2013

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Recommended Citation

Connolly-Newman, Hayley R., "EFFECT OF COVER ON SMALL MAMMAL ABUNDANCE AND MOVEMENT THROUGH WILDLIFE UNDERPASSES" (2013). *Graduate Student Theses, Dissertations, & Professional Papers*. 350.
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EFFECT OF COVER ON SMALL MAMMAL ABUNDANCE AND MOVEMENT THROUGH WILDLIFE UNDERPASSES.

By

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B.A. University of California Santa Cruz, Santa Cruz, California, 2008

Thesis

presented in partial fulfillment of the requirements

for the degree of

Master of Science

in Environmental Studies

The University of Montana

Missoula, MT

May 2013

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Connolly-Newman, Hayley, M.S., Spring 2013 Environmental Studies

EFFECT OF COVER ON SMALL MAMMAL ABUNDANCE AND MOVEMENT THROUGH WILDLIFE UNDERPASSES.

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Crossing structures enable wildlife to safely cross highways by physically separating wildlife and vehicles. Most wildlife underpasses and overpasses are designed to accommodate a wide variety of species. Their suitability for individual species, however, varies by location (surrounding habitat), structure type (e.g. underpass or overpass), and dimensions (height, width, length). For some taxa, the habitat immediately adjacent to and inside an underpass or on top of an overpass is critical. For instance, small mammals, reptiles, amphibians and many invertebrates may avoid open areas because they require cover (e.g., live vegetation, tree stumps, branches, or rocks) to reduce predation risk and because of the microhabitat it provides (e.g., temperature, moisture). I investigated the effect of cover on the abundance and movements of small mammals in ten large mammal underpasses (approximately 7 m wide, 4 m high) along U.S. Hwy 93 North on the Flathead Indian Reservation, Montana. Track tubes recorded abundance of small mammals in and around 10 structures (5 control/ 5 treatment) in 2011 and 2012. I placed cover (dead tree limbs) inside half (five) of the underpasses in winter 2012 ("treatment"), while the remaining five underpasses served as control with no cover added. Capture-mark-recapture using live traps was conducted in the fall of 2012 to record abundance and movement of small mammals in and around the underpasses. There was no statistically significant effect of cover on small mammal abundance detected by track tubes or live traps. . There was a statistically significant effect of cover on movement between the right of way and crossing structure for small mammals detected by live traps. By placing cover inside wildlife underpasses, wildlife managers can increase crossing structure use by small mammals at minimal cost.

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INTRODUCTION

There are >6 million km of public roads in the U.S., 22% of the U.S. land surface may be impacted by road infrastructure (Forman 2000, Riiters and Wickham 2003), and 73% is within 810 m of a road (Riiters and Wickham 2003). Habitat fragmentation and the loss of large landscape connectivity due to roads can have detrimental effects on many species of animals, including loss of wildlife habitat, road mortality, create barrier effects, decrease habitat quality, and introduce non-native ecological processes in the road verges (Yanes et al. 1995, Gerlach and Musolf 2000, Huijser and Bergers 2000, Trombulak and Frissell 2000, Ng 2003, Aresco 2005, Jaeger et al. 2005).

The barrier effect can also affect small mammal populations. Barriers created by roads create genetically isolated populations, and thus create smaller, less viable populations (Gerlach and Musolf 2000, Rico et al. 2007, Holderegger and Di Giulio 2010). By reducing gene flow the genetic diversity of a population suffers (Frankham 1995, Balkenhol and Waits 2002, Fahrig 2002). Lack of genetic diversity increases risk of extinction, especially if populations are also small and isolated, and although there is no immediate risk of any small mammal species extirpation in the study area, the presence of roads may block attempts to recolonize empty habitat patches (Mader 1984, Forman and Alexander 1998, Keller and Waller 2002, Balkenhol and Waits 2002).

Negative road-related impacts on wildlife, such as the barrier effect, are often mitigated through the construction of wildlife crossing structures (Foresman 2004). Crossing structures enable wildlife to cross roads without exposing themselves to traffic by providing a safe crossing opportunity under or over the roadway. Daily movements, seasonal migration, and dispersal through crossing structures can help maintain viable populations with adequate genetic diversity (Adams and Geis 1983, Forman 2000, van der Ree et al. 2007).

For small mammals, the road surface is the main deterrent when faced with crossing a road, rather than other common factors associated with roads such as traffic noise or volume (Swihart and Slade 1984, Goosem 2002, Ford and Fahrig 2008, McGregor et al. 2008). In addition, many small mammal species move greater distances along the road than the actual road width, exhibiting the physical ability to travel across the road but not the willingness (Richardson 1997). Therefore, crossing structures are a feasible alternative for connecting small mammal habitat when fragmented by roads (Clevenger and Waltho 2000a, Foresman 2004, McDonald and St. Clair 2004).

Even if roadways have underpasses, the crossing structures may still be inhospitable to small mammals if they lack sufficient cover (Foresman 2004). Small mammals generally seek cover to avoid detection or capture by predators (Diffendorfer et al. 1995, McDonald and St. Clair 2004). Corridors with suitable habitat have been successful in linking fragmented habitats of small mammals (Andreassen et al. 1996, Bolger et al. 2001, Coffman et al. 2001). Vegetative cover including grasses, forbs, trees, and shrubs, located near the entrance to crossing structures are positive attributes for multi-species use of wildlife underpasses (Hunt et al. 1987, Clevenger and Waltho 2000a, Bolger et al. 2001, Foresman 2004, McDonald and St. Clair 2004). However, little research has focused on whether cover provided by coarse woody debris inside underpasses affects use and movement of small mammals through underpasses.

To improve the long-term effectiveness and success of a project, it is important to recognize the needs of multiple species, as well as the effort and cost involved with structure construction (Clevenger and Waltho 2000b). To date, there has been no research focused on modifying crossing structures with course woody debris that were originally made for larger animals and the subsequent effects on small mammals use of those structures. My objective was to test whether underpasses with course woody debris placed inside and adjacent to the entrances had higher abundance and rates of movement of small mammals than underpasses without woody debris.

I focused on three general questions: 1) what is the effect of course woody debris on small mammals in the crossing structure, in the ROW, and beyond ROW, 2) what is the abundance of small mammals inside the crossing structure, in the ROW, and beyond the ROW and 3) are small mammals using the crossing structures and, if so, do animals move between the ROW and crossing structure zones? Another outcome of the research was a power analysis of needed sample size to test these sorts of questions for small mammals in the future.

METHODS

Study area

This study was conducted in northwestern Montana on US Hwy 93 between Evaro and Polson on the Flathead Indian Reservation. In 2012, US Hwy 93 had an average traffic volume of 7,047 vehicles per day (MDT 2012). Most of the road section in the study area was upgraded between 2004 and 2009 to make the roadway safer for the travelling public. The reconstruction spanned 90 km of road, and included 13.4 km of wildlife fencing, 40 wildlife underpasses and 1 wildlife overpass. Terrain surrounding US Hwy 93 consisted of rolling hills and elevation ranged from 896 m to 974 m.

Predominate land use in the valley was cattle ranching and farming of hays and grains, but there were also patches of natural or semi-natural habitat.

Design and research of the crossing structures on U.S. Interstate Highway 93 (US Hwy 93) located between Evaro and Polson, Montana has focused mainly on large mammals (e.g. mule deer (*Odocoileus hemionus*), whitetail deer (*Odocoileus virginianus*) and Grizzly bear (*Ursus arctor horribilis*)). Other large mammals found in the area are American black bear (*Ursus Americanus*), cougar (*Puma concolor*), and elk (*Cervus canadensis*). Mid-sized mammals include raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), bobcat (*Lynx rufus*), northern river otter (*Lontra canadensis*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), domestic dog (*Canis lupus familiaris*), and domestic cat (*Felis catus)*. Small mammals include weasel (*Mustela* ssp.), shrew (*Sorex* spp.) and several members of the *Sqiuridae* family. Many *Muridae* species are common in the area, some of which include vole (*Microtus* spp.), deer mouse (*Peromyscus maniculatus*), and bushy tailed wood rat (*Neotoma cinerea*).

Experimental design

Crossing structures were selected for entry size (approximately 7-m wide, 4-m tall), unmanaged vegetation outside of the right of way (ROW), and a drainage feature (ditch or stream) in the middle of the structure. Using these selection criteria, ten similar-sized underpasses were selected for the study from the original 40 structures. Crossing structures were located in different habitat types, including mixed forest, grass and marsh habitat, and mixed grassland and shrub habitat, in order to capture variation across the landscape (table 1). Dominant species in the mixed forests included ponderosa pine

(*Pinus ponderosa*), Douglas fir (*Psuedotsuga menziesii*), black cottonwood (*Populus trichocarpa*) and a mixture of native and exotic grasses and forbes. Grass and marsh habitat consisted of willows (*Salix* spp.), quaking aspen (*Populus tremuloides*), cattails (*Typha* spp.), and a mixture of native and exotic grasses and sedges. Mixed grassland and shrub habitat consisted of Rocky Mountain juniper (*Juniperus scopulorum*), invasive knapweed (*Centaurea diffusa*) and a variety of grasses and forbs. Structures were also selected for the presence of a drainage feature in the middle of the structure. Most of these drainages were small ephemeral streams and only ran for a portion of the year.

The ground surface of the ten underpasses was generally bare soil or rocks, with no vegetative or woody cover or debris. Some initial re-vegetation efforts in the ROW were completed immediately after construction, but no additional maintenance has since occurred in the ROW. Mowing and spraying for invasive weeds has taken place in the area, but not contiguous to any of the study sites and did not directly influence small mammal movement within the study area.

Table 1: Crossing structure characteristics. The 10 selected crossing structures were within 45 km of each other on CSKT land. In 5 randomly chosen structures, out of these 10 cover was placed in January 2012. All but 2 crossing structures had a drainage feature running down the middle, most with water present for a portion of the year. Dominant vegetation described the natural habitat beyond the ROW.

Crossing Name	**Cover placed January 2012**	**Stream Feature**	**Year Structure construction completed**	**Dominant Surrounding Vegetation**	**UTM Easting**	**UTM Northing**
North Evaro	No	Yes	2009	Mixed forest	11 722099E	5215866N
Finely Creek #3	Yes	Yes	2009	Mixed forest, Grass and marsh habitat	11 723941E	5217756N
Finely Creek #4	No	Yes	2009	Mixed forest	11 724294E	5218074N
Ravalli Hill #1	No	Yes	2006	Mixed grassland and mixed forest	11 713357E	5240749N
Ravalli Hill #2	Yes	No	2006	Mixed grassland	11 713640E	5241084N
Pistol Creek #1	Yes	Yes	2006	Mixed grassland	11 716563E	5242682N
Pistol Creek #2	No	No	2006	Mixed grassland	11 716810E	5242871N
Sabine Creek	Yes	Yes	2006	Mixed grassland, Grass and marsh habitat	11 717997E	5243962N
Post Creek #2	No	Yes	2006	Mixed grassland, Grass and marsh habitat	11 719310E	5247178N
Post Creek #3	Yes	Yes	2006	Mixed grassland, Grass and marsh habitat	11 719293E	5247669N

Crossing structures were monitored for small mammals using two detection methods: track plates and capture-mark-recapture. Track plates placed in tubes were used to record small mammal abundance in each of the zones. Capture-mark-recapture techniques using Sherman live traps were used to record animals movement between zones.

The study area at each structure was divided into three zones (figure 1): (1) underpass structure, (2) ROW, and (3) beyond the ROW. Total sample stations per structure equaled 30.

1) Crossing structure: Three sampling stations were placed along the edge of each wall of the crossing structure, totaling six sampling stations inside each structure. Station layout was set from the middle of the crossing structure. Stations were spaced 3m from each other and placed within 1m of the layout design, to allow for the selection of the most suitable site for each sampling station.

2) ROW: Six stations were placed at least 10 m from the outermost crossing structure sampling station, divided into two groups of three. This pattern was on both sides of the crossing structure, totaling 12 sampling stations in the ROW.

3) Beyond ROW: The same design used in the ROW was used outside the ROW. The distance used between sampling stations in the crossing structure and ROW was used to determine where the beyond ROW stations were placed.

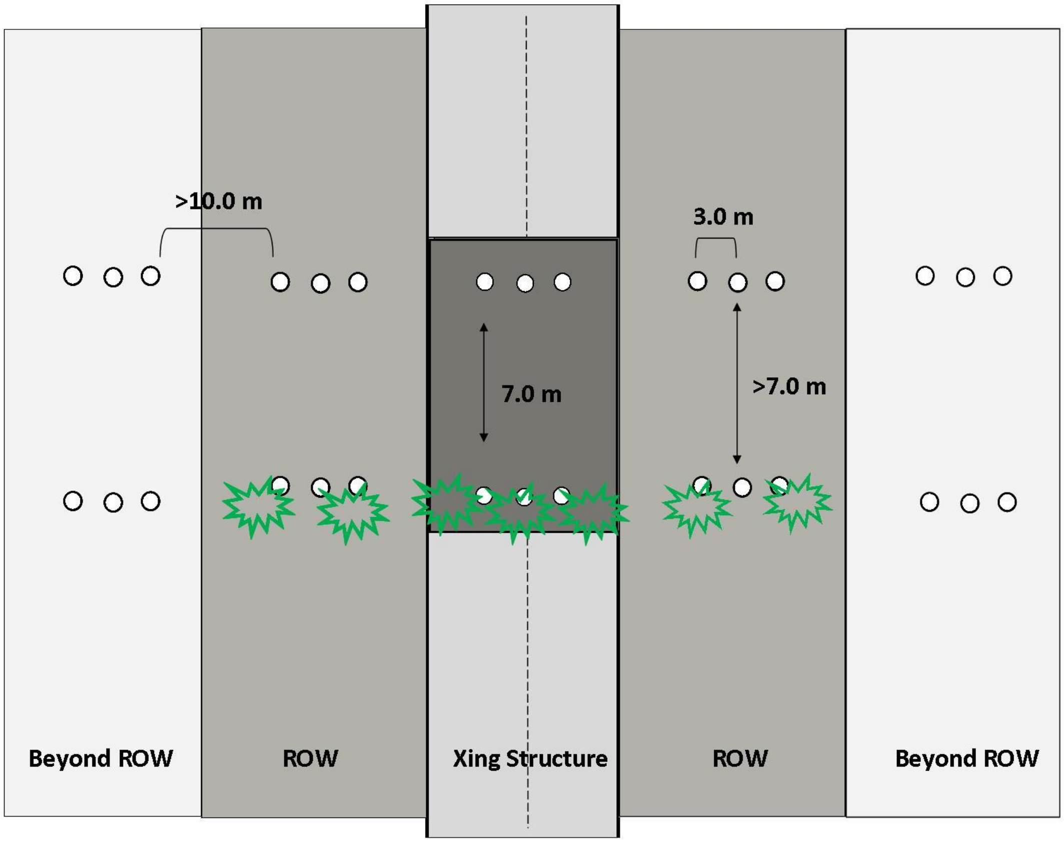

Figure 1: General placement and layout of the sample stations (track tubes traps and live traps). Each white dot represents a track tube or a live trap. The sample stations were arranged in groups of 3 (spaced 3 m apart) with two groups in each zone : crossing structure (Xing Structure), right of way (ROW), beyond right of way (beyond ROW). The distance between the groups in different zones was at least 10 m. The distance between groups within the same zone was 7-20 m. Cover was on one side of the structure, which is represented by green stars.

In order to ensure that the traps did not act as stepping stones for small mammals and alter natural behavior and movement in the area (Andreassen et al. 1996, Wiewel et al. 2007, Yletyinen and Norrdahl 2007), traps were at least 10 m apart between zones. The exact distance between traps varied from 10-20 m, due to varying structure length.

The coarse woody debris was a mixture of blue spruce *(Picea pungens)*, black cottonwood, ponderosa pine and Douglas fir. To minimize affecting movement of large animals using the crossing structure, course woody debris was placed on only one side of the crossing structure. Cover extended continuously through the crossing structure and was placed in piles (approximately 1 m^2 in size at 3m intervals) in the ROW zone.

Track Tubes

In August and September 2011 (before course woody debris was placed in five of the 10 structures) and 2012 (after course woody debris was placed in five of the 10 structures), I sampled small mammal abundance using track tubes.   For five consecutive trapping nights per structure, small mammals were detected by tracking plates in each tube. Tubes were constructed out of polyvinyl chloride (PVC) pipe, 30.0 cm in length (Mabee 1998) and 10 cm in diameter. Tracking plates consisted of felt ink pad squares (7 cm x 4.5 cm) placed on the outer ends of the tube, with a sheet of clear contact paper (30 cm x 7 cm) in the center of the tube (Wiewel et al. 2007). The felt squares were soaked in a toner and mineral oil mixture (1:2 ratio), allowing tracks to be left on the contact paper (Glennon et al. 2002, Nams and Gillis 2003). Tracking plates were checked daily and replaced with a new plate if used. Unbaited tracking tubes were used due to the presence of larger and often curious and destructive carnivores (e.g., black bear).

During track plate sampling, there was no way of recording whether the tracks were made by one individual animal or multiple individuals. For this reason track data was recorded for every individual tube as presence/absence (1/0) for each of the 5 sampling nights. Individual species identification from the track tubes was impossible, but it was possible to distinguish between larger animals such as bushy tailed woodrats, chipmunks, and weasels versus smaller species such as mice, voles, and shrews.

Live Trapping

In September and October 2012 (after placing course woody debris in five of the 10 crossing structures), I live trapped small mammals for 5 consecutive nights per structure. Tracking tubes were removed before live trapping was initiated. Sherman live traps were set using the same sampling configuration used for the tracking tubes (figure 1), with 30 total traps per structure. Traps were baited with dry oatmeal and bedding of 6-8 cotton balls. Additional insulation consisted of straw covering the outside of the traps and cedar shingles placed on the top of the trap to protect the animals from precipitation. To allow animals to habituate to the presence of the traps, traps were propped open and baited for one night prior to trapping (Renwick and Lambin 2011). Traps were set in the evening and checked at first light the following morning for five consecutive nights. Traps were closed during the day in order to prevent daytime captures and extended capture periods (> 12 hr).

Trapped animals were marked with permanent marker on the under belly as a non-invasive and non-toxic marking method (Ekernas and Mertes 2006). Five colors were used to record animals and their initial trap location: 1) inside underpass 2) west side ROW 3) east side ROW 4) west side beyond ROW 5) east side beyond ROW. Subsequent nights were recorded by an additional strip of color in accordance to where the animal was trapped. The captured animal was marked, recorded and released. All animals were captured and handled in accordance with University of Montana and Montana State University Institutional Animal Care and Use Committee protocols.

Statistical analysis

Statistical analysis differed slightly between track tubes and live traps since before-after (2011 and 2012, respectively) and control-impact (no course woody debris and course woody debris, respectively) (BACI design) data existed only for track tubes, while only control (no cover) and impact (cover) data existed for live traps.

To assess if cover increased small mammal abundance (all species combined) in and adjacent to the crossing structure, I first calculated for each sampling year and site track numbers within each crossing structure and mean track numbers within each of the other two zones (ROW and beyond ROW) to account for both sides of the highway (12 total sampling stations were placed in both ROW and beyond ROW, where only six were placed in the crossing structure). Each track station (30 per structure) had the possibility of 5 occupancies (5 nights of sampling). I then calculated the change in track numbers between 2012 and 2011 for each zone at each structure. An analysis of variance (ANOVA) was conducted (GenStat Release 8.1) to assess if there were between treatment differences in change of small mammal abundance. It was expected that cover would result in increased abundance and movement by small mammals, rather than decreased abundance and movements, which allowed for one-sided tests rather than two-sided tests. Individual tests were run on the effect of cover on small mammal abundance in the each zone: crossing structure, ROW, and beyond ROW, as well as crossing structure + ROW, and crossing structure + ROW + beyond ROW. In addition, the same tests were run for all mice, voles and shrews; this excluded the larger species (woodrats, chipmunks, weasels). The difference between 2011 and 2012 track tube data was calculated with the 2011 track tube data as a covariate to correct for relative population size at each structure.

ANOVA tests (GenStat Release 8.1) were run for all species combined and the smaller species group made up of mice, voles, and shrews.

Given the variation that was present in the data I conducted power analyses (Pass12) to calculate the number of replicate crossing structures that would need to be sampled to detect an effect of the treatment ($P<0.05$, power 0.80), if there indeed was one, given the variation that was present in the data. A power analysis test was run on the difference between 2012 and 2011 crossing structure zone data for all species combined.

Live trap data recorded both the total number of animals captured in each zone, and any movement between the crossing structure zone and ROW zone, as well as from one side of the crossing structure to the other. An ANOVA was run on live captures by separating into crossing structure, ROW, beyond ROW, crossing structure + ROW, and crossing structure + ROW + beyond ROW as was done with the track tubes. Data were normalized by taking the natural log and transformed using $\ln(x+1)$. Movement data were separated into two distinct categories: 1) complete cross through the structure, from one side of the road, through the crossing structure to the other side of the road and 2) movement from one side of the road to the crossing structure or vice versa. An ANOVA was run to observe effect of treatment. Separate tests were conducted for all species combined and for deer mice (which represented the majority of live captures).

RESULTS

Track Tubes

During the 2011 sampling period, crossing structures had a total of 25 occupied track tubes, ROW had 107, and beyond ROW had 91.5 (figure 2). The reported ROW and beyond ROW results were divided by 2 to standardize for the east and west sides of the highway for statistical analysis. Mean tracks (n/5) found in the control crossing structure was 2.8 (SD = 3.11), while the mean tracks (n/5) found in the future treatment crossing structure was 2.2 (SD = 2.34). Mean tracks (n/5) found in the control ROW was 7.5 (SD = 4.24), while the mean tracks (n/5) found in the future treatment ROW was 13.9 (SD = 5.52). Mean tracks (n/5) found in the control beyond ROW was 8.5 (SD = 8.20), while the mean tracks (n/5) found in the future treatment beyond ROW was 9.8 (SD = 7.97).

Before cover was added (2011), the mean abundance of small mammals was higher at the underpasses that later received cover than in the underpasses that served as a control. This pattern applied to two of the three zones (figure 2). After cover was added (2012), the mean abundance of small mammals was higher in treatment structures for all three zones (figure 3).

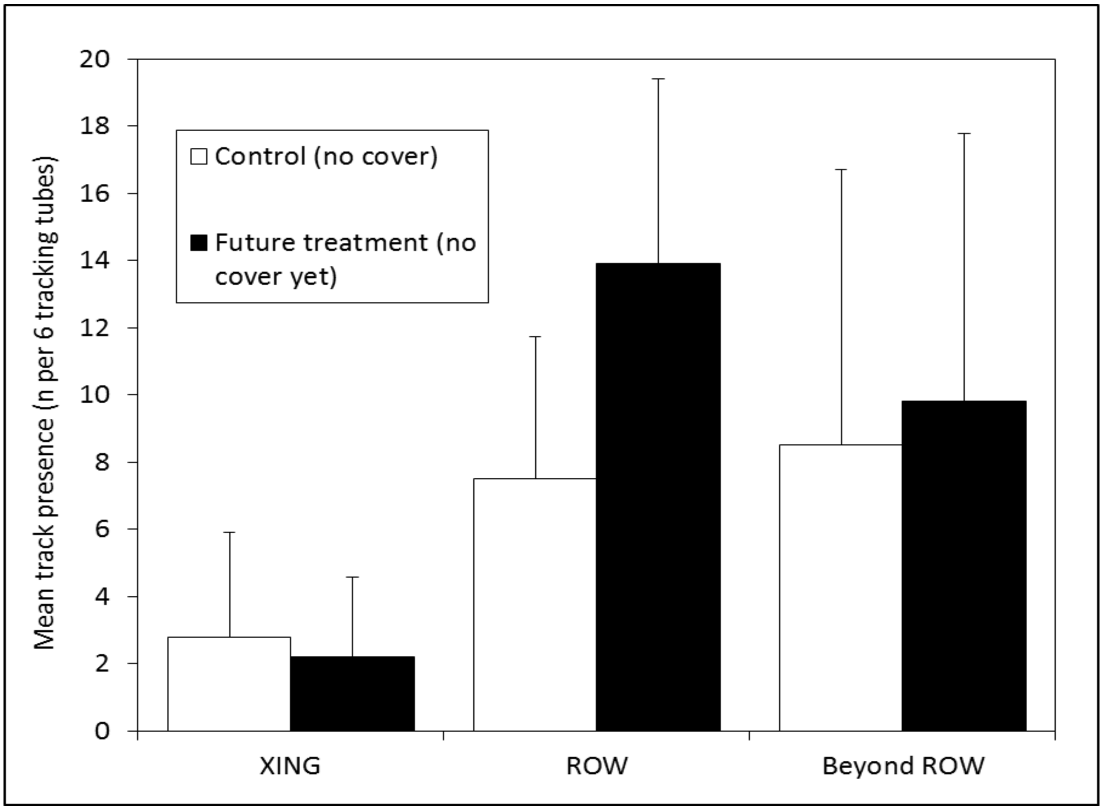

Figure 2: The mean abundance and standard deviation of small mammals (all species combined) recorded in the crossing structure, ROW, and beyond ROW zones from 2011 track tube sampling. “Future treatment” represents the structures that received added cover in January 2012.

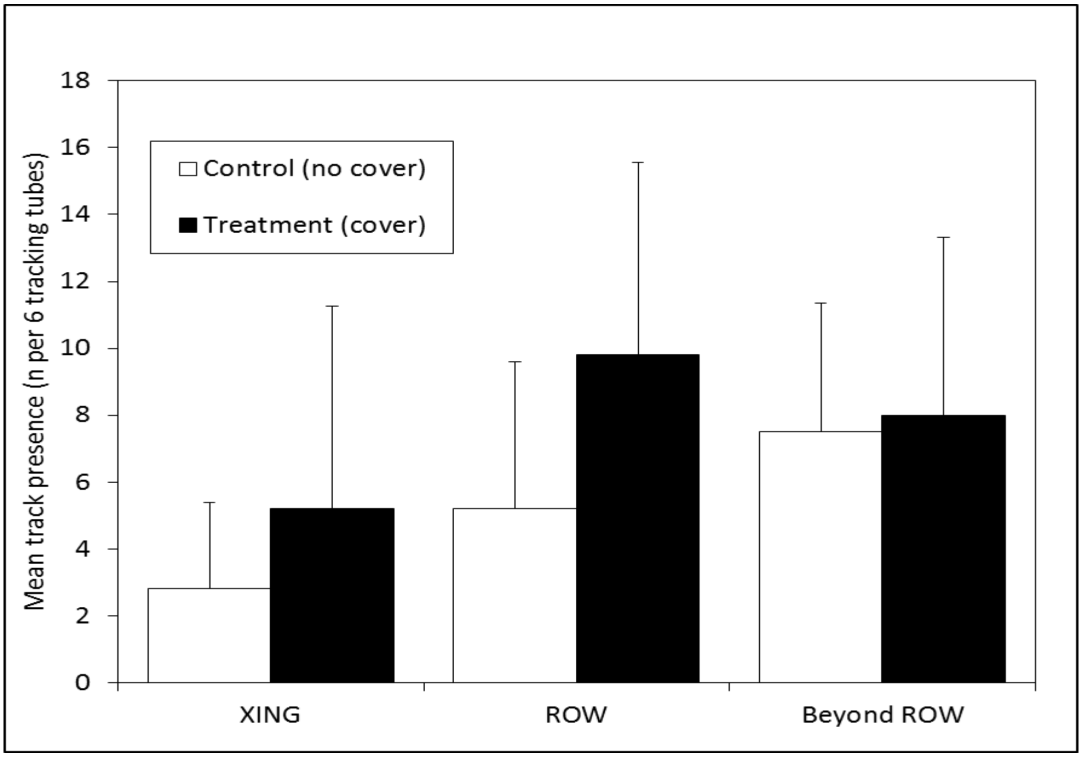

Figure 3: The mean abundance and standard deviation of small mammals recorded in the crossing structure, ROW, and beyond ROW zones from 2012 track tube sampling.

An ANOVA run using the difference between 2012 and 2011 track numbers as the test parameter, and the 2011 dataset as a covariate was run (to account for relative small mammal population size at each structure and yearly population fluctuations). The ROW (p=0.452), beyond ROW (p=0.327), crossing structure + ROW (p=0.249), and crossing structure + ROW + beyond ROW (p=0.423) were not significantly different between treatment and control. Effect of cover on crossing structure was nearly significant (p=0.066).

Table 4: Track tube sampling analysis results: all species.

Zone	Control Mean	Treatment Mean	P value (one sided)	D.F.	F value
XING	-0.40	3.40	0.066	1	2.909
ROW	-3.00	-3.40	0.452	1	0.016
Beyond ROW	-2.40	-0.40	0.327	1	0.220
XING + ROW	-3.40	0.00	0.249	1	0.513
XING + ROW + Beyond ROW	-6.40	-5.00	0.423	1	0.041

The same analysis was run for mice, voles, and shrews using the 2011 track data as a covariate with no significant differences found for crossing structure (p=0.197), ROW (p=0.290), beyond ROW (p=0.324), crossing structure + ROW (p=0.448), or crossing structure + ROW + beyond ROW (p=0.423).

Table 5: Track tube results: mice, voles, and shrews.

Zone	Control Mean	Treatment Mean	P value (one sided)	D.F.	F value
XING	-0.71	0.71	0.197	1	0.830
ROW	2.70	-4.70	0.290	1	0.339
Beyond ROW	-3.00	-1.00	0.324	1	0.228
XING + ROW	-3.40	-4.00	0.448	1	0.019
XING + ROW + Beyond ROW	-6.40	-5.00	0.423	1	0.041

The power analyses showed that based on the crossing structure difference observed between 2012 and 2011 track tube data, 16 control and 16 treatment structures would have been required to be able to detect a significant difference, should there indeed be a treatment effect (80% detection probability).

Live Trapping

For 5 nights of live trapping, 377 individual animals were captured, with 274 recapture events. Of the individual animals captured, 64% were deer mice (*Peromyscus* *maniculatus*; n=242). Other species captured included meadow vole (*Microtus pensylvanicus*; n=102), long tailed vole (*Microtus longicaudus*; n=9), water shrew (*Sorex palustris*; n=1), shrew (*Sorex* spp; n=9), bushy tailed woodrat (*Neotoma cinerea*; n= 4), yellow pine chipmunk (*Neotamias amoenus*; n=4), red tailed chipmunk (*Neotamias ruficaudus*; n=2) and short tailed weasel (*Mustela ermine;* n=4). There was only one *Microtus* sp. and no *Sorex* spp. trapped inside the crossing structures.

Table 6: Live trapping results,. Total captures included recaptured animals. Individual capture totals excluded recaptures, and recapture rate (=1-(individual captures/total captures)).

Species	**Total Captures (including recaptures)**	**Individual captures (excluding recaptures)**	**Recapture rate**	**Captured in beyond ROW**	**Captured in ROW**	**Captured in crossing structure**
deer mouse (*Peromyscus maniculatus*)	488	242	0.503	Yes	Yes	Yes
meadow vole (*Microtus pensylvanicus)*	126	102	0.190	Yes	Yes	Yes
long tailed vole (*Microtus longicaudus)*	9	9	0.000	Yes	Yes	No
water shrew (*Sorex palustris)*	1	1	0.000	No	Yes	No
shrew (*Sorex* spp*)*	10	9	0.100	Yes	Yes	No
bushy tailed woodrat (Neotoma cinerea)	7	4	0.429	Yes	No	Yes
yellow pine chipmunk (Neotamias amoenus)	4	4	0.000	Yes	No	Yes
red tailed chipmunk (Neotamias ruficaudus)	4	2	0.500	Yes	No	Yes
short tailed weasel (Mustela erminea)	4	4	0.000	Yes	No	Yes
Total	651	377	0.421			

Table 7: 2012 live trap abundance analyses.

Zone	**Control Mean**	**Treatment Mean**	**P value (one sided)**	**D.F.**	**F value**
XING	1.22	1.48	0.245	1	0.522
ROW	2.50	2.95	0.148	1	1.254
Beyond ROW	2.64	2.93	0.215	1	0.693
XING + ROW	2.71	3.16	0.112	1	1.740
XING + ROW + Beyond ROW	3.36	3.73	0.152	1	1.212

Table 8: 2012 live trap abundance for deer mice.

Zone	**Control Mean**	**Treatment Mean**	**P value (one sided)**	**D.F.**	**F value**
XING	0.94	1.34	0.205	1	0.760
ROW	2.68	2.95	0.247	1	0.515
Beyond ROW	2.56	2.89	0.184	1	0.916
XING + ROW	2.79	3.16	0.158	1	1.142
XING + ROW + Beyond ROW	3.34	3.71	0.165	1	1.075

Only deer mice and meadow vole were trapped in all three sections. Bushy tailed woodrat, yellowpine chipmunk, and short tailed weasel were trapped in the beyond ROW area and crossing structure, but never the ROW. For all combined species trapped, the effect of treatment doubled animals movement between the crossing structure and ROW in treatment structures (p=0.039, d.f.=1, f=4.081). For additional analysis, I separated deer mice because they represented the majority of live captures. As with all combined species, the effect of treatment significantly increased deer mouse movement between the crossing structure and ROW in treatment structures (p=0.02, d.f.= 1, f=6.250).

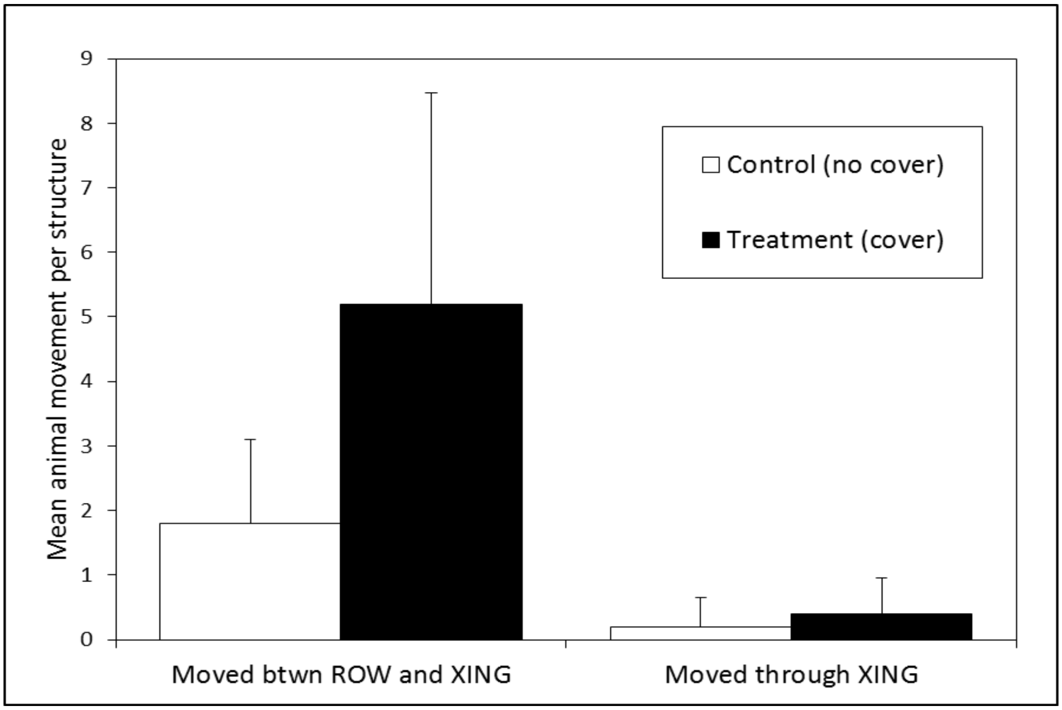

Figure 4: Effect of cover on live trap abundance: all species. Individual animals that completely crossed through the structure were also higher in treatment structures than in control structures.

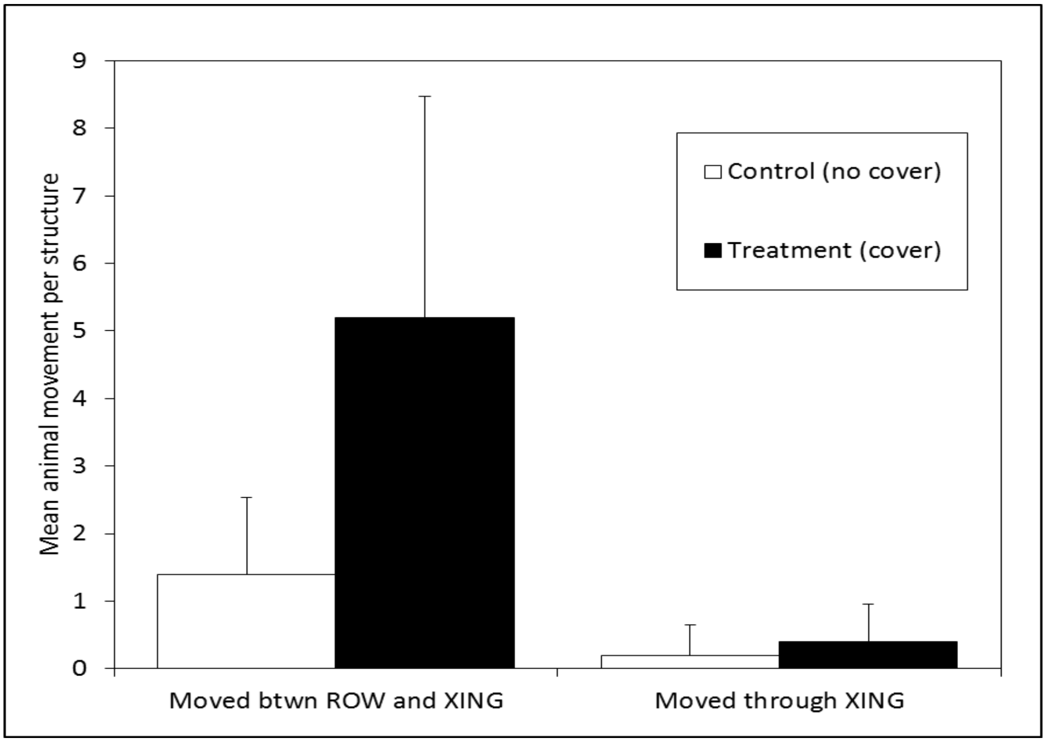

Figure 5: Deer mice that moved between ROW and XING more than doubled in the treatment structures. Individual animals that completely crossed through the structure was also higher in treatment structures than in control structures.

DISCUSSION

This study was an effort to specifically measure if added cover of coarse woody debris in structures resulted in an increase in abundance or movement by small mammals. Although several investigators have stressed the importance of cover near the entrances of culverts, tunnels, and underpasses (Hunt et al. 1987, Clevenger and Waltho 2000a, Bolger et al. 2001, Foresman 2004, McDonald and St. Clair 2004), there are no prior studies that specifically address whether large culverts (made for large carnivores and ungulates) can be modified to increase use by small mammals in the US. The results from this study conclude that structures with cover likely have higher abundance and movement of small mammals and suggest that cover can thus increase small mammal use of culverts originally designed for large mammals.

Live trap movement results were consistent with our original hypothesis. Results from all species combined and deer mice only recorded a statistically significant effect of cover on movement between the crossing structure and ROW, therefore, adding cover to large structures is likely to increase small mammal movement in underpasses. Indeed, the movement of individuals from ROW into the crossing structure was more than doubled by the addition of cover. This represents an important increase in movement facilitated by the placement of cover that could increase the probability of population persistence and aid the maintenance of genetic diversity in populations formerly separated by roadways (Gerlach and Musolf 2000, Rico et al. 2007, Holderegger and Di Giulio 2010). The mark-recapture detection method was the most accurate of those employed due to the marking and recapture of individuals. While track tube detection methods did not find a statistically significant effect of cover on small mammal abundance in the crossing structure, those results trended towards significance ($P< 0.1$), consistent with the mark recapture data. All zones except ROW tended toward an increase in mean from control to treatment. Although none of these tests produced a statistically significant increase in abundance of small mammals, the mean increase from control to treatment structures suggests a positive effect of cover. Because track tubes could not distinguish between individuals using the same tube multiple times in a sample period versus multiple individuals, the track tube results are biased low and therefore have less sensitivity to an effect.

Additional factors that may have influenced small mammal detection were habitat variations and population dynamics at individual structures. In fact, site variability may have been a larger source of variability than the treatment. Yearly population density variation likely played a role in our results since population crashes are common in rodent populations (Krebs and Myers 1974). There were no apparent external events (e.g. weather or poisoning) that caused a change in detection probability between sampling. After comparing 2011 and 2012 track tube abundance data at individual structures, several structures (Pistol Creek 1, Pistol Creek 2) experienced dramatic crashes in small mammal population between 2011 and 2012. Small mammal population fluctuations could affect small mammal abundance and utilization of the crossing structures from year to year. It would be beneficial for multiple years of data to identify trends since small mammal populations can be so volatile. The lack of stronger statistical significance was ultimately due to limited replication. Although our sample size needed to be larger, the opportunity to examine even 10 structures of similar dimensions and within 45 km of each other is rare in wildlife underpass research.

Live trap abundance analysis did not result in any significant effect of cover. Similar to the track tube results, the mean increased in all zones except ROW from control to treatment structures, consistent with a positive effect of cover although not statistically significant. Again, abundance measures are less able to distinguish actual use and movement. Thus, the lack of significance of the results given the achievable sample size is not surprising and does not diminish the evidence provided by the mark-recapture methods of detection.

The potential barrier effect of crossing structures for small mammals must be considered and addressed using adaptive measures such as cover or elevated shelves (Clevenger and Waltho 2000a, Foresman 2004, McDonald and St. Clair 2004). The barrier effect and consequent genetic sub-structuring of populations caused by roads has been demonstrated in several instances (Richardson et al. 1997, Gerlach and Musolf 2000, Rico et al. 2007). As a result, it is vital to ensure that larger sized crossing structures are benefitting the maximum number of species in the direct vicinity.

Small mammals avoid road surfaces (Swihart and Slade 1984, Goosem 2002, Ford and Fahrig 2008, McGregor et al. 2008), making habitable crossing structures a viable option to mitigate barriers created by roads. Additional cover in structures may benefit more than just small mammals. It is common practice to focus on a specific species when analyzing crossing structures, since underpass attributes may have different effects on individual species. Clevenger and Waltho (2000b) examined 24 structures of varying size and subsequent use by small and medium sized mammals with respect to 18 structural, landscape, and road attributes. They found varied preferences for each species. However, they concluded that a variety of culvert sizes depending on the local and relevant species, as well as cover near culverts would increase use by both carnivores and small mammals. Their results demonstrate the utility of adding cover to underpasses for a wide spectrum of species.

Small mammals prefer structures with <3m diameter, most likely due to their preference for dense and proximate overhead cover (Diffendorfer et al. 1995, McDonald and St. Clair 2004). Because larger, bare culverts tend to create a formidable barrier to small mammals, placing cover creates an effect of protection and overhead cover similar to that of the smaller culverts. On Highway 93 South, Foresman (2004) recorded many of the same species captured in this study using small culverts (1.2 m diameter). By adapting culverts using elevated shelves, Foresman (2004) was able to successfully modify culverts for small mammals that were traditionally designed to route water. In my study, additional cover was used to create a more protected corridor for small mammal movement in large culverts. Placing woody debris in smaller culverts made for drainage may plug or block the culvert, so placing cover in and around structures may only be feasible in larger structures.

Species specific behavior may have a large influence on structure use. The fact that most captures were deer mice may be explained by several factors. Trapping hours were mainly at night and thus nocturnal deer mice had a greater probability of capture than other diurnal species such as meadow vole (McDonald and St. Clair 2004). When captured and relocated across a road, McDonald and St. Clair (2004) found that meadow voles were unable to return to home ranges through underpasses when no cover was provided. Meadow voles are also less mobile than deer mice, and consequently have smaller home ranges (Blair 1940, Reich 1981, McDonald and St. Clair 2004, Wood

2010). These results correspond with our minimal vole captures inside the structure (n=1) and may have influenced results in the Highway 93 N structures. Although cover was not successful in influencing vole abundance and movement inside structures, an increase was observed for all species combined.

Finally, placing course woody debris in wildlife underpasses is likely to be little or no cost to managers and beneficial for all small mammal species, especially deer mice. During wildlife underpass construction, it is common for construction crews to unearth large trees, rootwads, and/or branches. Customary management techniques call for the removal of the material from the construction site. Leaving the natural material would reduce waste, reduce cost and likely improve the habitat in and adjacent to crossing structures.

ACKNOWLEDGEMENTS

I would like to thank the Confederated Salish Kootenai Tribes for permission to conduct research on tribal lands and Montana Department of Transportation for permission to conduct research in crossing structures and the adjacent right of way. I'd like to thank CSKT wildlife biologists Whisper Camel-Means, Stephanie Gillin, and Dale Becker, and technicians Ryan Adams and Kari Eneas for their support, recruitment of supplies and time spent in the field. I am grateful to field technicians and volunteers Jennifer Dupree, Taylor Hopkins, Yomi Kleinman, Ryan Rubie, and Megan Twohig for their effort in field preparation and data collection. Donations by Mountain Water Supply and Diamond Imaging, as well as grants provided by B and B Dawson Fund and funds from the Western Transportation Institute at Montana State University (U.S. Department of Transportation funds through its University Transportation Center program administered by the Research and Innovative Technology Administration (RITA)).

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