainage and escape for small animals under wildlife guard, Arizona, USA. The openings on the side allow for drainage under the culvert. The openings also allow invertebrates, amphibians, reptiles, small mammals and other species that may fall in between the metal bars to escape.

Figure 19. For wildlife guards that have a fully enclosed pit with contiguous walls sometimes wooden planks or metal strips are attached, potentially allowing small animal species to climb out of the pit.

Wildlife guards can be designed to be more friendly to pedestrians and cyclists (Figure 20, 21, 22).

Figure 20. Bicyclist on wildlife guard for wild boar (*Sus scrofa*) and moeflon (*Ovis orientalis*) at a bicycle path, National Park Hoge Veluwe, The Netherlands. This wildlife guard has an escape ramp for small animals that fall into the pit under the metal grate.

Figure 21. Detail of the modified bridge grate material used for wildlife guards installed at access roads along US Hwy 93, near Ravalli, Montana, USA. This material is more suitable for pedestrians and cyclists compared to the bars of a traditional wildlife guard or cattle guard.

Figure 22. Push button on timer (turns electricity off for 1 minute) for pedestrians at an electrified barrier embedded in travel lanes to keep large mammals, including bighorn sheep, out of fenced road corridor, MT Hwy 200, Thompson Falls, Montana, USA.

For non-motorized traffic, swing gates may also allow for access to and from the fenced road corridor (Figure 23, 24, 25).

Figure 23. Swing gate at a wildlife fence, set at an angle so it closes through gravity, The Netherlands.

Figure 24. Wildlife guard (right) and horse gate (left), Heugterdijk, Weerterbos, near Maarheeze, The Netherlands. The riders do not have to dismount and can push the rotating gate while in the saddle. The gate is set at an angle so that gravity will bring the rotating fence in line with the main fence.

Figure 25. Pedestrian gate with steps (for high snow accumulation) at a wildlife fence, Alberta, Canada.

Escape opportunities from fenced road corridor

Consider implementing jump-outs (or escape ramps) to allow animals that get caught in the fenced road corridor to escape to the safe side of the fence (Figure 26, 27, 28, 29, 30, 31, 32). A jump-out should be low enough for animals to readily leave the fenced road corridor. At the same time, the jump-out should be high enough so that animals do not readily jump into the fenced road corridor.

While widely implemented, little is known how well or how poor wildlife jump-outs or escape ramps function. The appropriate height depends on the jumping and climbing capabilities of the target species. Since there is often more than 1 target species, there is no one recommended height. However, jump-outs for deer may need to be around 5 ft high and for elk around 6 ft. A bar on top of the wildlife jump out can help reduce the likelihood that animals will jump into the road corridor. Animals that want to jump down can first step over the bar and take advantage of the low height of the wall of the jump-out. For mule deer, a 5 ft high face of the jump-out, combined with a bar that is 18 inches high above the top of the jump-out, and that has a setback of 15 inches is recommended (Huijser & Getty 2022b). This design resulted in 80.4% of all mule deer that were observed on the top of the jump-out within the fenced right-of-way jumping down to the habitat side of the jump-outs (Figure 28).

The face of the jump-out can consist of rocks, concrete blocks, wooden planks or other material. In general, it is advisable that the face is smooth to discourage animals from climbing the wall. The face can even be a metal plate (e.g. to discourage bear species from climbing the jump-out into the fenced road corridor.

Alternatively, instead of a mount, a jump-out may also be constructed through excavating a pit on the habitat side of the fence (Figure 32). While no data on effectiveness are available, this may allow more animals that are caught in the fenced road corridor to reach the edge of the jump-out as animals may walk around a mount and associated jump-out.

Figure 26. Wildlife jump-out or escape ramp with a rock wall and bar designed for desert bighorn sheep (*Ovis canadensis nelsoni*), US Hwy 93, Arizona, USA. The bar reduces the probability that bighorn sheep will jump up into the fenced road corridor while it does not decrease the probability that the bighorn sheep will jump down to the safe side of the fence. The sheep can crawl under the bar before jumping down.

Figure 27. Wildlife jump-out with concrete blocks and a bar for bighorn sheep (*Ovis canadensis*), near Thompson Falls, Montana, USA. Note that it is probably better to not have the concrete blocks protrude as it makes it easier for species to climb the face.

Figure 28. Wildlife jump-out along US Hwy 93, Flathead Indian Reservation, Montana, USA. Jump out is 5 ft tall with rebar on top.

Figure 29. Wildlife jump-out with a smooth metal face to reduce the likelihood that bear will climb the jump-out and end up in fenced right-of-way, Banff National Park, Alberta, Canada.

Figure 30. Wildlife fence and jump-out with a face consisting of wooden planks, near Havre, Montana, USA.

Figure 31. Wildlife fence and jump-out along A28 motorway, near Spier, Drenthe, The Netherlands. The fence is a barrier for medium and large mammal species. The electric fence is an additional barrier for livestock (sheep, cattle) that are used as a tool for nature management in the area.

Figure 32. Wildlife fence with jump-out, Kootenai National Park, British Columbia, Canada. The pit is dug on the habitat side of the fence.

While many jump-outs have a short perpendicular fence on top, its potential benefits or lack thereof are not known (Figure 33).

Figure 33. Jump-out for bighorn sheep (*Ovis canadensis*) with a short perpendicular fence, near Thompson Falls, Montana, USA. The potential benefits of the perpendicular fence in guiding wildlife to the jump-out are not known.

6. PURPOSE, LOCATION AND SPACING OF CROSSING STRUCTURES FOR MULE DEER

6.1. Introduction

This chapter focuses on the purpose, location and spacing for crossing structures for mule deer. While there can be overlap with the needs for other species, abiotic processes (e.g. streams, rivers) and the need for human access (e.g. side roads, ranch roads), these other interests are not part of this chapter.

6.2. Purpose and location

The appropriate location of crossing structures for mule deer can be determined in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Maintaining or improving mule deer population viability based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (including allowing for successful dispersal movements).
- Providing the opportunity for mule deer to continue seasonal migration movements as this can be seen as a component of the biological integrity of an ecosystem, regardless of the viability of the population.
- Allowing individual mule deer that have their (winter) home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is substantially permeable, at least for the individuals that live close to the road. This may be especially important as mule deer may need to access the Malheur River that is adjacent to the road daily. Furthermore, south facing slopes may be important winter habitat in high snow years. On the other hand, south facing slopes are more prone to fire and the loss of sagebrush, an important winter food. Therefore, north facing slopes can be important too, both in low snow years, and after fires have resulted in the loss of sagebrush and other winter food on the north facing slopes.

Based on these possible goals, the location of crossing structures for mule deer can respectively be based on:

- Connecting or reconnecting important current and potentially also historic habitat to increase the accessible habitat for mule deer, and thereby increase their population size.
- Allowing for safe crossing opportunities based on existing and potentially also historic migration paths, allowing for seasonal migration to continue, or be restored.
- High permeability along the entire road for mule deer so that they can readily access the river and south and north facing slopes within a short distance anywhere along the road.

6.3. Spacing

A way to decide on "appropriate distance" between safe crossing opportunities is to evaluate what the spacing is for wildlife crossing structures on other wildlife highway mitigation projects. The average spacing for large mammal crossing structures in Montana (US Hwy 93 North and South), I-75 in Florida, SR 260 in Arizona, Banff National Park in Canada, and ongoing reconstruction on I-90 in Washington State is 1.2 mi (1.9 km) (range for the average spacing of structures in these individual areas is 0.5-1.8 mi (0.8-2.9 km)). However, the 1.2 mi (1.9 km) spacing is simply what people have done elsewhere, and it is not necessarily based on what may be needed ecologically, and the requirements for the target species in one area may be different from what is needed in another area.

For this report the spacing of crossing structures for mule deer is set to be equal to the diameter of their home range (Figure 34). In theory, this allows individuals that have the center of their home range on the road to have access to at least one safe crossing opportunity. However, individuals that may have had their home range on both sides of the road do not necessarily have access to a safe crossing opportunity (Figure 35). Nonetheless, this approach results in high permeability along the entire road for mule deer so that they can readily access the river and south and north facing slopes within a short distance anywhere along the road. In addition, it should allow for seasonal migration across the highway, but if there are concentrated paths for such migration movements rather than dispersed movements, care should be taken to identify where such migration paths intersect the highway and provide safe crossing opportunities on those locations.

Note that this approach assumes homogenous habitat and distribution of the individuals and circular home ranges, but habitat quality may vary greatly, causing variations in density and home range size of the individuals and irregular shaped home ranges, especially along linear futures such as the Malheur River and US Hwy 20. Species that have smaller home ranges need the crossing structures to be closer together than species with large home ranges (Figure 34).

This approach does not necessarily result in viable populations for every species of interest, and not every individual that approaches the road and associated wildlife fence will encounter and use a safe crossing opportunity. In addition, the approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the approach chosen is consistent, practical, can be based on available data, and is likely to result in considerable permeability of the road corridor and associated wildlife fencing for a wide array of species.

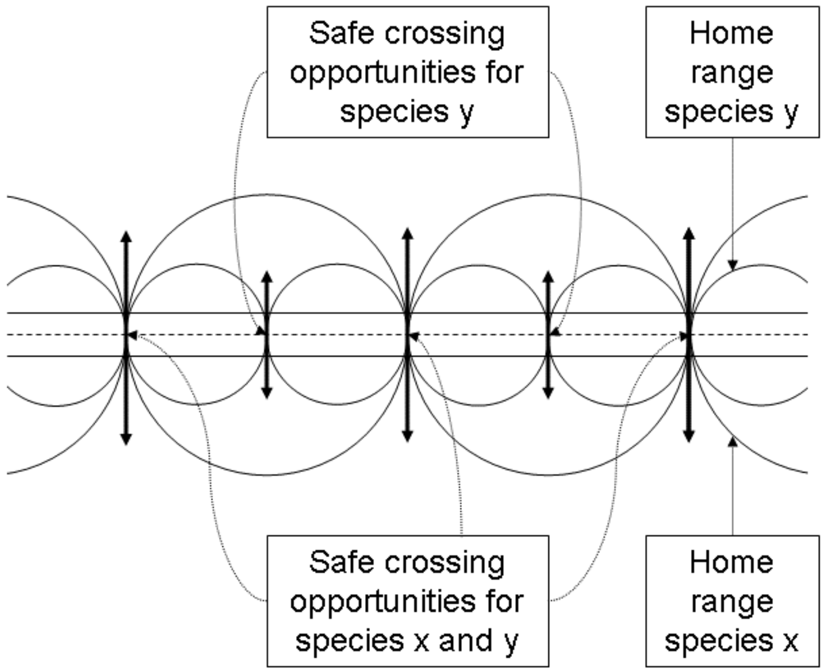


Figure 34. Schematic representation of home ranges for two theoretical species projected on a road and the distance between safe crossing opportunities (distance is equal to the diameter of their home range).

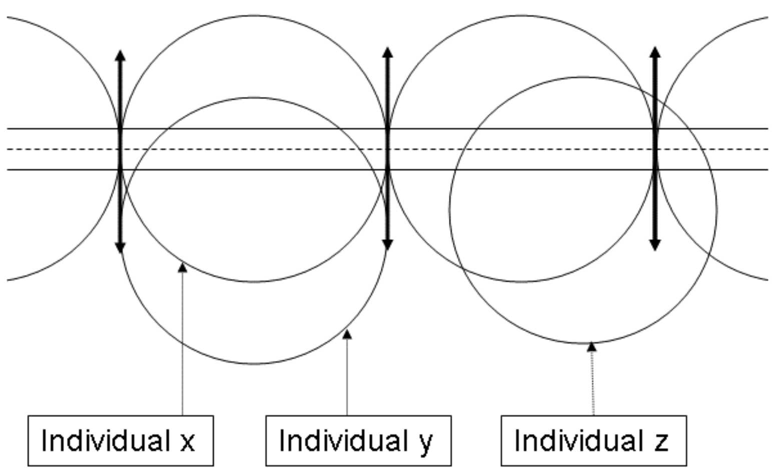


Figure 35. Schematic representation of home range for an individual (x) that has the center of its home range on the center of the road (access to two safe crossing opportunities), an individual (y) that has the center of its home range slightly off the center of the road exactly in between two safe crossing opportunities (no access to safe crossing opportunities), and an individual (z) that has the center of its home range slightly off the center of the road but not exactly in between two safe crossing opportunities (access to one safe crossing opportunity).

Location data from GPS-collared mule deer in the study area were obtained from Tom Segal, Wildlife Habitat Biologist, Oregon Department of Fish and Wildlife. The location data from 10 individual mule deer were used to calculate the diameter of the winter home range. For an individual to be included, it had to have its home range on both sides of the highway. The diameter of the home range for these 10 individual mule deer was calculated in three ways (Figure 36):

1. The greatest east-west diameter (straight line) of an individual's home range (given that US Hwy 20 is generally an east-west oriented highway).
2. The distance (straight line) between the highway crossing of an individual that was furthest west and the highway crossing of the same individual that was furthest east.
3. The distance (following the path of the highway) between the highway crossing of an individual that was furthest west and the highway crossing of the same individual that was furthest east.

While the variation in diameter was greatest when following the road (due to variable curvature of the road), the median diameter was about 1 mile for all three approaches (Figure 36). For further calculations we used the median value for the third approach as that encompassed the curvature of the road (median diameter 1.04 miles) (Figure 36).

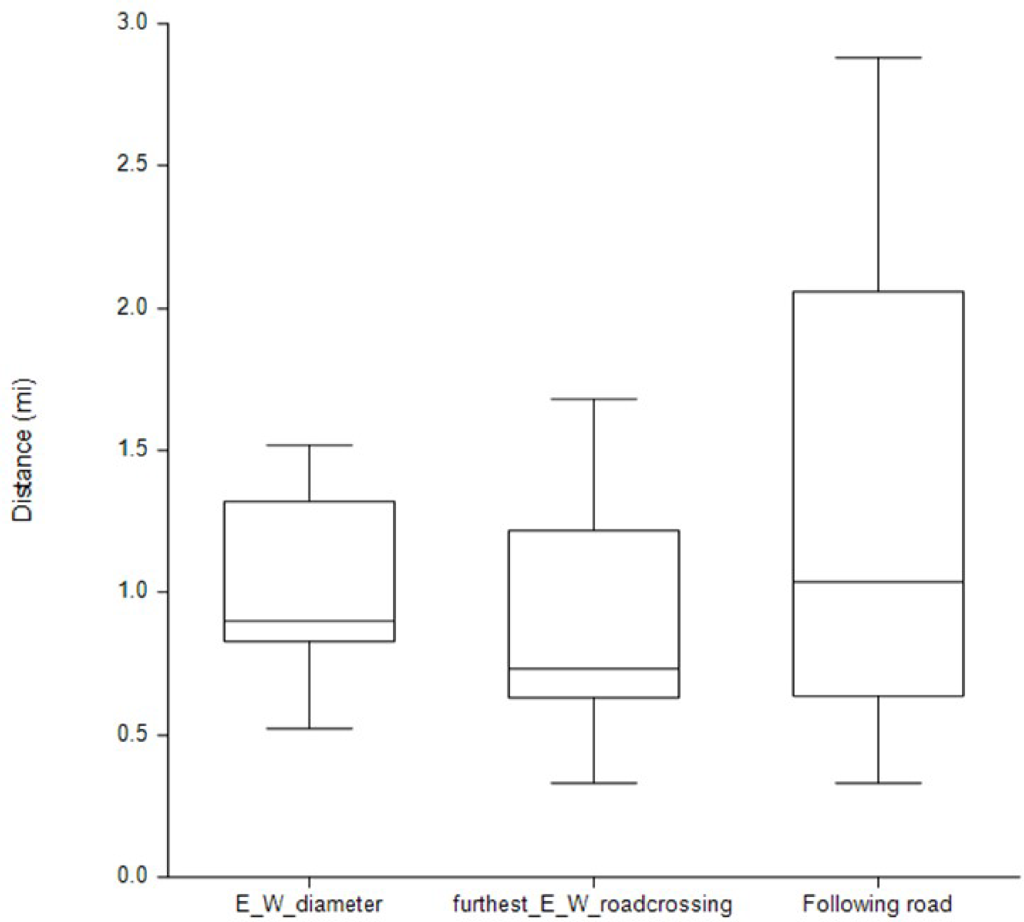


Figure 36. Boxplot of the diameter of the winter home range for 10 individual mule deer in the study area. The diameter was measured in 3 different ways (see text).

Based on the percentiles of the diameter of the home ranges for individual mule deer, a curve was fitted (Figure 37). The curve illustrates that if suitable crossing structures for mule deer are 1.04 miles apart, 50% of the mule deer (given the variability in the diameter of their home range) would have access to at least one suitable crossing structure. If suitable crossing structures would be 0.33 miles apart, 100% of the mule deer (given the variability in the diameter of their home range) would have access to at least one suitable crossing structure.

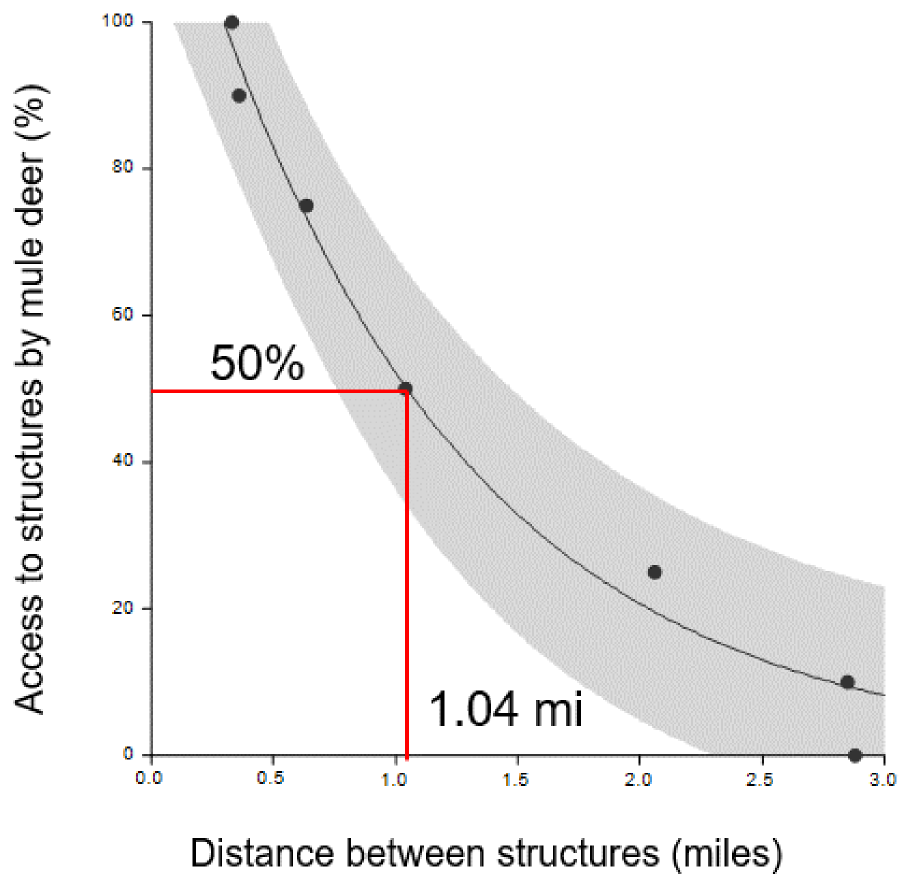


Figure 37. The percentage of mule deer, given the variability in the diameter of their home range, that would have access to at least one crossing structure, given the spacing between the crossing structures. Y = access to structures (%), X is distance between structures (miles). Equation for the curve: Y = 131.76802*(EXP(-0.92568*X)). R^2 = 0.985.

Most of the existing structures built for other puposes (mostly across the Malheur River or side streams), are much further apart than a mile (Figure 38). Based on the fitted curve (Figure 37) and the distance between the existing structures (Figure 38), the percentage of mule deer (given the variability in the diameter of their home range) that has access to at least one of the existing crossing structures was estimated for each road sections between the existing structures (Figure 38). This calculation assumed that each of the existing crossing structures is suitable for mule deer or will be made suitable for mule deer, and that there will be continuous wildlife fences between these structures. For crossing structures that are close together, e.g. around mile post 206, 100% of the mule deer that have their home range between these structures would have access to at least one of the two structures (Figure 38). However, for structures that are far apart, the access to the structures drops drastically. For example, between mile post 195 and 203, the percentage of mule deer (given the variability in the diameter of their home range) that have access to at least one of the existing crossing structures was estimated at less than 1%. Overall, many of the structures were so far apart that the permeability for mule deer, based on the diameter of their winter home ranges, was below 10% or even below 5% for most of the road. In summary, the data illustrate that continuous wildlife fences along the highway and solely relying on existing crossing structures would substantially impact the permeability of the highway to mule deer, especially when existing structures are far apart. However, it is also possible that mule deer would adapt and change the configuration of their home range to access structures that are further than the dimater of their current home range. Nonetheless, that requires the animals to change their habitat use and this change is hypothetical rather than a demonstrated phenomenon.

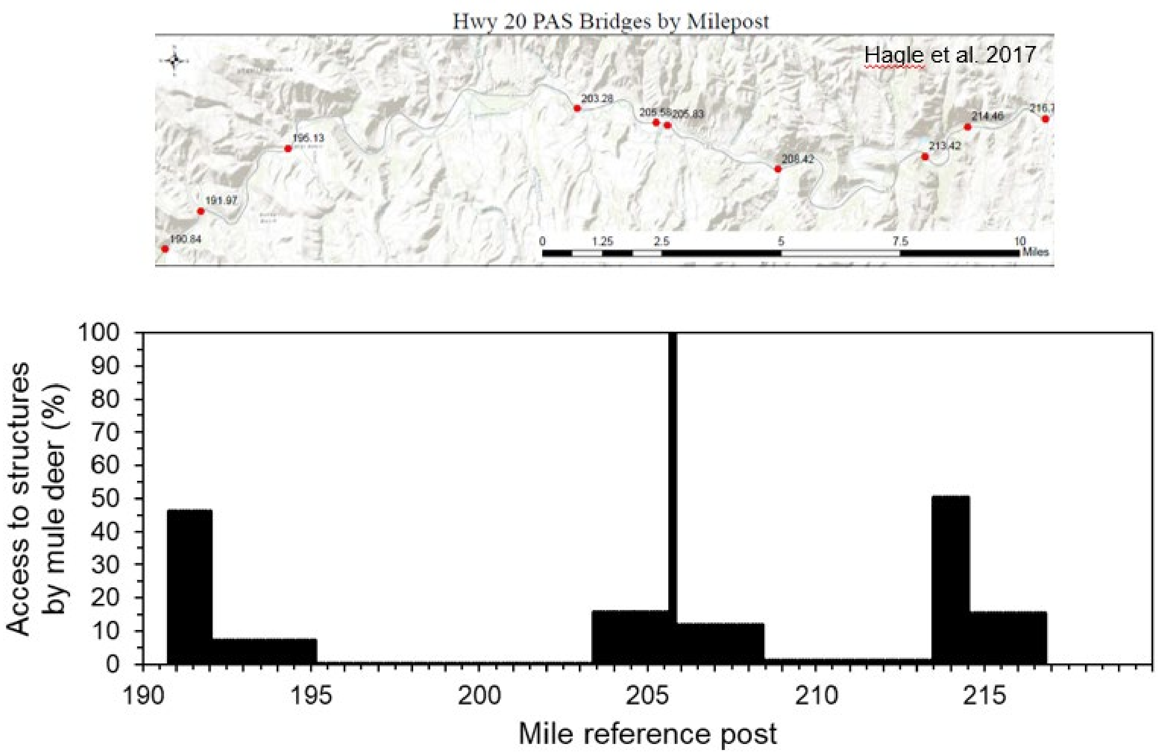


Figure 38. The location of the existing crossing structures (red dots in top graph) and the permeability of this section of US Hwy 20 to mule deer (bottom graph). The top and bottom graphs are approximately aligned based on their mile reference posts.

7. SITE CONDITIONS

7.1. Introduction

The findings of the site visit are summarized below. However, Hagle et al. (2017) and ICF (2021) have a more extensive documentation of the site conditions, including the suitability of the individual existing crossing structures for large wild mammals and the potential for modifications to these structures.

7.2. Wildlife fences

Some sections of US Hwy 20 have right-of-way or livestock fence (Figure 39). From a technical perspective, these fences could be replaced with wildlife fences. Other road sections have no right-of-way or livestock fence, and there is sometimes little room between the road and the river (Figure 40). Erosion may occur during floods, and if the flood levels reach the fence, debris may be caught in the fence, further jeopardizing the stability of the potential future barrier.

Figure 39. Right-of-way or livestock fence along US Hwy 20 between Juntura and Harper, Oregon.

Figure 40. There is little space for a wildlife fence between the Malheur River and US Hwy 20, and floods may jeopardize the stability of the fence.

7.3. Existing structures

Some existing bridges along US Hwy 20 are wide and high enough for elk (Figure 41-42). Note that line-of-sight and an open flat landscape on either side is extremely important for pronghorn, and that wildlife overpasses would be the most appropriate and least risky choice for both elk and pronghorn.

Figure 41. This bridge is sufficiently wide and high for mule deer, it has a good line-of-sight through the structure, and there is enough dry and flat terrain for them to travel under the bridge, at least in winter.

Figure 42. This bridge is sufficiently wide and high for mule deer, it has a good line-of-sight through the structure, and there is enough dry and flat terrain for them to travel under the bridge, at least in winter.

Some structures have a right-of-way or livestock fence on the approaches (Figure 43). If these fences are still needed, e,g, to separate different grazing units, consider making these into wildlife friendly livestock fences (e.g. Paige 2015). Other physical barriers that may have to be removed or modified are riprap on the slopes or tumbleweed that has accumulated on the approaches (Figure 44).

Figure 43. A right-of-way or livestock fence hinders access to the structure for large wild mammals. If this fence is still needed, consider replacing it with a wildlife friendly livestock fence.

Figure 44. Riprap (large rocks and boulders) and tumble weed that has accumulated inside a structure or on its approaches can be a physical barrier to mule deer and other large ungulates.

For other structures, height, or height and width may be too small for mule deer to readily use the structures (Figure 45-46).

Figure 45. Low clearance (height) of a structure likely impacts use by large wild mammals, including deer.

Figure 46. A double box culvert like this one is likely too small for mule deer (width and height).

The slopes under a bridge may be rather steep or eroded for mule deer and other large mammals to readily pass under (Figure 47-48). Consider a flat dry path (at a minimum 2 m wide, 3 m wide (Clevenger & Huijser 2011)) with sufficient clearance (height) with sand or gravel (no large rocks) to allow for easier passage by ungulates.

Figure 47. A steep slope can reduce use by large wild mammals.

Figure 48. An eroded slope can reduce use of an underpass by large wild mammals.

An open structure, e.g. an over-span bridge, with a clear line-of-sight to the other side of the road is recommended (Figure 49). If there are supports for the structure, consider pillars (Figure 50) rather than walls (Figure 51) as pillars allow for better visibility inside the structure and also towards the other side of the road.

Figure 49. An open structure with a clear line-of-sight towards the other side of the road is recommended. Note that this structure would still benefit from a dry flat path with sand or gravel.

Figure 50. A structure with pillars can still allow for visibility under the bridge and a good line-of-sight towards the other side of the road. Note that this structure would still benefit from a dry flat path with sand or gravel with sufficient clearance (height).

Figure 51. A structure with walls typically hinders visibility under the bridge and hinders a good line-of-sight towards the other side of the road.

Designated wildlife crossing structures could include underpasses or overpasses. Underpasses can be challenging in relatively flat areas and because of the proximity of the Malheur River and associated high groundwater table (Figure 52). Crossing structures should be implemented where the target species (e.g. mule deer, elk, pronghorn, or potentially in the future also bighorn sheep) are willing to come close to the road (Figure 53) and where they are potentially interested in crossing the road. Nonetheless, a roadcut where there is higher ground on either side of the road may be a convenient possible location for an overpass (Figure 54).

Figure 52. It is likely difficult to construct an underpass in flat terrain, especially near a river where the ground water table may be high. Raising the roadbed for hundreds of meters on each side of the underpass is a potential solution.

Figure 53. The flat areas along the Malheur River at the Denny Jones Ranch, Malheur River Mitigation Site, managed by the Burns Paiute Tribe, is a site that may attract both elk and pronghorn, and one may consider an overpass in this location.

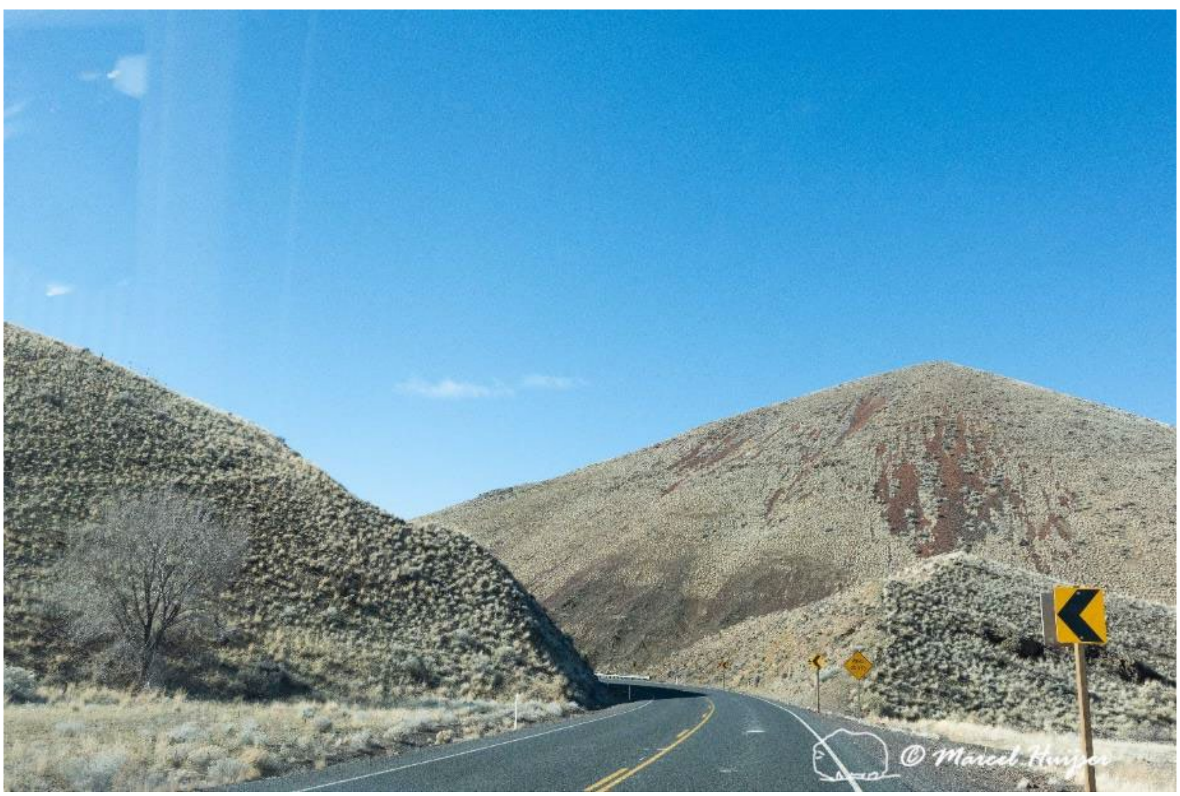


Figure 54. A roadcut may be a convenient location for a wildlife overpass.

8. PHASES OF A POTENTIAL FUTURE MITIGATION PROJECT

To be effective in reducing collisions, and to be effective in terms of connectivity, wildlife fences and designated wildlife crossing structures need to be implemented over long distances. In the context of this project, this means the entire corridor between Juntura and Harper. However, the associated funding may not all be available at once. In this context, one may consider different phases of a project where the first phase would consist of limited wildlife fences in combination with modified existing structures built for other purposes. If so, the following recommendations apply:

1. Select a road section with an existing structure that is suitable, or that can be made suitable for mule deer, and potentially also for other large mammal species in the area. The road section may also have more than one existing structure, but damage to connectivity for mule deer can occur, especially when structures are further than a mile apart.
2. The selected road section should be fenced for at least 3 miles of road length. This is likely to result in a substantial reduction in collisions (>80%) within the mitigated road section.
3. If the mitigation measures are only applied to just a few miles of road, it is still possible that collisions will increase in the adjacent road sections and that there may not be an overall reduction in collisions until the mitigation measures have been implemented over longer distances. In this context, one may consider ending the fence at an existing crossing structure or installing an animal detection system in place at the fence-ends. Such an animal detection system may then be moved when the mitigated section is increased in length in a following phase.
4. Built the following phase adjacent to the first phase. Longer fenced road sections are more effective in reducing collisions and are less likely to result in moving collisions to adjacent road sections. However, such a next phase would likely require designated wildlife crossing structures.

9. EVALUATION OF EFFECTIVENESS

Before evaluating the effectiveness of the mitigation measures it is essential to clearly define the objectives. Associated quantitative parameters will likely relate to human safety, direct road mortality of wildlife, and habitat connectivity for the target species (van der Grift & Seiler 2016). If one wants to know whether the objectives have been reached, then there should be a commitment to measuring the relevant parameters according to an appropriate study design.

For many road ecology studies, a Before-After-Control-Impact (BACI) study design is a powerful way to answer questions related to the reduction in collisions, reduction in direct road mortality, and maintaining or improving habitat connectivity for wildlife (e.g. van der Grift et al. 2013). Note that obtaining “before” data may require research to start several years before implementing the measures and that suitable “control” road sections should also be included in the study design (Rytwinski et al. 2016). A suitable “control” road section would have to be beyond the influence of an “impact” section. For example, a control section cannot be immediately adjacent to an impact section as a fence-end run (at-grade crossings) and an associated concentration of collisions is possible, perhaps even likely at or near a fence-end. In some cases, expected benefits may also be predicted or evaluated based on population viability modelling (e.g. van der Ree et al. 2009).

The time required for research may start well before, and end well after, the period during which the mitigation measures are implemented. For habitat connectivity, there may even be a learning curve of at least several years, perhaps up to 5 to 10 years during which the animals learn about the location of wildlife crossing structures, that it is safe to use them, and during which the absolute use continues to increase (e.g. Clevenger & Barrueto 2014, Huijser et al. 2016b). In other words, wildlife use of wildlife crossing structures increases with the age of the structures, and one is more likely to reach objectives related to connectivity for wildlife 5-10 years after construction of the structure compared to the first few years.

Specifically, the following recommendations apply for evaluating the effectiveness in reducing collisions:

1. Design a Before-After-Control-Impact (BACI) study. Make sure the control road sections are independent from the treatment sections; leave at least 0.2-0.5 mile space in between.
2. Include at least 4 treatment sections or at least 4 years of data collection (Rytwinski et al. 2016). The time of construction is of limited value (and one may choose not to measure collision or carcass data during this period), but “after” construction has been completed, the “after” data should be collected in the same road sections for an additional period.
3. Measure the location of wildlife-vehicle collisions precisely, especially near the edges of the (potential future) control and impact road sections. It is essential to be confident whether a collision occurred just inside or just outside a control or impact road section. This also relates to the before data. In other words, if it is not exactly known where the control and impact road sections will be, start collecting collision (and/or carcass data) with a high degree of spatial precision everywhere along the road corridor at least 3-5 years before implementation of the mitigation measures. This may involve the use of an app on a device with GPS.

Specifically, the following recommendations apply for evaluating the effectiveness with regard to wildlife movements:

1. Design a Before-After-Control-Impact (BACI) study. Make sure the control road sections are independent from the treatment sections; leave at least 0.2-0.5 mile space in between.
2. Include at least 4 treatment sections or at least 4 years of data collection (Rytwinski et al. 2016). The time of construction is of limited value (and one may choose not to measure movement data during this period), but "after" construction has been completed, the "after" data should be collected in the same road sections for an additional period.
3. Measure the location of wildlife-crossings precisely, especially near the edges of the (potential future) control and impact road sections. It is essential to be confident whether a crossing occurred just inside or just outside a control or impact road section. This also relates to the before data. In other words, if it is not exactly known where the control and impact road sections will be, start collecting crossing location data with a high degree of spatial precision everywhere along the road corridor at least 3-5 years before implementation of the mitigation measures.
4. Most studies that "evaluate" wildlife crossing structures simply count how many individual animals or what species use the structures over a certain amount of time. While wildlife use can often be described as substantial, these simple counts do not inform us about the effectiveness of the structures in relation to what animal movements were before a road was present, before a highway was widened, or before the highway was mitigated. Very little information is available on true effectiveness of crossing structures, but they have been found to be "effective" in several studies. For example, when a highway is widened in combination with exclusion fences and wildlife crossing structures, connectivity of animal populations can remain similar or can even be improved compared to what it was before the highway widening (Huijser et al. 2016b). Exclusion fences and wildlife crossing structures can also increase the population size, increase gene flow, allow for seasonal migration, and improve population viability or population persistence of target species by reducing unnatural mortality and reducing the barrier effect of the transportation corridor (van der Ree et al. 2009; Sawyer et al. 2012; Sawaya et al. 2014).
5. There is typically a "learning curve". Wildlife use increases with the age of the structures (Clevenger & Barrueto 2014, Huijser et al. 2016b). This means that one can consider not to measure wildlife movements during the first few years after constructing the mitigation measures as it is a fast-changing situation rather than a stable situation.
6. Before and after movement data may be collected through estimated road crossing locations by GPS-collared individual animals, both in "impact" and "control" road sections. In addition to evaluating the effectiveness of the structures in providing connectivity, such data would also allow to detect possible changes in the location of the animal's home ranges, and the shape of their home ranges in response to the implementation of the mitigation measures. For example, mule deer may change how far they are willing to travel along a wildlife fence to either access a crossing structure or an at-grade crossing opportunity at a fence-end. If such changes indeed occur, it may influence the locations and numbers of wildlife crossing structures in future phases of the mitigation project.

10. ALTERNATIVE MITIGATION MEASURES

Wildlife fences in combination with wildlife crossing structures and associated measures are the only combination of mitigation measures that (review in Huijser et al. 2021):

1. Can substantially reduce collisions with large wild mammals (>80%).
2. Can address the barrier effect of roads and traffic and make it easier for animals to cross.

Animal detection systems can also substantially reduce collisions with large wild mammals (>80%) (Huijser et al. 2015b, 2021). However, their range of effectiveness is much wider (33-97%) and many animal detection system projects fail for a variety of reasons before their effectiveness can be evaluated (Huijser et al. 2015b). In addition, animal detection systems do not make it any easier for animals to cross roads as they still have to navigate a wide open space with unnatural substrate and deal with fast moving vehicles. Nonetheless, when applied as a stand-alone measure, animal detection systems do not restrict where animals can cross the road. The traffic volume on US Hwy 20 is <2,000 AADT (ICF 2021), which is low enough to consider an animal detection system. However, the costs associated with animal detection systems are not necessarily lower than the costs for wildlife fences in combination with wildlife crossing structures (Huijser et al. 2009).

Wildlife culling, relocation, and anti-fertility treatments can also substantially reduce collisions with large wild mammals (>80%), but their effectiveness depends on the effort (review Huijser et al. 2021). More importantly, these measures are likely in direct conflict with the conservation goals and are unlikely to be an acceptable management practice for the mule deer herd. In addition, these measures do not make it any easier for the remaining animals to cross roads as they still have to navigate a wide open space with unnatural substrate and deal with fast moving vehicles.

11. CONCLUSION

If the objectives are to reduce mule deer-vehicle collisions and to have measures in place that can reduce the barrier effect of the road and traffic for resident mule deer and migratory mule deer along US Hwy 20 between Juntura and Harper, then:

1. Implement mitigation measures (fences, crossing structures, and associated measures) along the entire corridor. Fenced road sections that are shorter than 3 miles in length are far less effective (about 50% on average) in reducing collisions than long sections (almost always at least 80%), and the effectiveness of short fenced road sections is extremely variable between locations (Huijser et al. 2016a). While collisions in mitigated road sections can be substantially reduced (>80%), they may still result in "moving" collisions to adjacent road sections (Huijser & Begley 2022). Therefore, the scale at which mitigation measures should be implemented for large wild mammals is much larger than just a few miles. In this case, the entire road section between Juntura and Harper can be considered important winter habitat and a migration route for mule deer. Therefore, for mitigation measures to be effective in reducing collisions, fences should be implemented along the entire road section.
2. Consider implementing designated wildlife crossing structures (large mammal underpasses, larger underpasses, or wildlife overpasses) and do not only rely on existing structures originally built for other purposes to provide safe passages for mule deer. Having continuous wildlife fences between Juntura and Harper and only allowing mule deer to cross at the existing structures would result in a very substantial reduction in habitat connectivity. Based on the diameter of the home range of mule deer that winter along both sides of the highway, a suitable crossing structure would be needed every 1.04 miles to allow 50% of the mule deer access to at least one suitable structure. Also note that depending on how many or how few wildlife crossing structures are provided, connectivity for mule deer across US Hwy 20 may or may not be improved.
   It can even be reduced compared to an unmitigated road with relatively low traffic volume such as US Hwy 20.

If the objectives stated above are extended to other large mammal species observed in the area, then:

1. The measures described above for mule deer would likely also be suited for mountain lion and potentially also for bighorn sheep if they were reintroduced. However, in open landscapes, wildlife overpasses are likely better for bighorn sheep.
2. Elk and pronghorn require larger structures than mule deer, especially wildlife overpasses. Large mammal underpasses are not suitable for elk and pronghorn (Clevenger & Huijser 2011, Huijser et al. 2022).

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