FINAL REPORT

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The Effects of Highways on Fragmentation of Small Mammal Populations and Modifications of Crossing Structures to Mitigate Such Impacts

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16. Abstract

Highway 93 south from Missoula to the Idaho border is currently being widened from 2 lanes to 4. This construction project has incorporated the use of small diameter, drainage culverts fitted with animal shelving in an attempt to mitigate for habitat fragmentation and loss of animal population continuity. The present research was conducted to determine the effectiveness of such shelving and to modify the design, where necessary, so that the widest variety of species could be served.

Three 1.2 m diameter steel corrugated culverts were fitted with shelving and 3 additional culverts adjacent to these, without shelving, were chosen to serve as controls. Over the period November 1, 2001 to January 31, 2004 remote sensing 35 mm cameras, placed in each culvert, recorded animal activity. Water levels within culverts was measured on a weekly basis and environmental variables (temperature, light, and humidity levels) were recorded adjacent to these culverts at 10 minute intervals. Relative abundance of small mammal species adjacent to the entrances of each culvert were determined through use of live-trap transects.

Over 4,500 photographs and 8,100 events of animal activity (movement past detectors) were recorded documenting culvert use by 14 different mammal species. In general, the amount of use by a species reflected its relative abundance adjacent to the culvert. When water was present in the control culverts, animal use was greatly limited, if not completely prohibited. Using photographs which illustrated the behavior of animals while using shelving, modifications were made to increase the effectiveness of the shelf surface and entrance ramp. Following modifications, shelving allowed for continued use of culverts even when water was present. Fourteen species of mammal were observed to use the shelves. Animal movement patterns were highly seasonal reflecting responses to cold temperatures, standing water levels which prohibited access to culverts (and shelving ramps), and species behavioral differences. Vegetative cover at culvert entrances greatly influenced culvert use; protective cover was required in order for most species to move to the culverts. Meadow voles did not use culverts until a protected tube was provided which could be accessed without having to leave the surrounding vegetation. There was no strong correlation between traffic volumes and animal activity. However, most species at these locations were nocturnal and thus their movements occurred at night when traffic was light.

Animal use of larger culverts with, and without, animal shelves was also studied. Recommendations for shelf use and for modifications of other culvert types is provided.

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All of these individuals made this research possible and I am indebted to them.

Conversion Chart	
Metric	**English**
1 meter (m)	39.37 inches (in)
1 centimeter (cm)	0.3937 inches
2.54 cm	1 inch

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INTRODUCTION

In the 1930's people began to document the threat which highways posed to animals (*1,2*). As highways have widened and vehicle speeds have increased over the past 70 years, an increasing number of wild animal (and human) mortalities have been observed (*3,4,5,6,7*). Data suggests that many larger species, such as wolves [*Canis lupus*, (*8*)] and grizzly bears [*Ursus arctos*, (*9*)], prefer not to cross these open expanses while others such as deer (*Odocoileus* sp.) and elk (*Cervus elaphus*), may be attracted to them (for salt or the abundance of green vegetation along the roadside) with dire consequences. Though less research has been conducted on the fragmentation effects that highways may present to small mammal populations, what data does exist suggests that such effects may be significant. Smaller mammals are actually impacted in 2 primary ways. First the wide expanses of a 4-lane highway (and shoulders) provide a formidable barrier for species that are primarily prey for mammalian carnivores and raptors, species such as shrews (Order Insectivora) and rodents (Order Rodentia). These species are very vulnerable if they attempt to cross a highway, given the lack of protective cover. Indeed early trapping studies by Oxley et al. (*10*) found that dispersal of small mammals across a divided highway (a distance of 90+ m) was significantly reduced, consistent to the barrier effect posed by open bodies of water (*11,12*). They concluded that such a highway "...may be as effective a barrier to the dispersal of small forest mammals as a body of fresh water twice as wide" (*10*:57). A majority of these species have indeed evolved behavioral patterns that cause them to avoid areas devoid of vegetative cover thereby reducing their susceptibility to predation and, as a result, their populations are readily fragmented by highway construction. Secondly, species that do attempt to cross these openings [e.g. the predators which behaviorally do not perceive openings as threatening such as striped skunks (*Mephitis mephitis*), weasels (*Mustela* sp.), raccoons (*Procyon lotor*), red foxes (*Vulpes vulpes*), coyotes (*Canis latrans*)] are often killed in this attempt because the distance is great and vehicles are moving so quickly. Such effects on these species are greatly magnified when highways bisect unique habitats such as wetland communities or forested areas which have historically served as wildlife corridors, areas which are often relatively small in overall size.

Beginning in the 1980's and continuing today, studies have focused on the use of wildlife underpasses and culverts by animals, a majority of such research being conducted in Europe (*13,14,15,16,17,18*). More recently, studies in the United States have begun, as is evidenced by research presented at 5 international conferences on wildlife ecology and transportation (*19,20,21,22,23*) and by the recent compendium entitled *Road Ecology* published in 2003 (*24*). At the moment, research falls into 1 of 2 areas, that of (1) identifying how animals perceive highways and railways as potential barriers (e.g., *25,26, 27,28*), and (2) mitigating for such impacts (e.g., *29,30,31,32,33*). The latter efforts involve development of safe passageways over or under such barriers to allow unimpeded movement for a variety of wildlife species. Importantly, any mitigation procedures which are implemented need to be validated. Many studies have begun to assess the effectiveness of such procedures (*32,34,35,36,37,38,39*) the results of which will allow for their further modification in the future.

Assessing the state of our knowledge to date [an excellent review is presented in (*24*)], it becomes abundantly clear that further documentation of these fragmentation effects are needed since data from many of these earlier studies were anecdotal or the studies themselves were limited in scope and experimental design. Additionally, though culverts and other such devices to allow movement of animals under or over highways have been shown to be used, to date little experimental rigor has been applied in most studies and few detailed conclusions have been drawn about proper design of such devices. With this background as a foundation, we conducted preliminary research in 2001 on a new highway project in west central Montana.

The widening of Highway 93 from Lolo, Montana to the Idaho border began in several phases, one of which was identified as the "Lolo South Project" encompassing the section between Lolo and Florence. During this expansion Montana Department of Transportation (MDT) modified several culverts placed along wetland zones to include a ramp and walkway-shelf. The hope was that small animals might use such platforms to move through the culverts even when water was present. Our preliminary research (*40*) suggested that certain species [e.g., raccoons, striped skunks, short-tailed weasels (*Mustela erminea*), deer mice (*Peromyscus maniculatus*)] routinely used these culverts to traverse the highway while others, such as the meadow vole (*Microtus pennsylvanicus)*, which is the most abundant species living adjacent to the culverts, did not use them. In addition, species which used the culverts are influenced by water in the culvert, opting to use the shelf when water was present. Additionally, live-trapping data suggested that vegetation within the barrow pits significantly affected species distributions and that areas at the entrances of culverts which are devoid of vegetation limited animal movement to the culverts. From these preliminary results 3 objectives emerged which framed the following research:

(1) Modify shelf structures to enhance small mammal use during wet periods.
(2) Modify shelf structures to accommodate vole species.
(3) Analyze the importance of a continuum of vegetative cover from the barrow pit to the culvert entrance.

MATERIALS AND METHODS

Objective #1: *Modify shelves to enhance animal use*

Montana Department of Transportation installed animal shelves in 3 1.2 m diameter steel drainage culverts during construction of the Lolo South segment of Highway 93 (Fig. 1; Appendix I). We paired each of these culverts with an adjacent culvert, not containing shelving, which then served as an experimental control [designated as Carleton Creek Experimental and Control (CCE and CCC), Gravel Pit Experimental and Control (GPE and GPC), and Maclay Flat Experimental and Control (MCE and MCC) (Fig. 2); MCC was subsequently found to be continually flooded and was removed from further study]. These remaining 5 culverts served as the primary focus of this research and will be referred to as the "main culverts" throughout this report. As this research progressed, the number of culverts monitored on a daily basis increased to 12 (including culverts on I90 and Highway 203), spanning a wide range of sizes and configurations (Fig. 2, Table 1, Appendix II). Two of these additional culverts [Gravel Pit Large (GPL) and Bass Creek Large (BCL)] were also eventually retrofitted with modified animal shelving.

Our preliminary research (*40*) suggested that modifications would be needed in the shelf design, in particular the floor surface and the entrance ramp. To address the floor surface, 2 diamond mesh sizes (25 mm and 6 mm), and one solid surface (heavy gauge polypropylene truck bed liner), were subsequently tested. Entrance ramps were repositioned upwards and a prototype of an entrance ramp design fabricated out of wood and extruded sheet metal was tested on all shelves.

a b c

Figure 1. Original culverts, (a) and (b), and 25 mm diamond shelving (c).

Remote 35 mm cameras (Model TM 550, TrailMaster®, Goodson and Associates, Inc. Lenexa, KS) were installed to the roof of each culvert approximately 10 m inside the east entrance (Fig. 3 a). These cameras were activated by dual sensors an infrared detector which responded to heat and a microwave detector which responded to motion, thus any warm-blooded animal passing in front of the cameras was photographed. Each camera was capable of taking 36 color slides (Kodak Elite Chrome, ASA 200); if all 36 exposures were expended prior to weekly checks, the detector continued to document animal events and these were recorded. Though species determinations could not be made for these additional events, they did provide valuable information on overall use and activity patterns. In 2003, a remotely activated video camera (Model TM 700v, TrailMaster®, Goodson and Associates, Inc. Lenexa, KS) was installed in one culvert and periodically moved to other locations to record animal behavior within culverts (Fig. 3 b).

Environmental data loggers (Hobo® H08-004-02 or Hobo® Pro Series H08-032-08, Onset Computer Corporation, Pocasset, MA) were placed adjacent to the culverts, to record ambient temperature, light, and relative humidity levels. These measurements were recorded at 10 minute intervals throughout the 2.5 year study. A passive infrared vehicle counter (Traffic Tally 3®, Diamond Traffic Products, Oakridge, OR) was installed at the GPE culvert (which lies approximately mid-way between the main culvert pairs) in June 2002 to record weekly traffic volumes.

Once each week cameras were checked and film was replaced as necessary. Water levels within each culvert were also recorded at this time as was the information collected on the traffic counter and the data loggers, the latter of which were reprogrammed at this time for the following week. The species of animal captured on each slide, as well as the date and time of each event, was recorded for each culvert using a stereomicroscope, and unique images were scanned in to digital files. Spreadsheets of environmental data were also constructed so that a comparison could be made between animal activity and these environmental parameters.

An assessment of small-to-medium sized mammal species present adjacent to each main culvert pair, and a rough index of individual species abundance of the smaller species, was periodically made using live-trap transect lines and selective use of larger wire mesh traps. Twenty-five Sherman® live traps (H. B. Sherman Traps, Inc., Tallahassee, FL) were placed at 5 m spacing adjacent to and centered at each culvert entrance, baited with rolled oats and checked morning and evening for 4 days per session (Fig. 4). Each trap checked (morning or evening) constituted 1 "trapping opportunity". Animals captured were identified to species, weighed, sexed, and aged (juvenile, subadult, adult) before release at the point of capture (no marking of individuals was made and thus no mark/recapture population estimates were attempted). Tomahawk® traps (Tomahawk Live Trap Company, Tomahawk, Wisconsin), baited with sardines, were also periodically set at culvert entrances to document presence of medium-sized mammals (e.g., weasels/squirrels/skunks).

Figure 2. (*See following page*) Location of culverts in which cameras were installed. Culverts containing shelves and culvert dimensions are identified in the figure legend below.

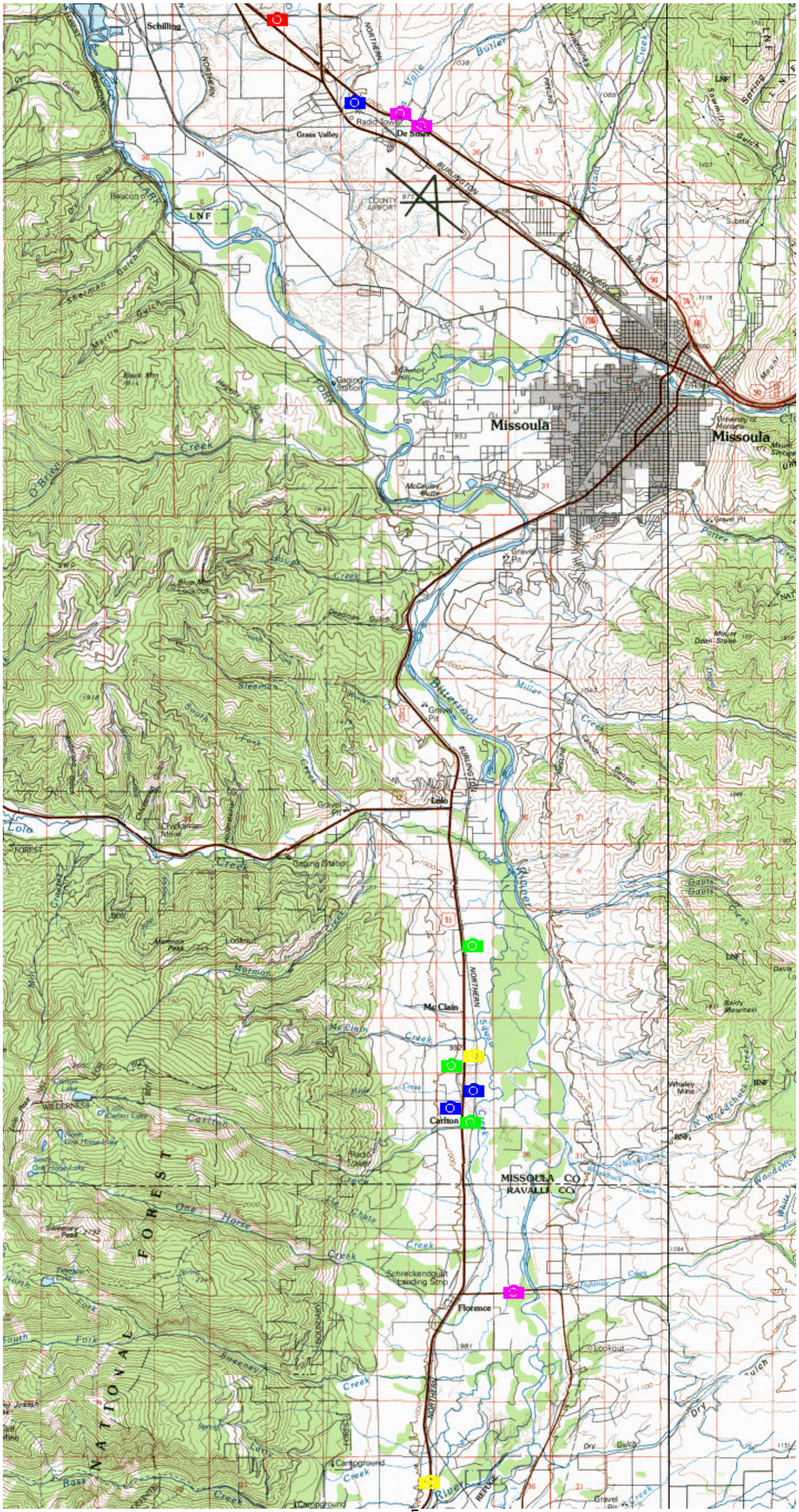
- 0.9 m diameter culverts (and controls).

- 1.2 m diameter culverts with existing shelves.

- 1.3 m to 2.2 m diameter culverts.

- culverts selected for shelf additions.

- 2.3 m to 3.75 m diameter culverts.

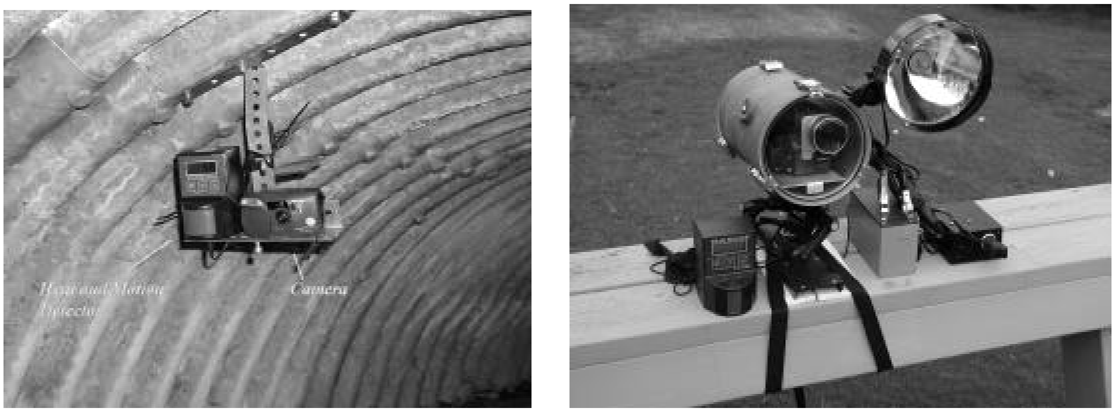


Schilling
Grass Valley
De Smet
COUNTY AIRPORT
LNF
Missoula
University of Montana
Missoula
McCauley Butte
Gaging Station
Lolo
Chickaman Point
Lolo Creek
Gaging Station
McClain
Carlton
MISSOULA CO
RAVALLI CO
Schreckendgust Landing Strip
Florence
Lookout
Mormon Peak
Sweeney Peak
NATIONAL FOREST
Whaley Mine
Baldy Mountain
Mount Dean Stone

Table 1. Specifications of all culverts studied.

Site	GPS location	# Lanes	Shelf	Substrate	Length	Width	Height
Bass Creek Large (BCL)[1]	N46°34.902 W114°05.353	2	Yes	None	27.6 m	3.7 m	2.3 m
Florence Bridge Culvert (FLO)	N46°37.918 W114°03.598	2	No	Dirt (? of length)	25.0 m	2.1 m	1.0 m (1.5 m w/out dirt)
Carleton Crk. Experimental (CCE)	N46°40.714 W114°04.408	4	Yes	None	59.5 m (63.2 m shelf length	1.2 m	1.2 m
Carleton Crk. Control (CCC)	N46°41.015 W114°04.389	4	No	None	50.5 m	0.9 m	0.9 m
Gravel Pit Control (GPC)	N46°41.273 W114°04.369	4	No	None	48.8 m	0.9 m	0.9 m
Gravel Pit Experimental (GPE)	N46°41.472 W114°04.355	4	Yes	None	49.2 m (53.1 m shelf length	1.2 m	1.2 m
Gravel Pit Large Culvert (GPL)	N46°41.512 W114°04.352	4	Yes	None	50.0 m	1.4 m	1.8 m
Maclay Flat Experimental (MCE)	N46°43.563 W114°04.644	4	Yes	None	50.0 m	1.2 m	1.2 m
90 Large Culvert (I90L)	N46°57.769 W114°09.039	4	No	Dirt	65.0 m	3.5 m	3.75 m
90 Small Culvert (I90S)	N46°56.627 W114°07.053	4	No	Dirt and Stones (¼ of length)	79.0 m	0.9 m	0.9 m
Double Culvert 1 (DC1)	N46°56.276 W114°05.924	4	No	Dirt and Stones	61.5 m	2.2 m	0.95 m
Double Culvert 2 (DC2)	N46°56.272 W114°05.925	4	No	Dirt and Stones	61.5 m	2.2 m	1.3 m

[1] The shelf in BCL was removed each May and June to meet 50-year flood plans.



a b

Figure 3. Remotely activated cameras mounted in the culverts: 35 mm (a), and video (b).

Figure 4. Small mammal live-trapping design: transect trap lines illustrated by dotted lines.

Objective #2: ***Development and test of effectiveness of small mammal tubes to accommodate selective species.***

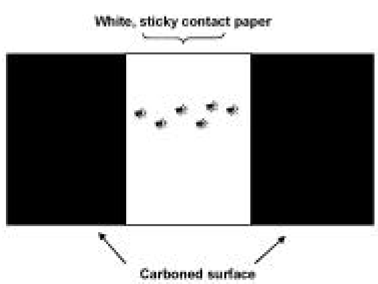
Preliminary research (*40*) indicated that at least 1 small mammal species abundant adjacent to the culverts, the meadow vole (*Microtus pennsylvanicus*), would not use the culverts to move under the highway. This avoidance behavior was felt to be due to this species' preference for protective cover so passageways were designed to provide a "safe" environment through which these animals could travel. Such "vole tubes" were initially constructed from 3 m sections of plastic rain gutter downspouts connected together and suspended from the undersurface of the shelves (Fig. 5a,b). These tubes were accessed by 1.2 m wide x 0.05 m high plywood funnels which narrowed at the point at which they connected to the tube (Fig. 5c). Funnels extended in to the surrounding vegetation allowing voles to enter without leaving protective cover. Animal use of these tubes was assessed by a carbon-sooted tracking plate inserted in the middle section (approximately 25 m from each entrance; Fig. 6a,b); tracking paper was checked and replaced each week.

a

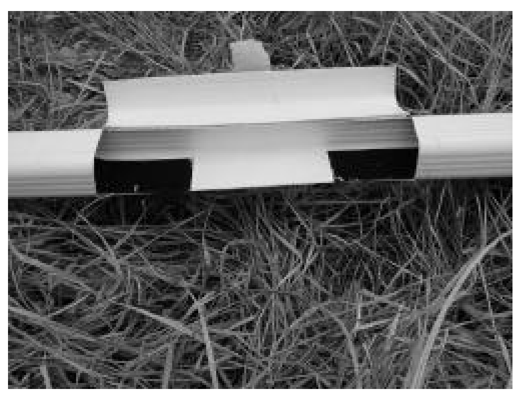
b

c

Figure 5. Prototype design of vole tubes and entrance ramps: (a) gutter tubes and (b) connected tubes suspended from shelf, and (c) entrance ramp to vole tube.



a

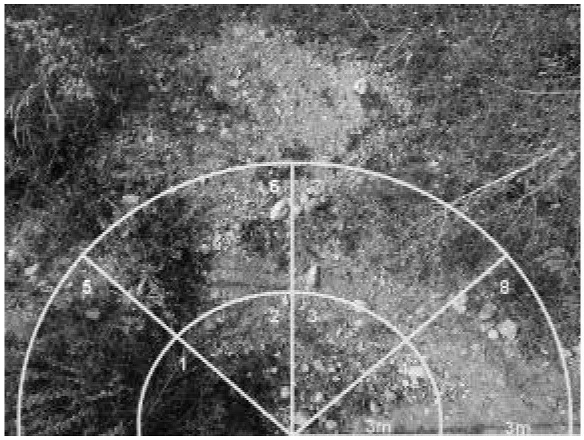


b

Figure 6. Sooted-tracking plate (a) placed in center section of prototype vole tube (b).

Objective #3: ***Determination of the importance of vegetative cover at, and adjacent to, culvert entrances.***

Vegetative cover measurements were made at entrances to main culverts 3 times over the course of the study. A visual estimate of percent cover was assessed in quadrants at 0-3 m and 3-6 m distances from the entrances (Fig. 7). Height of vegetation was also recorded by meter stick.



culvert entrance

Figure 7. Vegetation quadrants sampled at entrances to each main culvert.

RESULTS

Animal use of culverts:

Over the duration of the study more than 4,531 photographs and 8,135 total events were obtained of 14 different small mammal species (and 1 reptile, painted turtle – *Chrysomys picta*) using the main culverts. When all 12 culverts are considered, 7,510 photographs and 14,043 total events were recorded of 24 different species (Tables 2 and 3). The additional species observed in the larger suite of culverts in part reflects the culvert's larger sizes and thus use by larger species (e.g., deer, bear).

Table 2. Summary of animal activity in culverts from October 2001 through January 2004.

	CCC	CCE	GPC	GPE	GPL	MCE	90L	90S	DC1	DC2	BASS	FLO
# of Photos with Animals	872	773	679	724	1117	896	508	536	560	337	463	668
Total # of Photos	1374	1580	1015	1454	1752	2023	964	1321	1083	653	1026	1090
Estimated Total Activity[1]	1511	1738	1117	1599	1927	2225	1060	1453	1191	718	1129	1199

[1] **Estimated total activity** equals the total number of photographs taken (with or without identifiable animals) + the average number of additional events recorded monthly by detectors. The latter value was determined by taking the average % of additional detections recorded over a 6 mo. period and then estimating this percentage for the additional 17 mo. and adding this value to each respective month.

A definite seasonality in culvert use was observed, with an increasing number of events occurring during the late winter and spring (February through May; Fig. 8). The noticeable dips which occurred in June 2002 and April-to-June 2003 can be explained by increasing water levels. With increasing spring snowmelt and spring and summer rains, ground water levels rose in the wetlands adjacent to the main culverts, and the creeks at other culvert locations rose, affecting animal use (Fig. 9). Culverts without animal shelves became impassable for smaller species. Activity which occurred when water levels were high (e.g., March and June 2002) reflected either use of shelves in the experimental culverts to walk above the water (their intended purpose) and/or use of a control culvert without water at the same time that there was no use of one carrying water (i.e., the data is expressed as an average across all main culverts). Deer mice, raccoons, striped skunks, short-tailed weasels, and domestic cats were the dominant species using the main culverts; in addition, coyotes, red foxes, and white-tailed deer commonly used larger culverts (Table 3).

Table 3. Animal use of culverts as documented by photographs (October 2001 through January 2004).												
Culvert[1]/Species[2]	PEMA[3]	MIPE[3]	PRLO[3]	FEDO[3]	MUER[3]	MEME[3]	TAHU[3]	ONZI[3]	CALA	CAFA	VUVU	ODSP
ME	185	18	71	29	216	24	0	348	0	0	0	0
GPL	952	24	0	24	55	18	0	2	0	0	0	0
GPE	630	6	3	12	51	10	0	0	0	0	0	0
GPC	544	31	25	60	0	10	0	3	0	0	0	0
CCC	500	10	30	118	2	137	2	5	0	0	0	0
CCE	172	1	190	232	12	156	2	0	0	0	0	0
I90L	6	0	33	89	0	131	0	6	56	26	31	124
I90S	392	7	2	18	0	59	0	0	33	1	19	0
DC1	401	35	20	39	22	20	2	0	0	0	6	0
DC2	97	1	92	93	2	32	1	2	0	0	13	0
FLO	106	2	106	198	0	219	14	0	0	2	1	0
BCL	5	0	205	8	7	7	165	19	0	2	0	33
Total	**4010**	**135**	**777**	**925**	**367**	**823**	**186**	**385**	**89**	**31**	**70**	**157**
Culvert[1]/Species[2]	SPCO[3]	SORX[3]	MAFL	SYNU[3]	MUVI[3]	NECI[3]	ERDO[3]	TAAM	SINI[3]	URAM	MAPE	CHPI[3]
ME	1	3	0	0	0	0	0	0	0	0	0	0
GPL	3	3	0	7	0	0	8	0	0	0	0	0
GPE	0	0	0	0	6	0	0	0	0	0	0	6
GPC	4	2	0	0	0	0	0	0	0	0	0	0
CCC	68	0	0	0	0	0	0	0	0	0	0	0
CCE	4	1	2	0	0	0	0	0	1	0	0	0
I90L	0	0	0	5	0	0	0	0	1	0	0	0
I90S	0	5	0	0	0	0	0	0	0	0	0	0
DC1	0	0	0	9	0	4	1	0	0	1	0	0
DC2	0	0	0	2	0	1	0	1	0	0	0	0
FLO	7	0	9	0	0	0	4	0	0	0	0	0
BCL	0	0	0	0	5	2	0	0	0	0	2	0
Total	**87**	**14**	**11**	**23**	**11**	**7**	**13**	**1**	**2**	**1**	**2**	**6**

[1]Culvert notations as per Table 1, page 6.

[2]Species notations: PEMA (deer mouse), MIPE (meadow vole), PRLO (raccoon), FEDO (domestic cat), MUER (short-tailed weasel), MEME (striped skunk), TAHU (red squirrel), ONZI (muskrat), CALA (coyote), CAFA (domestic dog), VUVU (red fox), ODSP (white-tailed deer), SPCO (Columbian ground squirrel), SORX (shrew sp.), MAFL (yellow-bellied marmot), SYNU (mountain cottontail), MUVI (mink), NECI (bushy-tailed woodrat), ERDO (porcupine), TAAM (yellow pine chipmunk), SINI (fox squirrel), URAM (black bear), MAPE (fisher), CHPI (painted turtle).

[3]Species identified using animal shelves.

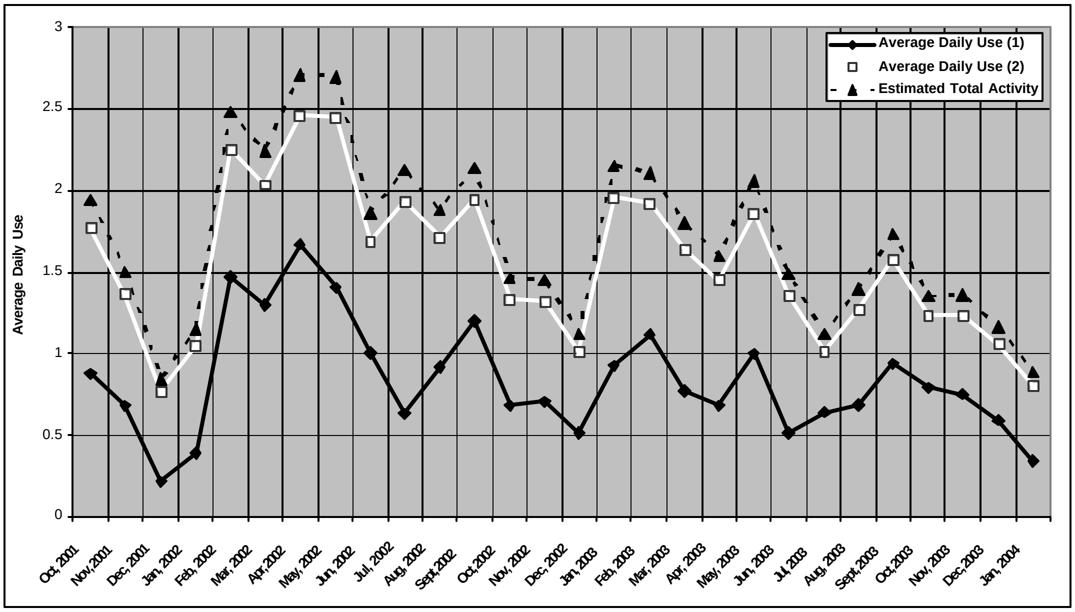


Figure 8. Seasonal activity pattern of animal use for all culverts. [*(1)* = average of total number of animals identified by photograph; *(2)* = average of total number of photographs with or without identifiable animals; *Estimated total activity = (2)* + average number of additional events recorded monthly by detectors. [The latter value was determined by taking the average % of additional detections recorded over a 6 mo. period and then estimating this percentage for the additional 17 mo. and adding this value to each respective month].

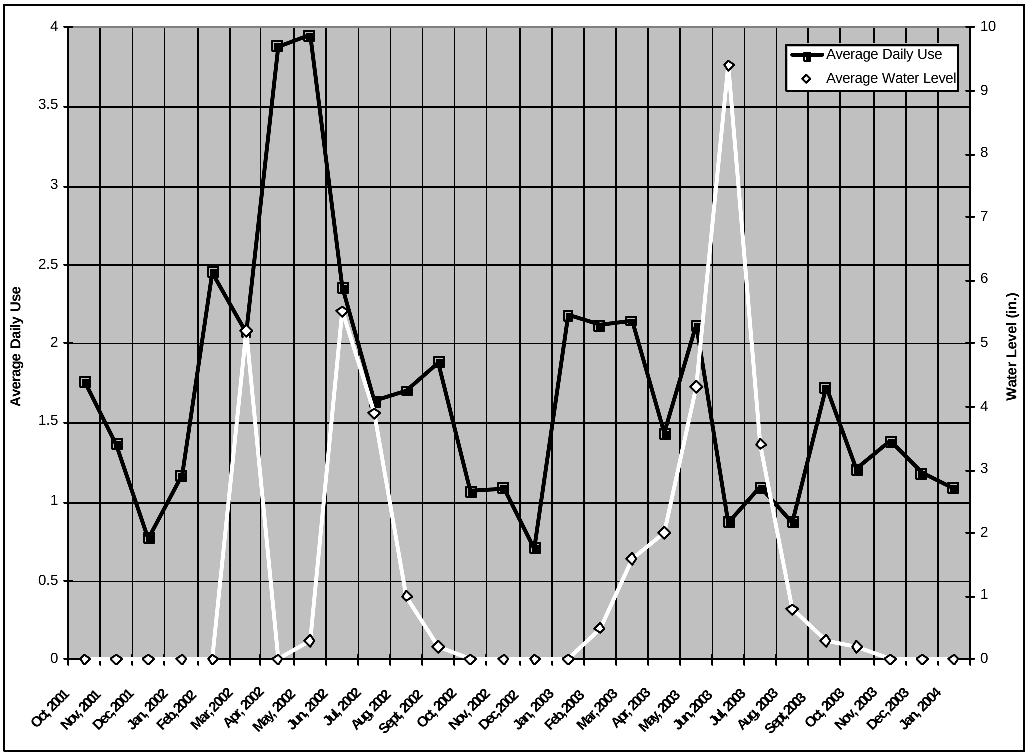
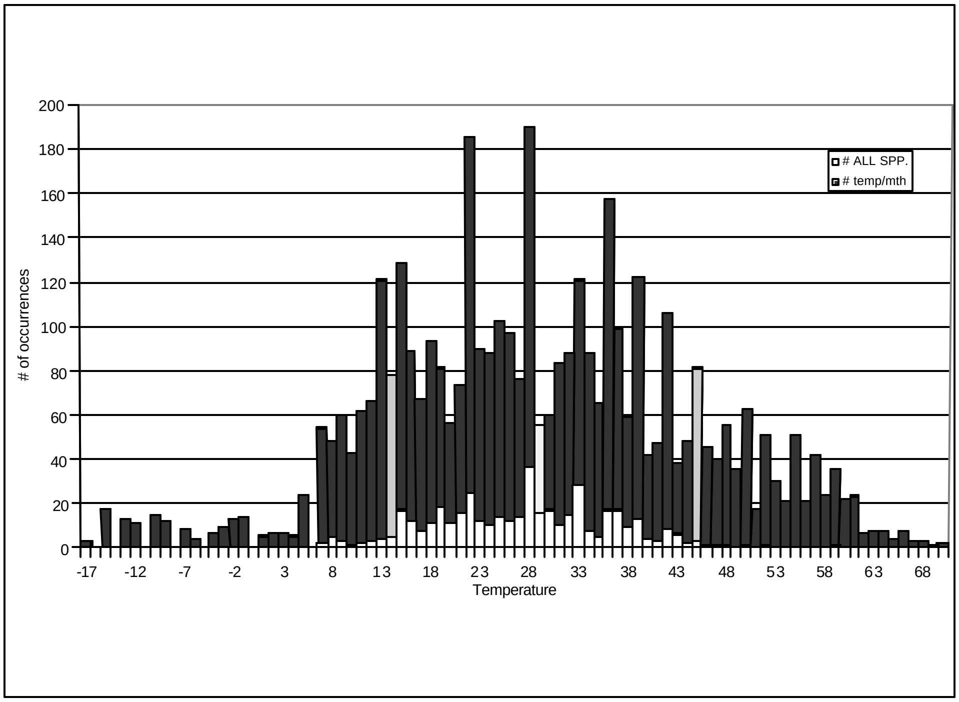


Figure 9. Animal activity in the culverts as a function of standing water levels (using only culverts CCC, CCE, GPC, GPE, GPL).

As would be expected, during warmer months animals were active over a wider range of temperatures and their activity was not concentrated around the monthly mean temperature (within ±1 S.E.) to the same degree as it was during colder months (e.g., compare July 2002/2003 to February 2002/2003, Fig. 10 a-d).



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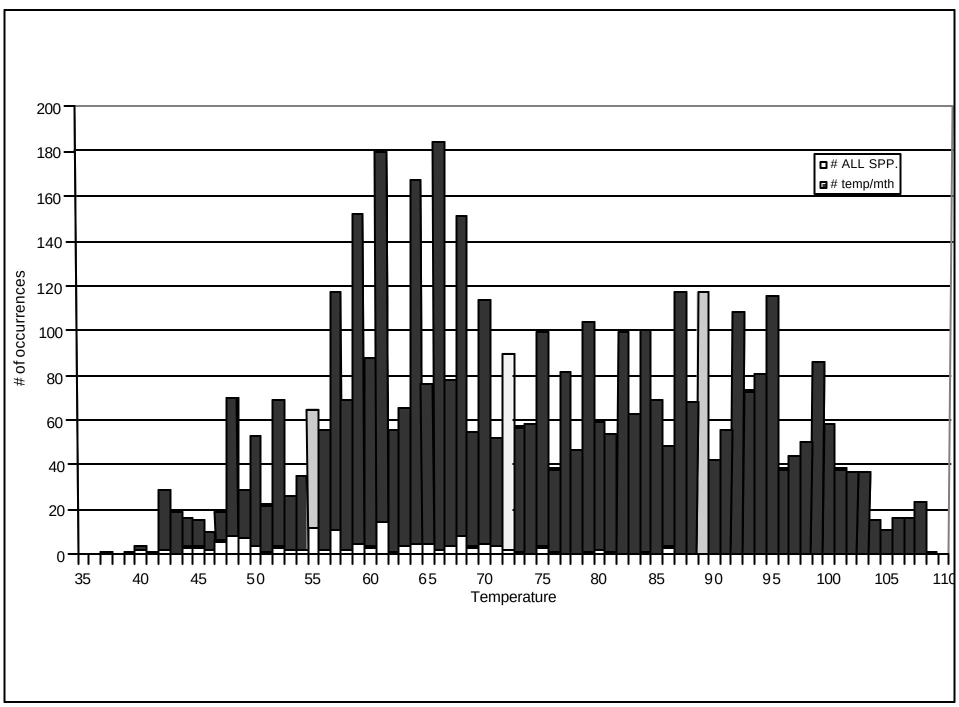

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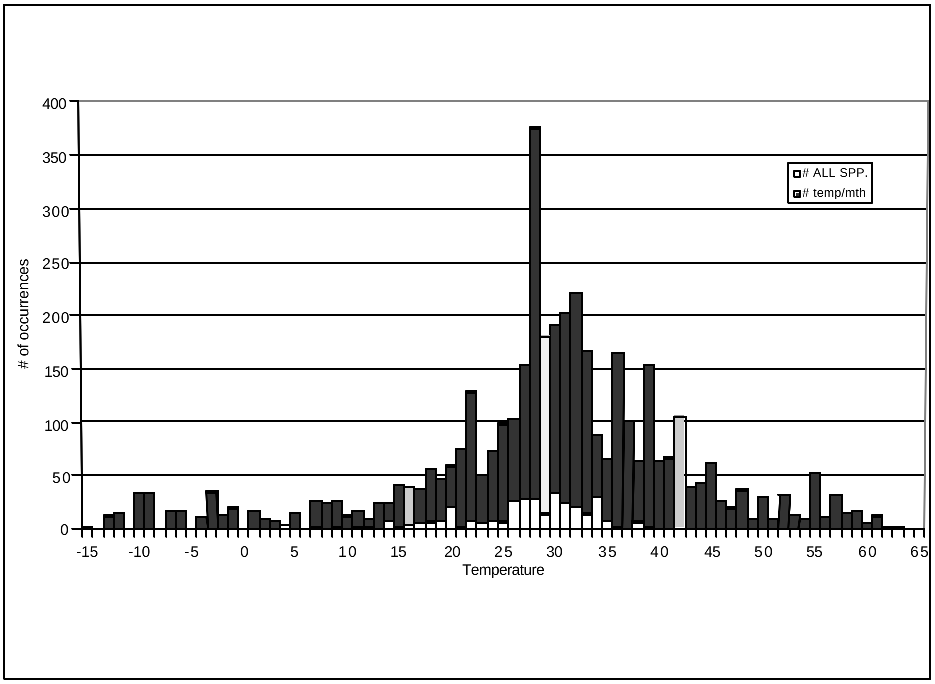

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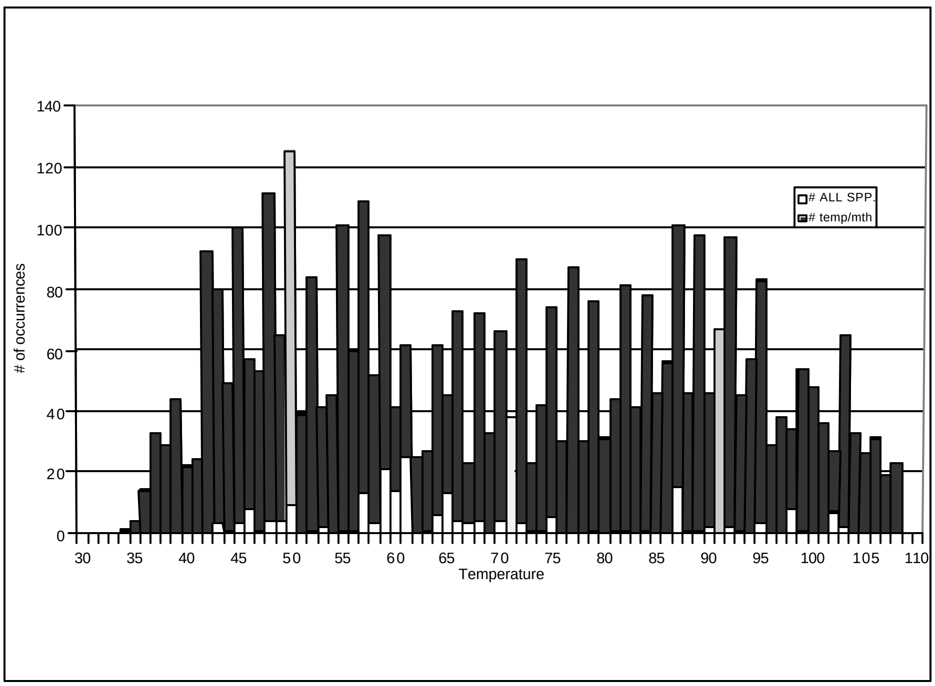

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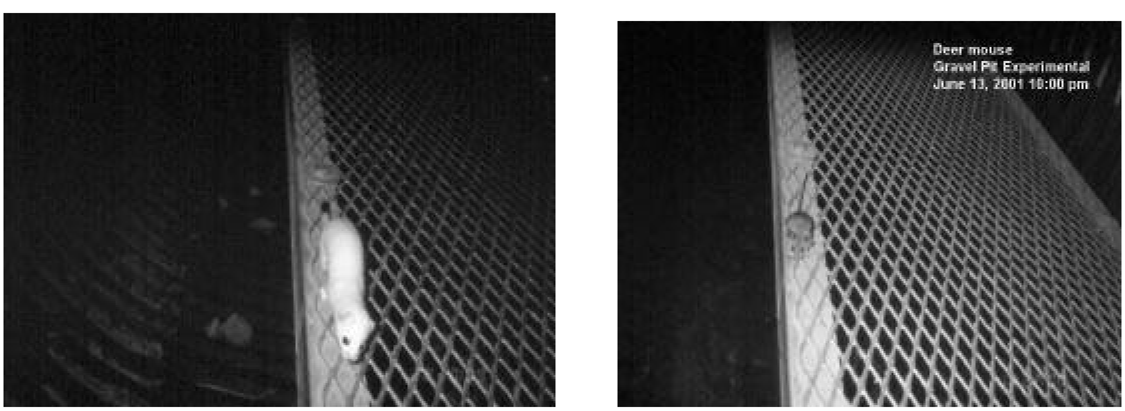
Figure 10. Activity as a function of environmental temperatures in February (a) and July (b) 2002, and February (c) and July (d) 2003. [Vertically crosshatched bars = mean temperature; diagonally crosshatched bars = ±1 standard deviation].

Of course the primary question is whether or not animal use of culverts is enhanced by the presence of shelving. In all cases, as water levels rose in the control culverts animal activity decreased. Some species (e.g., raccoons) will still wade through these culverts with small amounts of water present (5–10 cm; Fig. 11) but even this small amount of water will preclude such culvert use by the smaller species (e.g., deer mice and short-tailed weasels). Activity in the experimental culverts however remained high or even increased when water levels rose, due to consistent use of the shelving. A total of 15 different mammal species were documented using the shelving (Table 3).

Figure 11. Raccoon wading through Gravel Pit Control culvert; this amount of water would be prohibitive to smaller species.

Still photos and video sequences provided insight in to how smaller species were using the shelving. From this information, it became obvious that changes in the floor mesh were necessary to accommodate the smallest species. The 25 mm diamond mesh proved to be too open to allow rapid, easy movement of mammals the size of mice and weasels and these species were forced to move along the solid frame (Fig. 12 a,b). The solid plastic surface solved this problem and was readily used by all species (Fig. 13 a,b) but was not felt to be a permanent solution since it was not permeable to water if levels rose above the shelf. The 6 mm diamond mesh provided an appropriate surface for the smaller species but, as used, was not a heavy enough gauge to support the larger species. Ultimately a #13 flat galvanized expanded metal mesh was chosen which was accepted well by all species (Fig. 14 a,b).



a b

Figure 12. Examples of 2 species using original shelves: Short-tailed weasel (a), and deer mouse (b), using the frame rather than the floor mesh of the original shelves.

a

b

Figure 13. Examples of 2 species using solid plastic surface: Deer mouse (a), and painted turtle (b).

a

b

Figure 14. Examples of 2 species using modified shelves: Mountain cottontail (a), and porcupine (b).

Shelf entrances were originally positioned directly in line with the shelf proper by MDT (Fig. 1 b) but it quickly became obvious that these would slow water flow, trap debris, and make shelf access impossible when water levels rose. Entrances were repositioned to the side of the culvert so that animals moving along the barrow pit could walk up the ramp and on to the shelf (Fig. 15). From these results, a final design for the shelving was developed (Fig. 16; Appendix III). Two of these new shelves were purchased from Roscoe Steel & Culvert Co., Missoula, MT and placed in the GPL and BCL culverts for further assessment. Consistent, continued use of these shelves by a variety of species has been documented by still and video cameras (e.g., Fig. 14 a,b). For a short period of time (approximately 3 weeks) the entrance ramps to the GPL shelf were unavailable and yet animals still climbed up 0.6 m to use the shelf when water was present.

Figure 15. Entrance ramp at Carleton Creek Experimental positioned to side of shelving and culvert.

a

b

c

Figure 16. Photos of new shelf and entrance: (a) frontal view with entrance ramp entering from side, (b) side view, and (c) top view showing width of entrance ramp and shelf.

Effectiveness of small mammal shelf tubes

"Vole tubes" accessed by an entrance funnel extending in to the vegetation at culvert entrances were heavily used by meadow voles, deer mice, and short-tailed weasels (Figs. 17 and 18). Hundreds of tracks were obtained on the tracking paper each week. These tubes worked so well in overcoming the avoidance behavior of voles that they were incorporated as an integral component of the frame used in the final shelf design (Fig. 19 a,b).

Figure 17. Appearance of entrance funnel entering from side (plywood model in middle of photo). [Compare this prototype to the final design illustrated in Fig. 18b where the funnel is incorporated in to the entrance ramp]

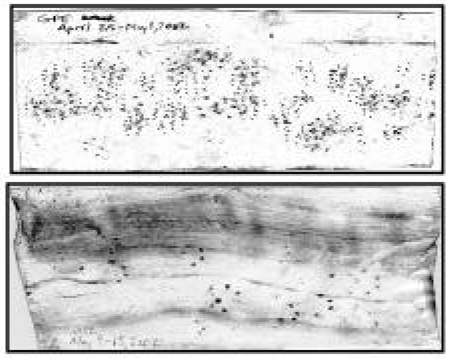
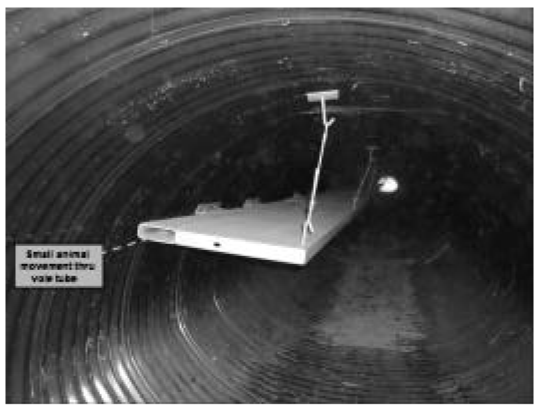


Figure 18. Animal use of vole tubes illustrated by sooted-tracking plates: (top) meadow vole and deer mouse tracks, and (bottom) short-tailed weasel tracks and drag mark of prey.



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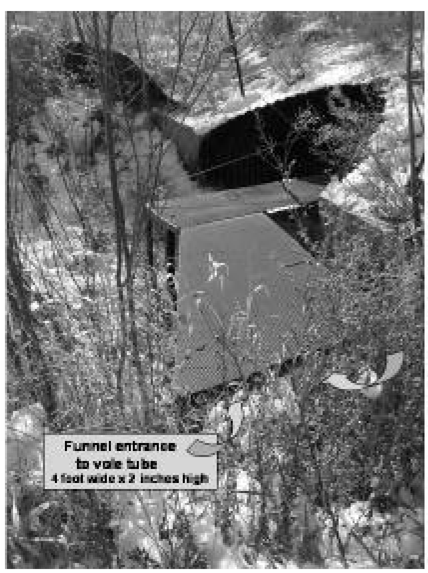
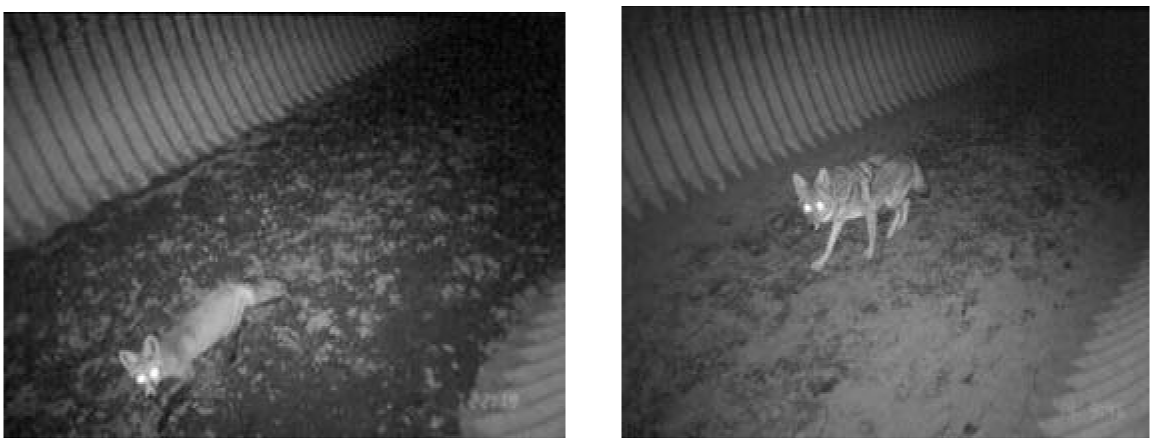


b

Figure 19. Cross section (a) of final shelf design illustrating vole tube incorporated in to the shelf frame and access funnel (b) built in to the shelf’s entrance ramp.

Animal activity at additional culverts

The 7 additional culverts added during the course of this research spanned a wide range of sizes and configurations (Table 1). Comparison of animal activity between these provides considerable preliminary information since some were dry culverts with gravel or sand floors, and others serviced permanent streams and were large enough to accommodate species such as deer. All of these culverts were actively used by a wide variety of animal species (Tables 2 and 3). Two results in particular stand out. First, canids, such as red foxes and coyotes, routinely used those culverts which had a more natural ground cover (e.g., I90L, I90S and FLO; Fig. 20 a,b). Second, white-tailed deer routinely used 2 of the largest culverts, I90L and BCL (Fig. 21 a,b); interestingly the former has a deep layer of silt built up covering the corrugated steel floor while the latter, servicing Bass Creek, is continually scoured such that the corrugated floor has remained clean. At BCL, deer walked in the stream through the culvert on the corrugated metal surface.



a b

Figure 20. Red fox (a), and coyote (b) using I90 Large culvert with a silted floor surface.

a b

Figure 21. White -tailed deer using I90 Large (a), and Bass Creek Large (b) culverts.

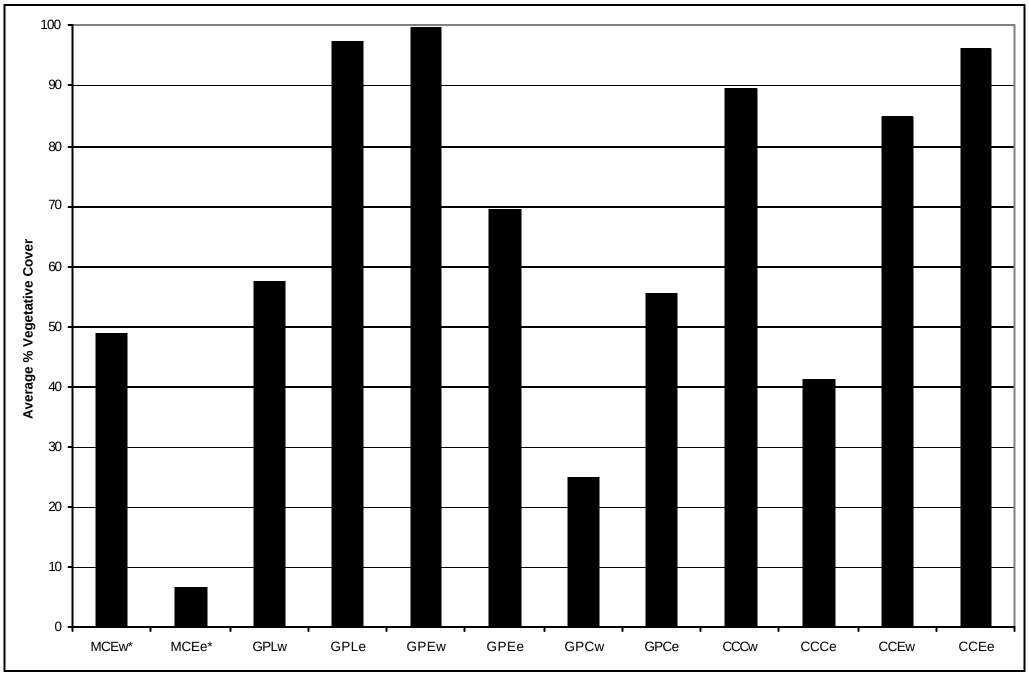
It was not uncommon for numerous species to use a particular culvert on a nightly basis, each moving through at a different time. For example, white-tailed deer, raccoons, striped skunks, red foxes, coyotes, muskrats, domestic dogs and cats were all observed to use I90L over a short period of time.

As indicated above, the final shelf design was tested in 2 additional culverts (GPL and BCL, Fig. 31 a,b, Appendix II). Both culverts were somewhat larger than those in the original study, BCL in particular was a 2.3 x 3.7 m steel corrugated squash culvert in which the shelf was hung approximately 1.5 m above the floor (Fig. 22). Within 1 day after placement this shelf was being used by numerous animals. In agreement with MDT, the shelf in BCL was removed during the May-June period to accommodate the 50-year flood plans for Bass Creek.

Figure 22. Modified animal shelf placed in Bass Creek Large culvert.

Importance of vegetative cover at culvert entrances

Percent vegetative cover (Fig. 23) and height of vegetation (Fig. 24) at the entrances to the main culverts originally varied greatly between sites. Vegetation on the eastern side of the highway was less disturbed during construction than that on the western side, since a rail line lies along the eastern boundary and highway expansion subsequently had to occur in the westerly direction (see Figs. 28-32, Appendix I). Over the duration of the current study, following the reseeding efforts of MDT, vegetation on the western side began to take hold effectively. Vegetative growth, of course, varied seasonally thus measurements were only recorded during the spring through fall months. Percent cover increased as a function of distance from the culvert entrance (Fig. 24 a vs. b). A strong correlation was also observed between percent cover/height and overall animal activity (Fig. 25). Those culverts exhibiting the greatest vegetative cover (GPE, CCE, and GPL-adjacent to GPE but not included in the main culvert design) were also the ones which exhibited the greatest amount of animal activity. One exception was noted at the MCE_e and MCE_w entrances – here, because the culvert was originally placed too low in the roadbed, standing water was continually present. The only vegetation at this entrance was either off to the sides or represented by cattails projecting through the water.



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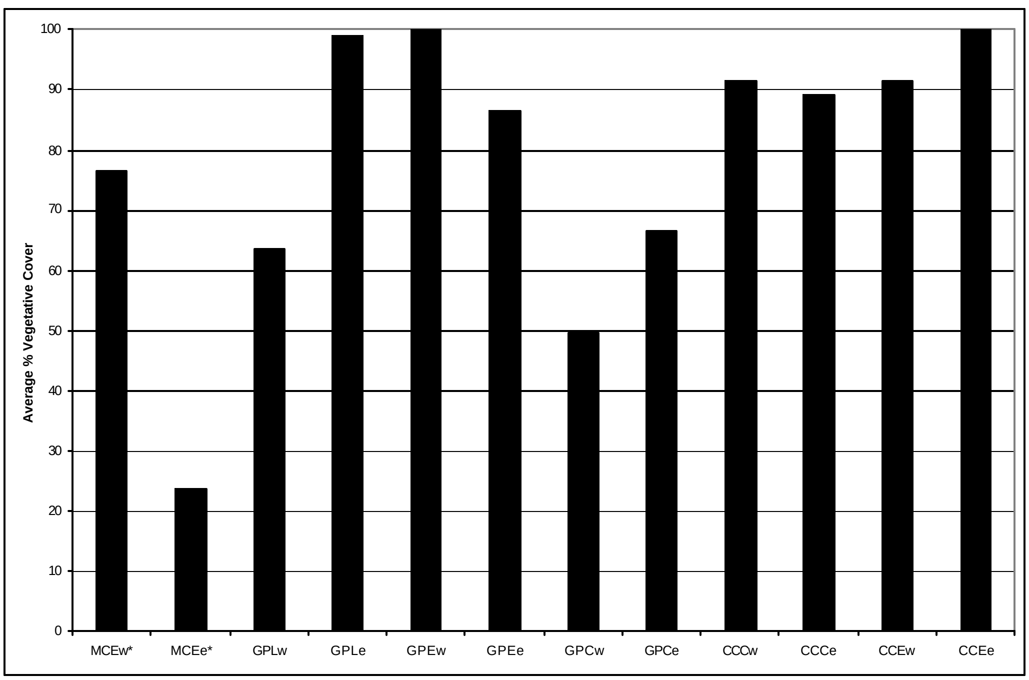

b

Figure 23. Vegetative cover at the entrances to each main culvert: (a) average % (of 3 surveys) of vegetative cover within 3 m of entrances, and (b) average % (of 3 surveys) of vegetative cover within 3-6 m of entrances (culvert abbreviations as per Table 1, page 6) [*MCE_w and MCE_e entrances were completely covered in water thus vegetative cover reflects clumps on the edges or cattails projecting through the water].

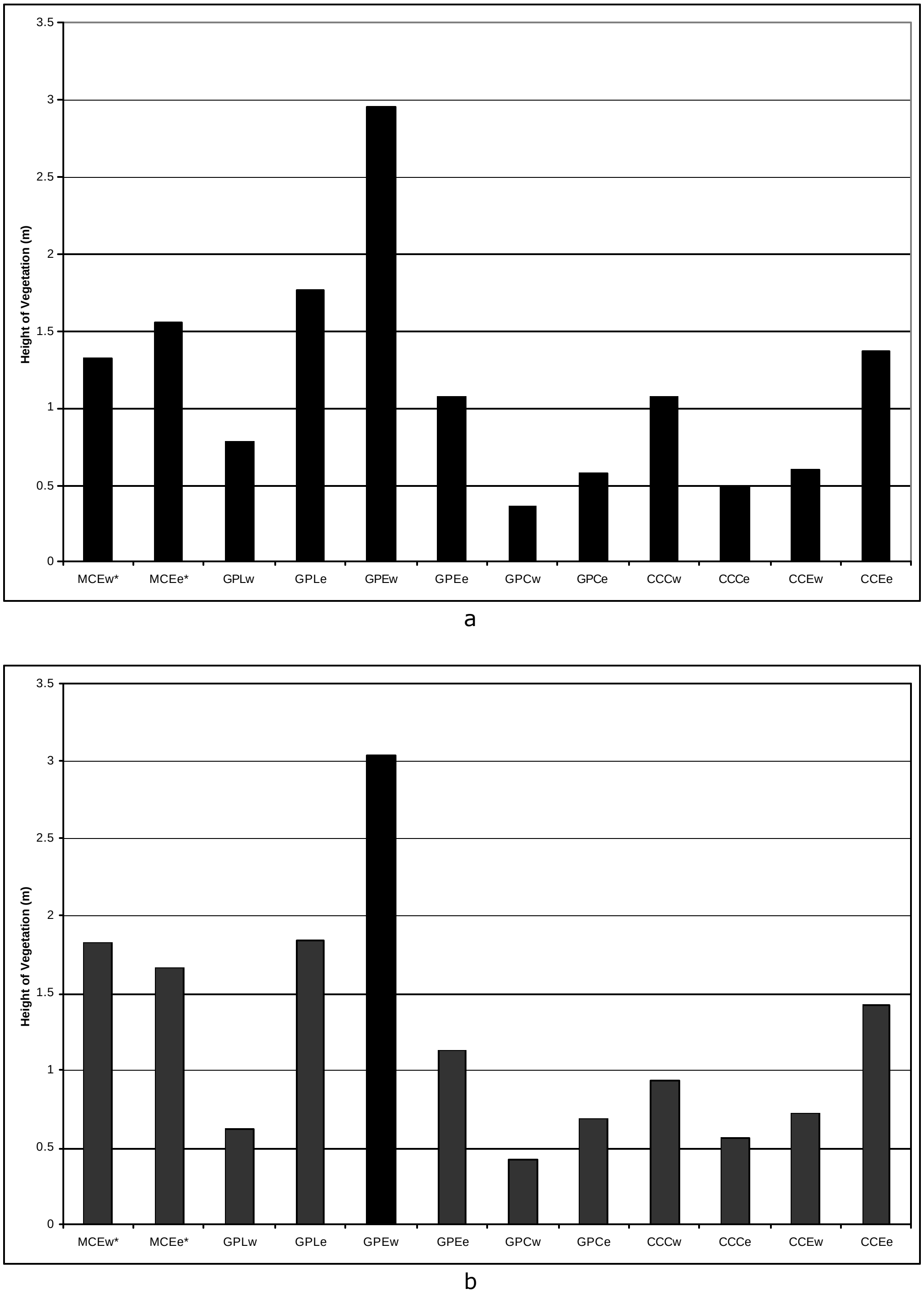

Figure 24. Height of vegetation at the entrances to each main culvert: (a) height of vegetation within 3 m of entrances, and (b) height of vegetation within 3 to 6 m of entrances (culvert abbreviations as per Table 1, page 6). [*MCE_w and MCE_e entrances were completely covered in water thus vegetative cover reflects clumps on the edges or cattails projecting through the water].

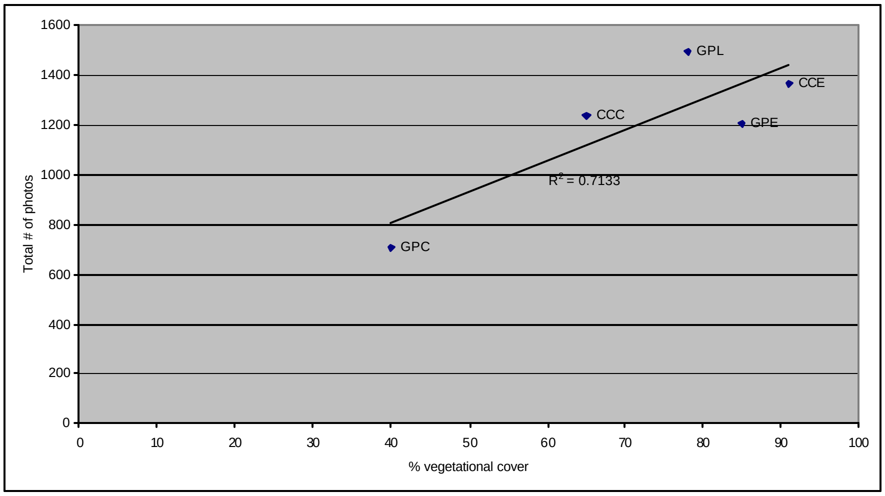

Figure 25. Relationship between vegetative cover adjacent to entrances of the main culverts and animal activity (as indexed by total number of photographs recorded; culvert abbreviations as in Table 1, page 6).

Traffic volumes

The traffic counter worked effectively between June 5, 2002, when it was installed, and December 18, 2002; at this point it began to give erroneous readings and was no longer employed. Weekly traffic counts however were very consistent during the summer and fall months averaging approximately 6,000 vehicles per day (both directions were recorded), with a peak occurring in mid-July (Fig. 26). Traffic levels were higher in early summer and noticeably declined in early winter. Since there were no exit points from the highway between the main culverts these traffic volumes accurately reflect vehicle loads along this highway section. No attempt was made to record hourly volumes though there are obvious peak periods between 6:00 - 9:00 am and 4:00 – 7:00 pm as travel from the Bitterroot valley to and from Missoula occurs. However, nearly 98% of the animal activity through the culverts occurred during darkness, generally between 9:00 pm and 3:00 am, a reflection of the nocturnal behavior of most species. Animals may thus be automatically avoiding these heavier traffic periods.

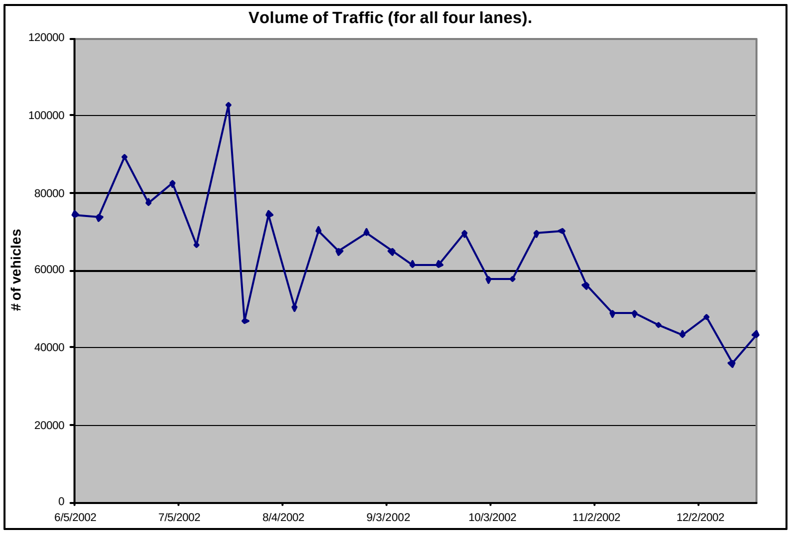

Figure 26. Weekly traffic counts along Highway 93 between Carleton Creek road and Lolo, Montana.

Animal presence adjacent to main culverts

When trapping sessions began, it became obvious that 25 traps in a transect line, along a narrow barrow pit, would not provide accurate estimates of small mammal populations. Though these populations were robust, the rail line lying along the eastern side and approximately 30 m from the highway, and a paved 2 m bike path and tilled fields immediately adjacent to the western side, limited available habitat. The decision was made instead to identify all species present in these strips and to estimate a relative index of species abundance. Animal numbers reflect total captures – some individuals may have been captured more than once. Toward this end, a total of 17 trapping sessions were run covering the period from March 2001 through September 2003, totaling 19,575 trapping opportunities. Data collected from the pilot study (*40*) is included here since it helps illustrate the overall trends observed.

One session was conducted during the first winter (January 2002), but trap mortality due to cold temperatures was so high that winter trapping was discontinued for the remainder of the study. As well, consistent rains in the late summer and fall of 2003 caused significant vole mortality so trapping was limited. A total of 7 different small mammal species were captured in the Sherman live traps over the duration of the study with meadow voles and deer mice predominating (Table 4). Trap success varied between sessions, being influenced by temperature levels, rain events, and specific animal behaviors (i.e., winter hibernation of Columbian ground squirrels; Fig. 27). An observable trend in small mammal abundance between spring, summer, and fall occurred, with meadow voles increasing while deer mice declined.

Table 4. Small mammal species captured adjacent to culverts.

Species	Relative Abundance
Meadow voles	1328
Deer mice	742
Short-tailed weasels	26
Vagrant shrews (*Sorex vagrans*)	81
Columbian ground squirrels	38
Western jumping mice (*Zapus princeps*)	1
House mice (*Mus mucsulus*)	1

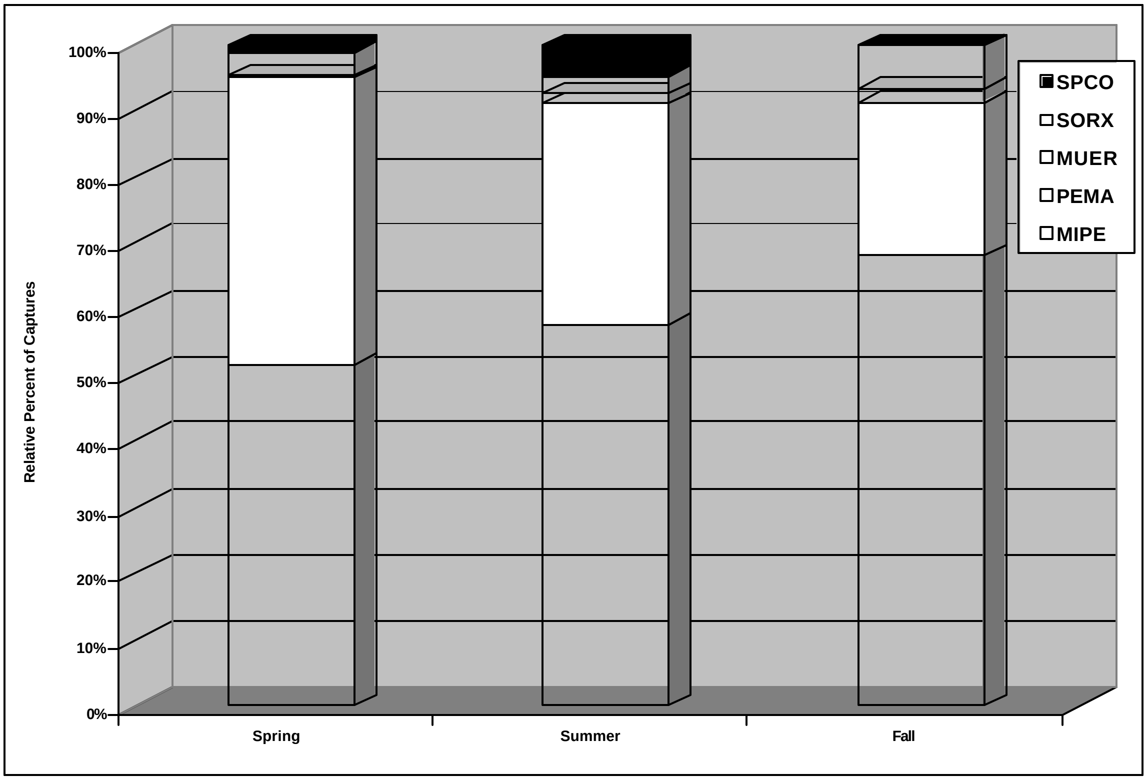

Figure 27. Summary of small mammal live-trapping sessions over the period March 2001 to September 2003. [Animal notations as per Table 3, page 10]

CONCLUSIONS

Highways by their very nature fragment the habitat through which they are built. Numerous studies have shown that such fragmentation lessens permeability to animal movement and may lead to a decrease in species diversity imparted by demographic changes as well as longer-term genetic effects (*8,9,10,41,42,43,44,45,46,47*). The present research was designed to address and hopefully mitigate for such fragmentation, specifically for small mammal populations. Specifically, the effectiveness of ramp/shelf structures within drainage culverts in allowing the movement of small mammals under a 4-lane highway during periods of water flow was studied. Initial research suggested several shelf modifications needed to be made; once these were addressed this design proved highly effective, allowing a wide variety of small mammals inhabiting the wetlands adjacent to the highway to move from one side to the other safely (Table 3; Figs. 12-14). Over 8,000 events (movements past detectors) were recorded representing 14 different mammal, and 1 reptilian species.

Movement patterns were highly seasonal (Fig. 8). Multiple factors may be responsible for these observed patterns. Decreased activity in late fall/early winter (November-January periods) most likely reflects periods of colder temperatures. Three species, the Columbian ground squirrel, yellow-pine chipmunk, and yellow-bellied marmot, hibernate during the fall and winter months and are thus not active during this period; others such as the deer mouse (the second most common species in the wetlands and the most common to use the culverts) will reduce its activity under colder conditions, entering nightly torpor, while striped skunks, porcupines, and raccoons will reduce their nighttime foraging as well (*48*). This is borne out by the observation that most activity during colder periods was concentrated within a narrow range of temperatures; in contrast, warmer temperatures provided a much wider range over which movement would occur (Fig. 10). Greater activity was observed in late winter and early spring (February-April 2002, February 2003) possibly reflecting the onset of breeding for many species and thus increased movement of males. Warmer temperatures, and little snow, were recorded during these months (the exception noted for March-April 2003 reflects significant elevation in water levels). Decreased activity in June and July may be due to lessened movement by pregnant/post-parturient females and rising water levels in and adjacent to the culverts due to spring snowmelt and rainfall (particularly the control culverts without shelving; Fig. 9). On the east side of the highway the barrow pit is narrow (~ 30 m in width) sandwiched between the highway bed and the railroad line. When the water table rises in the wetlands, this area is often under 0.5 -1 m of standing water restricting access to both control and experimental culverts. Culverts with shelves continued to record a high amount of activity, especially when water levels rose (Fig. 9).

Initial observations on how the smallest mammals walked on the shelving suggested that the 25 mm diamond-shaped, extruded metal shelf surface was too open for easy movement. Tests with a solid surface confirmed this observation and led to the test of a 6 mm mesh size. In order to meet strength constraints, the final material chosen for the shelf surface was a #13 flat galvanized expanded metal mesh. In addition, it was determined that entrance ramps had to be moved to the side of the culverts to allow unimpeded water flow, and access to the shelves when water was present. This design proved to be very effective (Figs. 15 and 16); video sequences of animal movement following these modifications further supported its effectiveness. The most common species inhabiting the wetlands adjacent to the culverts was the meadow vole yet this species was only observed in dry culverts on a few occasions. Development of vole tubes which allowed movement from the wetlands into and through the culvert without leaving protective cover also proved to be highly effective (Figs. 5, 15, 16, and 19).

The final shelf design incorporates these vole tubes in to the frame and the entrance funnel in to the surface ramp used by larger species. The entrance ramp is hinged so that it can conform to each site's topography. Built in 2.5 m sections, the shelving is designed to be easily inserted in to existing culverts so that they can be retrofitted for animal use (Appendix III).

The characteristics of larger, steel corrugated culverts were also studied in an attempt to determine their effectiveness for animal movement. Larger animal species seemed, in general, to behaviorally avoid such culverts, most likely because of the difficulty in walking on the hard, slick, corrugated surface. However, those culverts which had built up a layer of silt due to slow or intermittent water flow (notably I90L and FLO), were used routinely by a large number of species. I90 Large is particularly interesting because it lies under a 4-lane divided section of highway, and is fully 65 m in length. A total of 11 different species routinely used this culvert among which was white-tailed deer. This finding supports results of studies conducted in Banff National Park, Alberta which analyzed ungulate use of dry culverts (*38*). It must be noted however that in the cited study animal movement was dictated by continuous fencing which was not the case in our studies. In the current study, there was no indication that species such as deer respond to the "tunnel effect" (the visual impression that the distant opening of the culvert is too small to exit) created by the length of this culvert (Fig. 21 a). Canids, as well, readily used these culverts on a daily basis (Fig. 20 a,b); one coyote so consistently used the I90L culvert that it would even swim through it when the creek it served (O'Keefe Creek) rose in the spring. Another large culvert, BCL, is also of interest as this one serves South Bass Creek, and in so doing has continuous water flow. A majority of time there is 15-25 cm of water flowing through BCL, increasing to 1+ m during spring runoff. This volume is adequate enough to prevent any sediment from building up between the corrugations yet deer were often seen moving through (Fig. 21 b). This behavior further suggests that no "tunnel effect" is perceived and that deer will actively use such culverts. Most likely the riparian corridor along the southern tributary of Bass Creek, which is heavily wooded on both sides of this culvert directly up to both entrances, serves as a natural, protective funnel for deer (and other species as well, e.g. – raccoons, fisher). This illustrates the importance of adjacent vegetation to animal use of culverts.

Most wild species use vegetative cover to either hide from predators or sneak up on prey. As such, they avoid open areas as are often found at the entrances to culverts. Earlier studies identified vegetative cover near tunnels/culverts as one of, if not the most important attribute influencing small mammal use (*15,37,38,49*). Our studies support this finding, demonstrating a direct correlation between use of the main culverts and the % of vegetative cover present (Fig. 25). One interesting observation was made between meadow voles and deer mice, the predominant species in the wetlands. These two species exhibit nearly completely opposite behaviors: meadow voles hide under vegetation and move along runways which they themselves create, totally avoiding open areas and thus culverts (*10,48*); deer mice, however, prefer disturbed and open habitats and, as such, freely move across open areas at the entrances to culverts and enter them as has been documented (*18,40,48*). Vole tubes, as described above, solved this avoidance behavior of meadow voles.

The volume of traffic along a roadway translates in to a variety of disturbances such as increased noise levels, increased pollution, and a general increase in overall visual disturbance (*24,43*). These factors have been shown to affect animal populations in adjacent areas creating, in many cases, what is known as a "road avoidance zone" (*24,43,50,51,52,53,54*). Some studies suggest that animals may become habituated to a constant, predictable level of disturbance (*55,56,57*) but this is not borne out by other studies (*54*). Traffic volumes along the section of Highway 93 served by the main culverts in the current study remained relatively constant, though a slight elevation was observed in early summer (June/July), while a slight reduction occurred in early winter (November/December) (Fig. 26). No correlation between this activity and animal use of these culverts was apparent (compare Fig. 26 with Fig. 8). Though this section of highway was expanded from 2-lanes to 4, and would be expected to carry an increased traffic load in the future, it is unlikely that increased volumes occurred just during, or immediately following this expansion, the time period encompassing the course of this study. It would be interesting to revisit this issue along this section of highway in 10-15 years as increased development in the Bitterroot Valley, and thus increased traffic volumes, continues.

Live-trapping of small mammal populations adjacent to the main culverts over the duration of this study provided the data necessary for determining which species would effectively use these structures to circumnavigate the highway. As previously explained, this information was useful in determining the need for, and the creation of, tubes for meadow voles. Small mammal use appeared to be directly proportional to the relative abundance of the species (Table 4) with one exception, that of the Columbian ground squirrel. This species was trapped periodically during the summer months, specifically adjacent to the west entrances of GPE and GPC. Transect lines placed here lay directly adjacent to drier, cultivated fields which supported a large population of this species. The habitat on the eastern side of these culverts was much more moist, and more heavily vegetated, inappropriate habitat for this species, and thus little movement in this direction occurred. The trend which was noticed in deer mouse and meadow vole populations from spring through fall (declines in deer mice/increases in meadow voles) may be explained by the different reproductive characteristics of these species. Deer mice in Montana begin breeding in March and may produce 3-4 litters over the course of the spring and summer (*48*). Meadow voles however, can breed throughout the year and they exhibit a shorter gestation period and larger litter sizes. The trend in relative abundance may have also been influenced by mowing of the vegetation by MDT immediately adjacent to the pavement. This area was strictly inhabited by deer mice while meadow voles were restricted to the more mesic, lower sites. The paucity of Columbian ground squirrels in the spring and fall, compared to their abundance during the summer simply reflects the fact that they hibernate from early August until mid-April (*48*).

RECOMMENDATIONS

Three recommendations clearly arise from the results of this study:

(1) Small mammal shelving with built-in vole tubes should be employed in all culverts where habitat characteristics are appropriate and preclude the installation of dry culverts (e.g., wetlands adjacent to the highway, permanent water sources which are serviced by a culvert). The cost of such structures is minimal and their effectiveness in allowing animal movement under the highway is proven. Steel corrugated culverts can easily be retrofitted with such shelving. If placed in larger culverts, small mammal movement can be accommodated along with the movement of larger species (see recommendation #2 below) at a fraction of the cost of bridge-type wildlife structures.

(2) Evidence suggests that species such as deer will readily use large, steel corrugated culverts if these are tied to protective vegetation at their entrances. Further studies should be conducted to determine the best way to modify the floor corrugations to provide a more natural surface. Once appropriate modifications are identified, it is felt that this type of wildlife structure would be as functional as bridge-type structures for a fraction of the cost.

(3) Vegetative cover at culvert entrances is required in order for most, if not all, species to access them. Additional studies would be useful to identify the most appropriate plant species that would provide such cover while not impeding water flow.

IMPLEMENTATION

Small mammal shelves, as described here, have now been incorporated in to the final engineering plans of Peccia & Associates for Phase 5 of the Highway 93 South reconstruction from Florence to the Stevensville Wye. Additional such shelves have also been identified for placement along the Conner section of highway south of Hamilton, Montana.

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APPENDIX I: Main Culverts in this study and vegetative cover at their entrances

West entrance heavily vegetated

East entrance heavily vegetated

Figure 28. Carleton Creek Experimental Culvert

West entrance unvegetated

East entrance well vegetated

Figure 29. Carleton Creek Control Culvert

West entrance heavily vegetated

East entrance heavily vegetated

Figure 30. Gravel Pit Experimental Culvert

West entrance sparsely vegetated

East entrance vegetated

Figure 31. Gravel Pit Control Culvert

West entrance heavily vegetated

East entrance heavily vegetated

Figure 32. Maclay Flats Experimental Culvert

(*) The Maclay Flats Control culvert was placed too high in the roadbed to serve as an appropriate control as it is continually full of water thus it was omitted from this study.

APPENDIX II: Additional culverts added during this study


a


b

Figure 33. Additional culverts along Highway 93 South: (a) Gravel Pit Large, and (b) Bass Creek Large.

Figure 34. Additional culvert added along Highway 203: Florence culvert.


a


b


c

Figure 35. Additional culverts along Interstate 90: (a) I90 Large, (b) I90 Small, and (c) Double culvert

APPENDIX III: Final design of animal shelves.

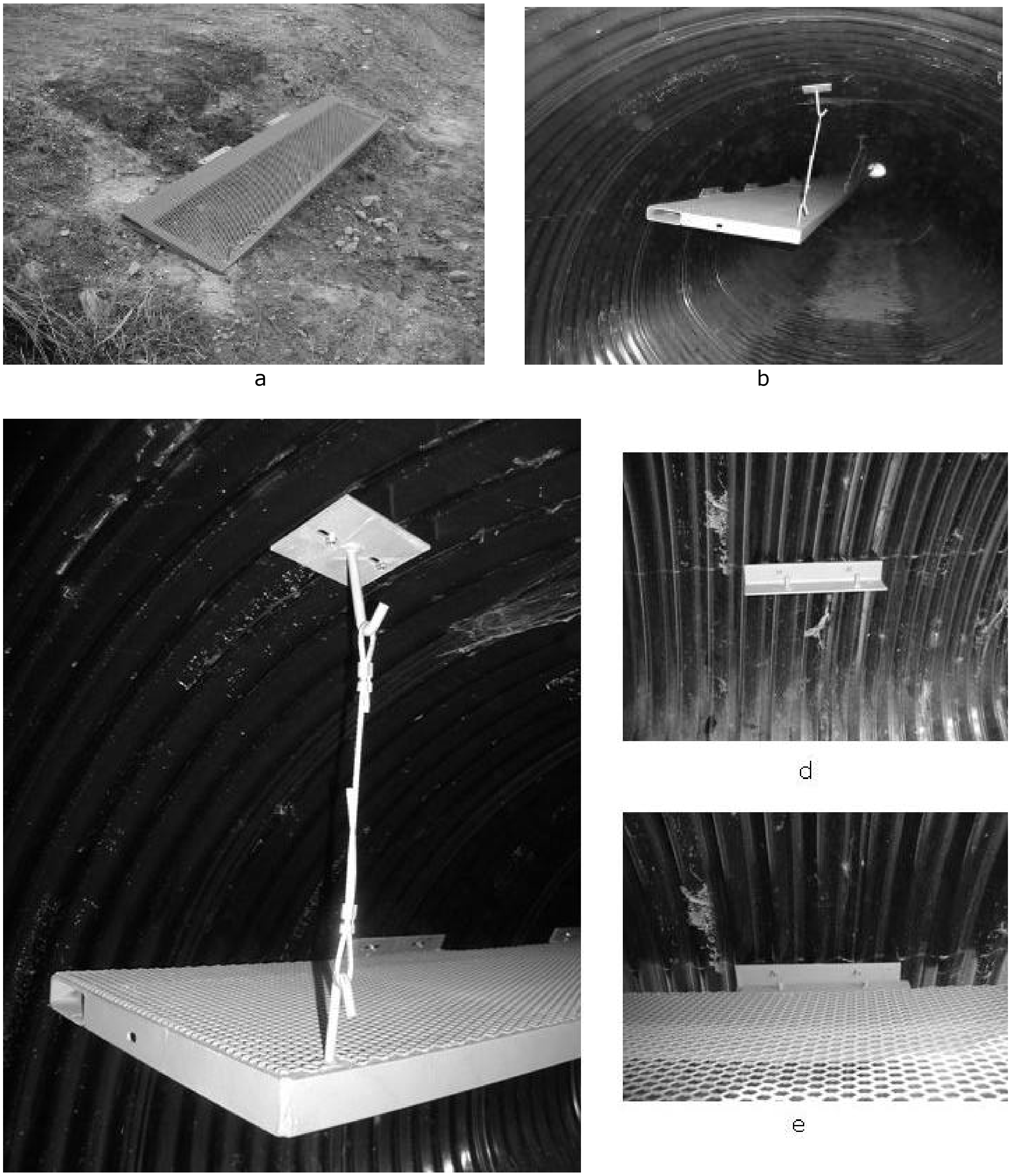

Figure 36. Final design of animal shelf: Individual 2.5 m sections were built with brackets to hang from the side of the culvert as well as from above (a), shelf in place illustrating connected sections as well as vole tube (b; see also Fig. 18a), roof bracket to support shelf and cable from which it is hung (c), side mounting bracket with pins to support shelf (d), and shelf in place (e). [Roscoe Steel & Culvert Co., Missoula, MT; www.roscoesteel.com]