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Effectiveness of wildlife crossing structures on providing habitat connectivity for wild animals

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Effectiveness of wildlife crossing structures on providing habitat connectivity for wild animals

Abstract: Roads running through the middle of forests provide connectivity for humans, but are considered to be barriers to wildlife searching for food, shelter and mates. Wildlife crossing structures are now being designed and incorporated into numerous road constructions in many places in the world. However, the effectiveness of these wildlife crossing structures on providing wildlife connectivity remains uncertain. Studies from Banff National Park, Clark Fork River Valley, and Utah State clearly indicate factors affecting effectiveness of the crossing structures, which includes types of structures, dimensions, placement, noise levels, light level, vegetative cover, moisture, temperature, time, human disturbances, etc. All the factors make the evaluation of crossing structure effectiveness complex. While it is impractical to design a perfect structure that accommodate all species affected by roads, it may be possible to generate a comprehensive mitigation strategy integrating with all affecting factors and make the highways more permeable for wildlife in the future.

Key words: wildlife crossing structures, effectiveness, habitat connectivity, roads

I. Introduction

Animals move from place to place searching for food, shelter and mates as well as in response to the change of environmental conditions (WSDOT's work to improve wildlife habitat connectivity). Habitat connectivity, which refers to the extent to which the landscape facilitates animal movement, is important in stabilizing population dynamics, assisting community processes as well as maintaining biological diversity (MacDonald, 2003). However, roads pose great threats to the integrity of wild life habitat. Roads run through the middle of forests cutting animal's habitats into patches, which inevitably results in direct mortality and habitat fragmentation (Fahrig and Rytwinski, 2009).

In many places in the world, wildlife crossing structures are built to mitigate the negative impacts of roads on wildlife. These structures are effective in reducing wildlife-vehicle collisions, and have been beneficial to a number of species such as bears, cougars, lynx, deer and others. According to the monitoring data in Banff National Park, the wildlife crossing structures were used more than 185,000 times by animals during the time from 1996 to 2009 (Clevenger, Ford and Sawaya, 2009). Nonetheless, the effectiveness of these structures on providing habitat connectivity remains uncertain. Most studies did not go beyond assessing the use of wildlife crossing structures when evaluating the effectiveness of crossing structures

In order to build infrastructures that can best serve wildlife and maintain habitat connectivity, it is necessary to evaluate the existing crossing structures and find out the attributes that affect the

performance and effects on providing habitat connectivity. This essay evaluates and compares the performance of existing wildlife crossing structures in the world; tries to find out factors that most affecting the wildlife's willingness to use these structures and also gives new solutions to improve the wildlife crossing structures in the future.

II. Use of crossing structures by wild animals

Study in Banff National Park:

For over 25 years, Banff National Park in Canada has put lots of efforts on mitigating the impacts of the Trans-Canada Highway (TCH) on wildlife mortality and habitat fragmentation (Clevenger, Ford and Sawaya, 2009). The TCH is the major transportation route bisecting Banff and Yoho National Parks. By the year 2009, the TCH have been mitigated with a total of 24 wildlife crossing structures, including metal culvert, creek bridge, box culvert, open span and overpass (Highway Wilding research by numbers, 2012). These structures covering 83km of highway and animal use has been detected more than 185,000 times during the research period from 1997 to 2009 (Clevenger, Ford and Sawaya, 2009).

From 1997 to 2009, Banff Wildlife Crossing Project did a long-term data collection by monitoring Banff National Park wildlife crossing structures. The purpose of the project is to gain a better understanding of how species familiarize themselves with these mitigation structures and how they benefit from them. One of the studies focused on how wildlife respond to different types of crossing structures and to find out whether structure type affects the passage rate. The study focused on 8 species of large mammals (black bear, cougar, coyote, deer, elk, grizzly bear, moose and wolf) and recorded the frequency of using different types of crossing structures over the 12-year study period by a snow-tracking method.

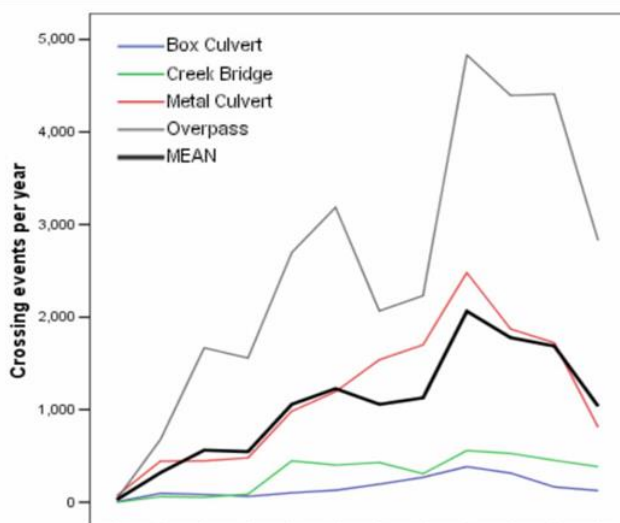


Figure 1 Number of deer crossing events by crossing structure design type from 1997 to 2008 (Clevenger, Ford and Sawaya, 2009).

Results of the study suggested that the species-specific responses to wildlife crossing design types are relatively constant over time and there are strong preferences (i.e., selection) by the eight species. As can be seen from Figure 1, deer in Banff National Park used overpasses the most, followed by metal culverts, creek bridges, and box culverts. The relative use of crossing design types by deer changed slightly during the entire 12-year period. Like deer, similar patterns are also found for elk, moose, grizzly bears, and wolves. All these five species use crossing structures consistently over time and have strong preferences. Grizzly bears, moose, and wolves

were found to use overpasses the most in contrast to other types of structures. Elk used metal culverts the most and also use overpasses as their second preference. Wolves were found to alternate between metal culverts and overpasses at the earlier period but also started to use the overpasses consistently the most in the latter part of the study. In contrast to species like deer, black bears use the crossing structures with a very different frequency pattern, as is shown by Figure 2. Black bears changed the use of crossing types significantly from year to year. They alternated between metal culverts, box culverts, overpasses and creek bridges during the entire study period. Cougars and coyotes also changed their use of crossing structures significantly as time passes. However, even though they use the different crossing structures alternatively, all of these three species have their least favourite crossing types. For example, black bears use creek bridge the least (Figure 2). Cougars and Coyotes also do not like overpasses and use them consistently the least over time.

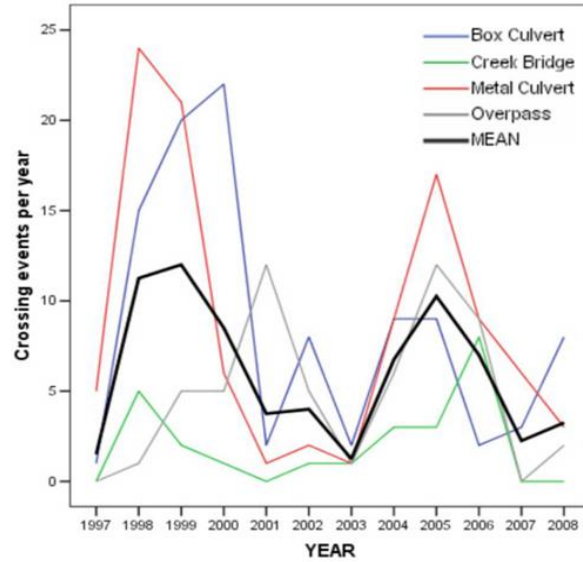


Figure 2 Number of black bear crossing events by crossing structure design type from 1997 to 2008 (Clevenger, Ford and Sawaya, 2009).

Apart from the constant crossing structure preferences by the eight species, this study also demonstrated an increasing usage trend by some of the species. According to the usage curve of different crossing types by the eight species, four of them increased the usage of crossing structures significantly as time passes (Clevenger, Ford and Sawaya, 2009). As shown by Figure 1, similar patterns were found for deer, moose, wolves and grizzly bears. It is assumed that wildlife might be more likely to use wildlife crossing structures as the passage of time. To test this assumption, another study of the Banff Wildlife Crossing Project compared the species-specific responses to newly and older installed structures, seeing how the eight species' responses differed as time passes. Results showed that animals tend to avoid using new structures while the older structures are more welcomed by animals. The long-period monitoring has proved that an adaptation period and learning curve exist for many large mammals (Clevenger, Ford and Sawaya, 2009). Therefore, time since construction can be a very important factor affecting animal use of crossing structures.

To conclude, studies in Banff National Park suggest that wildlife species, types of crossing structures and time since construction are three factors affecting the wildlife response to crossing structures. Different species has different preferences by wildlife crossing types. Overpasses might be the most preferred design types by most of the species within these eight species in Banff National Park. And also, animals need time to adapt the new crossing structures and tend to be more willing to use the structures as time passes.

Study in Clark Fork River Valley:

From October 2002 through July 2003, a ten-month period study was carried on in Clark Fork River Valley along Interstate 90 in western Montana, United States. Clark Fork River Valley possesses adequate habitats for wild animals including threatened and sensitive carnivorous species like Canada Lynx (*Lynx canadensis*), wolves (*Canis lupus*), wolverines (*Gulo gulo*), and possibly grizzly bears (*Ursus arctos*) (Servheen, Shoemaker and Lawrence, 2003). Interstate 90 (I-90) is a critical transportation corridor bisecting the Clark Fork River Valley between Alberton and St. Regis, Montana, where the study area is located.

Through heat and motion sensitive cameras, the study monitored seven underpasses and three culverts along the I-90 for ten months. The objectives of the study were to document the type and frequency of wildlife use and relate structures variables to the type and level of wildlife use. Based on the previous studies saying that a variety of factors affecting wildlife use of existing structures like distance to hiding cover, surrounding terrain, degree of human development, traffic volume, time of day and structural openness (Bruinderink and Hazebroek, 1996, Clevenger et al., 2002, Gleason and Jenks, 1993, Haas, 2001, Rodriguez et al., 1997), this study described each selected structure in terms of location, structure types, vegetation cover, and human activities etc. (Table 1) and then associated those variables to the wildlife crossing rates to see if there are any relationships between the two.

Table 1 Crossing structure descriptions and general description of the surrounding area for each (Servheen, Shoemaker and Lawrence, 2003)

Structure ID	Structure Type	Feature Spanned	LAND USE & GENERAL CHARACTERISTICS
81.5	Underpass	Clark Fork R.	Fishing access; light residential area w/ houses to the north & south, near wolf roadkill locations; deer trail parallel to I-90 on both sides & continues underneath bridge; high human activity directly underneath bridge on east side
69	Underpass	County road & railroad	Small housing development to the southwest; agriculture to the east; paved county road w/ low traffic; deer trail between pastures that parallels I-90 & leads underneath bridge
66.3	Underpass	Clark Fork R.	Steep terrain; canyons; kayaker launch on east side of bridge
58.5	Underpass	Clark Fork R.	Rest area to the west on both sides of I-90; USFS campground to the west; county road runs parallel to I-90 here
57.5	Underpass	Railroad	Low human activity; vegetative cover continuous below underpass; USFS campground to the east
53.7	Underpass	Clark Fork R.	Residential area to the west; vegetative cover continuous below road surface
39.8	Underpass	Clark Fork R. & county road	Agriculture; residences to the east; animal trails below underpass parallel to I-90; USFS campground to the southwest
57.5 C	Culvert	Intermittent stream	Low human activity; vegetative cover on both ends of culvert; USFS campground to the east
55.6 C	Culvert	Spring stream	Rapidly expanding residential development to the north; commercial activity to the north; landfill to the southeast; vegetative cover at both ends of culvert
42.4 C	Culvert	Intermittent stream	Light residential; residence directly north of culvert; railroad to the southwest

Table 2 Variables and crossing rates associated with each structure (Servheen, Shoemaker and Lawrence, 2003)

STRUCTURE ID	Ungulate Use Rating	Sm. Carn. Use Rating	Med. Carn. Use Rating	Lge. Carn. Use Rating	Total Wildlife Use	Human Associated Use Rating	Structural Openness Rating	In Linkage Zone?	Avg. LZP Score (500m)	Std.Dev. of Elev. (500m)	Distance to Cover (m)
81.5	0.4729	0.003	0.0025	0	0.48306	0.020232676	811.6308	NO	4.4667	21.16	8.15
69	0.2003	0.011	0	0	0.21088	0.003514691	27.7500	NO	3.8053	10.21	22.65
66.3	0.1118	0.012	0.0029	0.0029	0.13535	0.294230147	1058.77	NO	3.6644	28.77	13.25
58.5	0.8934	0	0	0	0.89344	0.004702342	659.4167	YES	4.5236	57.88	19.35
57.5	0.4574	0.01	0	0	0.48013	0.00648824	169.5417	YES	3.1310	15.6	6.00
53.7	0.431	0.017	0	0	0.45758	0.020885547	642.6615	YES	3.4740	15.04	3.00
39.8	0.6136	0.004	0.0143	0	0.61932	0.020885547	457.2733	NO	3.8262	33.89	18.10
Culvert											
57.5 C	0	0	0	0	0.0872	0.0116	0.2638	YES	3.2943	20.07	9.50
55.6 C	0	0.041	0	0	0.0407	0	0.1255	NO	4.3954	21.55	0.25
42.4 C	0	0.226	0.0982	0	0.2259	0.0393	0.7576	NO	4.3714	41.55	7.40

However, results of the study did not show significant relationships between the wildlife use of the crossing structures and structure variables. Table 2 shows the variables and crossing types associated with each structure. The study analysed these data by SPSS (a statistical analysis tool) to explore correlations between structure variables and use ratings, but no significant relationships were found.

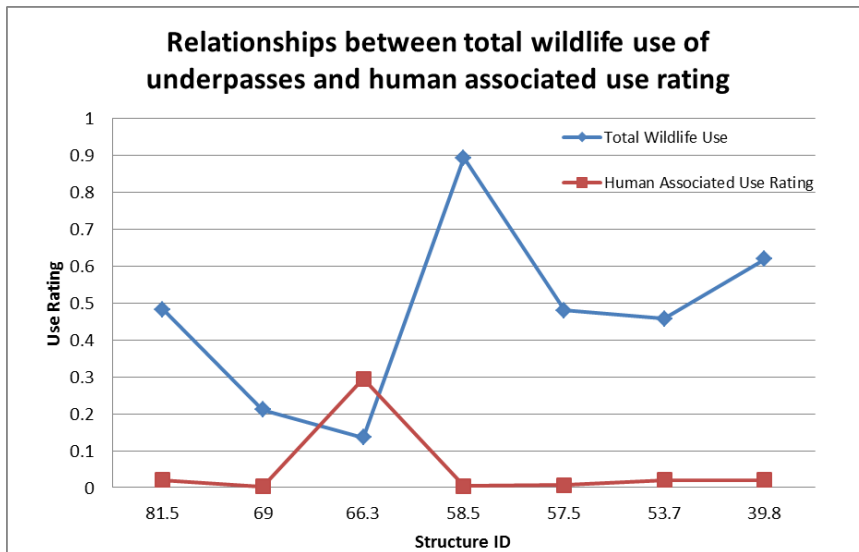


Figure 3 Relationships between total wildlife use of underpasses and human associated use rating.

Even so, the result still indicated some regular patterns on wildlife using of these crossing structures. First of all, in terms of human activities on affecting wildlife use of crossing structures, human associated use (including human use and domestic dog use) might affect the wildlife use of underpasses. Figure 3 on the left is generated from the data in Table 2, which may illustrate a reverse relationship between human associated use and total

wildlife use. When human associated use rating is high, total wildlife use is correspondingly low. However, this pattern may be the compound functions of other variables. Therefore, further research and evidence is needed to confirm this conclusion.

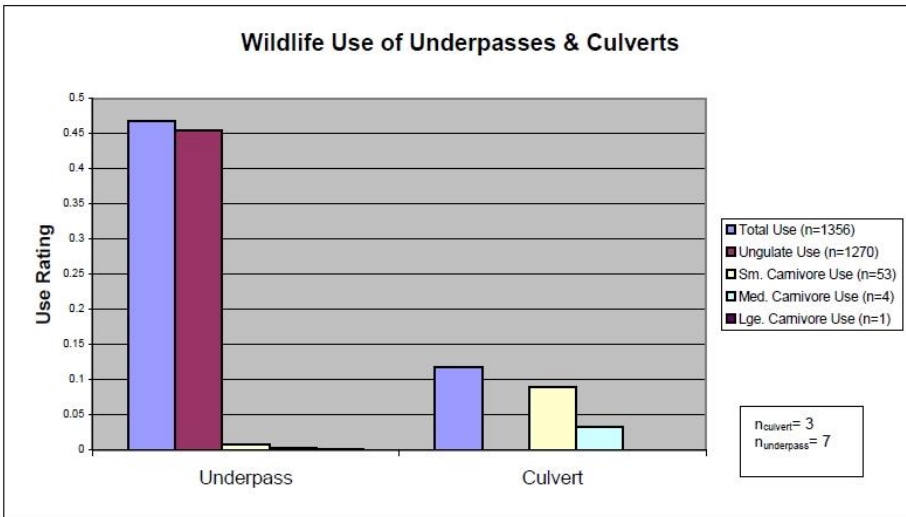


Figure 4 The type and frequency of wildlife use compared between culverts and underpasses (Use Rating = $(\sum \text{of photographs}) / (\sum \text{of functional camera days})$) (Servheen, Shoemaker and Lawrence, 2003).

Secondly, the overall wildlife use was more frequent at underpasses than in culverts. Figure 4 compares the structure-using frequency by different wildlife groups (ungulate and small, medium, and large carnivore) between culverts and underpasses. Use rating of underpasses was four to five times of the use rating of culverts.

Ungulates were the major users of underpasses while carnivore usage at underpasses was only a small portion. Small and medium carnivores like skunks, raccoons and house cats were frequent users of culverts. Large mammals did not use culverts very often even if the culverts were physically large enough for them to get through. Evidence was provided that no ungulates or large carnivores were detected using culverts with diameters ranging from 2 - 4.6m, which are much bigger than their body sizes. Researchers believed that this is mainly because the lack of suitable substrate in culverts and the low structural openness ratios. Underpasses were more appealing to big mammals when compared with culverts because underpasses are normally brighter with more vegetation, better substrate and lower moisture conditions; while culverts are usually cool and wet and may favor the use by small and medium carnivores. In accordance with the results of many past studies, this study may suggest that ungulates and most large mammals prefer large, open structures with high structural openness ratios.

To conclude, from this study, we can tell that compared to culverts, underpasses are more appealing to large mammals like deer or other large carnivores. This may be due to the structural differences that underpasses offer more natural lighting, vegetation, substrate, moisture conditions which are favoured by most large mammals, whereas culverts provide cool wet conditions for small carnivores. Moreover, Human activities might be a big factor influencing wildlife's using of crossing structures. Wildlife tends to be less likely to use the wildlife crossing structures when disturbed by humans but more evidences are still needed to prove this.

Study in Utah State:

From 2008 to 2011, a three-year project was done by the Utah Department of Transportation (UDOT) along Utah highways in United States. The research evaluated wildlife crossing structures in Utah State to help UDOT and the Utah Division of Wildlife Resources assess crossing effectiveness (Cramer, 2012).

The project placed 35 motion-sensitive cameras covering the state at 14 existing and future wildlife crossing sites, and 21 existing bridges and culverts (Cramer, 2012). Pre-construction and post-construction data of animal activities on site were collected and analysed. The objectives of the study were to assess how different culvert and bridge designs functions at passing wildlife species like mule deer and elk, and help to develop the most effective wildlife crossing structures for Utah (Cramer, 2012).

During the entire study period, the cameras detected 23,957 mule deer usage of the wildlife crossings, and 1,093 uses of the existing culverts and bridges, as well as 45 elk passages and 127 moose passages (Cramer, 2012).

The study in several sites compared the pre- and post-construction behavior of wildlife. Collected data from several sites showed that wildlife activities were altered by the present of crossing structures. For example, according to results from a bridge site on US Highway 6, mule deer activity was reduced at the site during the construction period (Cramer, 2012). An average of 2.2 mule deer per day was recorded in the area before the construction and this number was reduced to 0.8 per day during the construction. Mule deer usage of the construction remained at a low level until late January when mule deer started to feed on vegetation within the monitoring area. Wildlife exclusion fencing was also placed when the post-construction monitoring period began. In the first year of monitoring post construction, a total of 2.2 deer per day were detected using the crossing. This total increased up to 2.5 deer per day in the second year, making it one of the most frequently used wildlife crossing structures for mule deer in Utah (Cramer, 2012).

Moreover, observation on the same site on US Highway 6 did not detect other wildlife crossing excepting mule deer (Cramer, 2012). The study inferred that this may because the crossing is open and is lacked of vegetation. Vegetation is necessary to some wildlife species like elk that need hiding cover. The elk which was reluctant to use the structure was expected to use it at a later time when vegetation is regrown. And also, logs, stumps, and boulders placed in lines going into and through the crossing could increase use of the crossing structures by small and medium-sized mammals (Cramer, 2012).

Another important indication from the study is that wildlife might prefer shorter culverts than longer culverts. According to the comparison between two box culverts under Interstate 70 (I-70) (one is 202 feet (61 m) long and another is 98 feet (30 m) long) the shorter culvert had a higher mule deer cross rate which was 76% while the longer culvert only had a 63% crossing rate. Data from Camp creek culvert under Interstate 15 also showed such a preference by mule deer. The table below shows dimensions of the two experimental culverts and the repellency rate of mule deer crossing (Cramer, 2012).

Table 3 Mule deer data from two culverts under I-15 (Cramer, 2012)

	Height	Width	Length	Repellency Rate
Camp Creek South Culvert	9.8 feet	11.8 feet	280	100%
Camp Creek North Culvert	9 feet	11.5 feet	175	66.7%

From the table above, we can see the dimension of the two culverts under I-15 are similar except for the length. The South Culvert (Figure 5), which is the longest culvert of all the studying sites, 32 deer were detected approaching the site but none of them passed the culvert. The north culver, which is much shorter than the south culvert, has lower repellency rate. It may indicate that shorter provide a better connectivity for mule deer.



Figure 5 I-15 Camp Creek South culvert. No deer were caught on camera using this culvert (Cramer, 2012).

To conclude, this study in Utah State supported the following statements: Factors affecting wildlife usage of crossing structures including vegetation cover, dimensions of crossing structures, time, and fencing; crossing structures might be effective in providing wildlife mobility due to the frequent photographed crossing by mule deer after the construction of crossing structures. However, more research needs to be done in order to provide stronger evidence to prove the effectiveness of crossings.

III. Factors affecting the effectiveness of wildlife use.

Internal factors (structural variables)

According the previous studies and research, various factors will affect wildlife use of crossing structures, which includes types of structures (underpass or overpass), dimensions (width and length), placement relative to natural wildlife corridors (proximity), noise levels, light level, vegetative cover, moisture, temperature, etc. Whether animals use the crossing structures or not is a complex process and ultimately depend upon the ecological and behavioral demands of the species (Evaluation of Wildlife

Crossing Structures: Their Use and Effectiveness, 2001). Although it is impractical to design one perfect crossing structure that accommodates all wild animal species (Jackson and Griffin, 2000), attention need to be paid to structural variables in order to make the crossing structures permeable to a broad range of wild animals.

1. Structural type

Structure types can be a deciding factor in the usage of crossing structures by some animals. According to the study in Banff National Park, different structures are appealing to different species of animals. Overpasses might be the most preferred design types by big mammals like deer, moose, grizzly bear, and wolves. Large carnivores will also use underpasses as their favourite when no overpasses are available on site. Culverts are less appealing to large mammals but makes small animals like small mammals, reptile, and amphibians feel comfortable to use (Evink, 2002).

2. Dimension

Dimension is an important factor affecting wildlife use of crossing structures. According to the study in Utah State, shorter culverts are more welcomed than long culverts by mule deer (Cramer, 2012). In addition, there is also other studies pointed out that the larger the structure, the better it will facilitate the use for a wide range of species (De Santo and Smith, 1993, Reed, 1981, and Jackson and Curtice, 1998). Bigger structures provide a larger space and make the wildlife feel more willing to use them.

3. Vegetation cover

Vegetation near the opening of the wildlife crossing structures plays an important role on affecting wildlife use. According to studies (Rodriguez et al., 1996, Hunt et al., 1992, Clevenger et al. 2001a), whatever the structure type is, vegetation near the opening function as security cover and can make wild animals feel more comfortable to use the structure. What is more, vegetation can guide animals approach to the openings therefore prompt them to use the crossing structure. As indicated by the study in Utah states, lack of vegetation at the bridge site on US Highway 6 make elk reluctant to use the structure; and it is inferred that elk may use the bridge at a later time when vegetation is regrown (Cramer, 2012).

4. Light

Light can deter some animals' willingness to use the crossing structure (Evaluation of Wildlife Crossing Structures: Their Use and Effectiveness, 2001). As indicated by the study in Clark Fork Valley, underpasses are more favoured by larger animals compared to culverts as light being one of the important reasons. Underpasses offer more natural lighting than culverts, which is welcomed by most large mammals. In contrast, culverts are darker with less light, which is favoured by small mammals,

amphibians or reptiles. Therefore, when building a crossing structure, consider the animal species inhabit the area. If they prefer natural light, making the structure bigger will allow enough natural lighting come through and would make artificial-lighting-sensitive species like cougar feel more comfortable to use the structure (Beier, 1995).

5. Natural substrate

Studies show that the internal features of crossing structures such as logs, stumps, and boulders will help to make the crossings more appealing for some wildlife species (Norman et al., 1998 and Mansergh and Scotts, 1989). For example, underpasses with stumps inside appear to be welcomed by small mammals; over-sized culverts with wet terrain are turned out to be appealing to reptiles and amphibians (Jackson and Griffin, 2000).

6. Placement of the crossing structure (proximity to natural wildlife corridors)

Proper placement of the crossing structure is one of the most important features in determining success (Evaluation of Wildlife Crossing Structures: Their Use and Effectiveness, 2001). Structures that are put in the right place and close to the natural wildlife corridors can work effectively. Many studies show that crossing structures near traditional migration routes are more effective than those that are not (Hartmann, 2002). Poor placement of crossing structure might lead to failure on providing habitat connectivity (Alexander and Waters, 1999). For example, according to a study in Banff National Park, the Trans-Canada Highway is still a barrier for wild animals' movement despite the extensive efforts to facilitate wildlife passage. Alexander and Waters (1999) proposed that this might be because the crossing structures are too widely spaced. Therefore, crossing structures that are proximate to natural wildlife corridors with shorter distance between one another might best facilitate animal usage.

External factors

As mentioned before, whether animals use the crossing structures or not is a complex process and cannot be simply addressed by looking at the structural variables only. There are also other factors affecting the use of crossing structures, which are what we call "external factors". Any factors apart from structure itself are considered as external factors as long as they can affect the behavior of the wildlife species.

1. Human disturbance

Both studies in Banff National Park and Clark Fork River Valley have indicated human disturbance on wildlife using of crossing structures. Human usage of wildlife crossing structures and human activities near the crossing structures can reduce animals use. Human usage of crossing structures in Clark River Valley correlated negatively with wildlife use. Although the result did not exclude the impacts of other factors, this regular pattern still indicate that human usage can somehow affect wildlife usage. Besides, evidences form Banff National Park showed that underpasses near recreational areas were not used by

wildlife as frequently as those are not (Clevenger and Waltho, 2000). Therefore, when building a wildlife crossing structure, avoiding human activities areas and limiting human usage of the structure would help.

2. Time (Time since construction)

Time since construction can be an important factor affecting the wildlife using of crossing structure. As shown by study in Banff National Park, there is an increase usage trend by some species as time passes. Many wildlife species need time to adapt to use the crossing structures (Clevenger, Ford and Sawaya, 2009). What is more, not only time can change animals' response to crossing structures, it changes everything. "The planning process of crossing structures are permanently embedded in the landscape, but the ecological process going on around are dynamic." As stated by Clevenger (2003), to maintain the effectiveness of crossing structures over long time, we have to consider the dynamics of the ecological process as time passes.

2. Fencing

Fences help guide animals to the openings of crossing structures and are effective in reducing road mortality of wild animals. Fencing of highways is necessary for many species. For example, ungulates generally avoid using underpasses and will seek to cross the road directly without fencing (Hartmann, 2002). In Banff National Park, fences are used to deter animals from breaking into the highway (Jackson and Griffin, 2000); In Utah State, the placing of wildlife exclusion fencing greatly helped increase wildlife usage of crossing structures. However, fencing might not always be effective. Some animals are good at avoiding fences by climbing over (i.e., black bears) or digging under (i.e., coyotes) (Hartmann, 2002). In order to facilitate animal usage of crossing structures and reduce road kill, standard fencing should be high enough and be installed properly and maintained regularly.

3. Inter-species impacts

Impacts between species can also affect wildlife use of crossing structures. For example, the use by predators will limit the use by prey species. The presence of wolves will reduce deer passage of the crossing structures (Clevenger and Waltho, 2000).

IV. A comprehensive mitigation strategy

Form previous sections, it is clear that wildlife use of crossing structures is affected by many factors. The evaluation of effectiveness of crossing structures is thus a complex process. Although crossing structures

are now being designed and incorporated into numerous road constructions in many places in the world, little studies can approve the true effectiveness (Evaluation of Wildlife Crossing Structures: Their Use and Effectiveness, 2001). Most studies did not go beyond assessing the use of wildlife crossing structures (i.e. Clevenger et al., 2009; Servheen et al., 2003; Cramer, 2012). For example, from the study in Banff National park, more than 185,000 animal uses of crossing structures were detected during the study period from 1996 to 2009 (Clevenger, Ford and Sawaya, 2009). However, this cannot prove that those crossing structures are effective on mitigating habitat fragmentation by roadways. "Estimates of the extent to which a structure is used does not directly answer the question of what extent the impacts of the road and traffic on wildlife have been mitigated" (Edgar et al, 2012) Moreover, very few studies have been able to include the comparisons between before-after construction differences of wildlife activity in a long duration and large-scale landscape (Clevenger and Waltho, 2000). Although the third case study by Cramer (2012) implemented with pre- and post-construction monitoring, the limited time and study area failed in providing sufficient data to prove the effectiveness of crossing structures.

Therefore, in order to get strong evidence to evaluate the effectiveness, future studies should pay attention to the following aspects: First of all, before evaluating effectiveness, a list of criteria or standard to evaluate the effectiveness should be clear. Wildlife use of crossing structures cannot fully represent its effectiveness. Other indicators like movement patterns, population densities, genetic changes, and life history requirements should also be included in the consideration (Hardy, Clevenger, Huijser and Neale, 2003). Secondly, conducting monitoring over a long duration time and over a broader landscape is very important. Collecting data from a robust manner usually failed to draw on reliable conclusions (Jackson and Griffin, 2000). Monitoring periods should be longer than the time the wildlife needed to adapt to the crossings. The "habituation period" is depended on the species as they learn and adjust their behavior to the wildlife structures therefore can be species-specific (Clevenger, 2003). Thirdly, future studies have to focus on the comparison between pre and post construction. To evaluate the true effectiveness, we need to know how many animal crossings would have happened without the given structure (Hardy, Clevenger, Huijser and Neale, 2003).

Although more studies are needed to determine effectiveness, current studies from Canada, the United States and many other places in the world have suggested the necessity to generate a comprehensive mitigation strategy to make the highways more permeable for wildlife (Evaluation of Wildlife Crossing Structures: Their Use and Effectiveness, 2001). This mitigations strategy requires biologists and engineers to work collaboratively and consider the following components:

- 1) Do not build roads across wildlife habitat if we do not have to. There will never be one perfect structure to suit all species' needs. For already existing roads, wildlife crossings should be added with careful considerations (Lavendel, 2000).
- 2) Consider a variety of species. Do not focus on only one or two target species. All species are components of ecological systems and are functioning interactively rather than isolated (Hartmann, 2002).
- 3) Know the species in the area. Crossing structures cannot be built without understanding the ecological needs of the animals. Their distribution, abundance, and ecological and behavioral

demands are of great importance (Evaluation of Wildlife Crossing Structures: Their Use and Effectiveness, 2001).

- 4) Place the structures near known natural wildlife corridors and away from human disturbance.
- 5) Build crossing structures short in length, and wider in width.
- 6) Guarantee enough natural lighting while avoid high noise levels;
- 7) Fence the road to reduce wildlife intrusions and guide them to the crossing structures.
- 8) Consider both internal and external factors which affect wildlife usage.

V. Conclusion

Effectiveness of wildlife crossing structures can be affected by a variety of factors, which includes both internal and external factors. Internal factors refer to structure variables including types of structures (underpass or overpass), dimension (width and length), vegetation cover, light level, natural substrate of structures, placement, noise levels, moisture, and temperature. External factors refer to factors affecting effectiveness other than the structure itself, which including human activities, time, fencing or not, adjacent landscape features, and inter-species impacts.

Evaluation of the effectiveness of wildlife crossing structures is a complex process, for the time being, no study can give definitive conclusions on the true effectiveness on providing habitat connectivity. The failure suggests that future studies on assessing wildlife crossing structures efficiency should focus on long-time, pre- and post-construction monitoring so that to guarantee substantial data on evaluating the effectiveness.

Construction of future constructions for wildlife crossing structures should be improved with consideration of all the factors mentioned above. A comprehensive mitigation strategy including the eight important components in the last section is needed to make roads permeable for as many species as possible

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