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IDENTIFYING THE BEST LOCATIONS ALONG HIGHWAYS TO PROVIDE SAFE CROSSING OPPORTUNITES FOR WILDLIFE

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16. Abstract

This document is primarily a manual to aid highway planners and designers in managing wildlife crossing of roadways. Because the preferred habitat and behavior of a given species can vary across its range, it is important to employ professionals familiar with the landscapes and species of concern on the analysis team. The results of the study also suggest that to maximize cost- and biological-effectiveness, wildlife considerations should be incorporated into initial project planning and design. This approach avoids costly redesign delays stemming from environmental compliance obligations by considering reduction of wildlife/highway conflicts as a baseline design constraint. It also allows designers to find engineering solutions that do double duty, e.g., positioning retaining walls to stabilize slopes and serve as roadside barriers to guide animals to a safe crossing location. Finally, it may be necessary to work with the entities that manage landscapes surrounding projects to maintain the landscape structure cues that bring animals to mitigated crossing locations.

The purpose of the handbook is to describe the highway and landscape variables that highway planners/designers should consider when choosing the best locations for mitigation that helps medium- and large-sized mammals cross highways safely.

Implementation:

This manual should be used when planning and designing major highway improvements or new roadway alignments. It should also be used in designing wildlife impact mitigation projects.

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Identifying the Best Locations Along Highways to Provide Safe Crossing Opportunities for Wildlife

A Handbook for Highway Planners and Designers

by
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The purpose of the handbook is to describe the highway and landscape variables that highway planners/designers should consider when choosing the best locations for mitigation that helps medium- and large-sized mammals cross highways safely.

Executive Summary

Providing mid- and large-sized mammals with safe opportunities to cross roadways can reduce the impacts of highways on wildlife. To maximize effectiveness, this type of mitigation must be placed in locations where animals naturally approach and cross the highway. Results of a study funded by the Colorado Department of Transportation indicate that mid- and large sized mammals focus crossing activity at specific locations that are correlated to features of the surrounding habitat and the roadway itself. Therefore, both the design of a highway and its placement in the landscape should be considered when creating mitigation projects to help wildlife safely cross a highway. Design-based mitigation may consist of minimizing barriers to ease at-grade crossing or providing structures for above- or below-grade crossing while using barriers to discourage at-grade crossing. Appropriate habitat management in landscapes surrounding crossing locations may also be used to reduce crossing rates in some cases.

It is important to note that no single set of variables identifies all preferred crossing locations. Because every landscape and every highway is unique, identifying the best location for each mitigation project must be approached individually. However, the study results suggest a set of analysis guidelines, comprised of the following:

- Use habitat suitability as the primary indicator of crossing activity.
- Consider how landscape structure interacts with habitat suitability to increase or decrease the level of use an area of suitable habitat receives by a particular species.
- Consider how highway design will interact with habitat suitability and landscape structure to influence crossing behavior.
- Synthesize this information by mapping the landscape and roadway features/conditions likely to be associated with crossing or that are attractive/repellant to the species present. Use these maps identify the most likely crossing locations.

Because the preferred habitat and behavior of a given species can vary across its range, it is important to employ professionals familiar with the landscapes and species of concern on the analysis team. The results of the study also suggest that to maximize cost- and biological-effectiveness, wildlife considerations should be incorporated into initial project planning and design. This approach avoids costly redesign delays stemming from environmental compliance obligations by considering reduction of wildlife/highway conflicts as a baseline design constraint. It also allows designers to find engineering solutions that do double duty, e.g., positioning retaining walls to stabilize slopes and serve as roadside barriers to guide animals to a safe crossing location. Finally, it may be necessary to work with the entities that manage landscapes surrounding project maintain the landscape structure cues that bring animals to mitigated crossing locations.

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Part 1. Introduction

Results of a study (No. 32.40) funded by the Colorado Department of Transportation (CDOT) indicate that mid- and large-sized mammals do not cross highways randomly. Instead, they focus crossing activity in locations that can be correlated to characteristics of the surrounding habitat and of the roadway itself. The study recorded the locations where mule deer, elk, and coyotes crossed two Colorado highways for two years. One study area was located in the Trout Creek Pass area along US 24 (MP 116.0 – 126.0), a low-volume, two-lane highway. The other study area was located in the Vail Pass area along I-70 (MP 183.0 – 195.0), a moderate- to high-volume, four-lane highway. Both study areas were broken in to sub-areas for data analysis purposes (see Appendix A for maps and a complete description of the study areas and methods).

The study results apply directly to Colorado's mountain environments and the common species that live there. However, they also provide insight into identifying the best locations to provide safe crossing opportunities for other mid- to large-sized mammal species in a variety of habitats. The findings are summarized below, and discussed in greater detail in Part 2. Strategies to identify the crossing locations for mitigation are discussed in Part 3. Tactics for creating effective mitigation are discussed in Part 4. Detailed summaries of the study methods and results are presented in the Appendices.

At-Grade Crossing

Crossing "hotspots" were identified from the data collected, and correlated to features from the surrounding habitat and the roadway itself (see Appendix A for a detailed discussion of the methodology). The results of the study suggest the following three primary findings:

1) **Highway Placement Matters.** The characteristics of the surrounding landscape play a role in determining which sections of highway are crossed most often. Therefore, the placement of a highway within a landscape will affect how often each section of that highway is crossed.

2) Highway Design Matters. The locations of roadside barriers as well as structures that can act as under- or overpasses have a significant impact on where animals are most likely to cross the road.

3) No Single Set of Variables Identifies All Crossing Zones. Because every landscape and every highway is unique, choosing the location and design of each mitigation project must be approached individually. However, there is a basic set of guidelines that will direct each analysis.

Below-Grade Crossing

In addition to at-grade crossing, below-grade crossing opportunities were monitored for use by all wildlife during the study. Monitored structures included large concrete box culverts (CBCs) and bridges. Dimensions of the structures varied greatly, but dry footing was present in all. Although only one of the monitored structures was constructed specifically to act as a wildlife underpass, subsequent discussion of these structures will refer to them as “underpasses”. Roadside barriers did not force animals to use any of the monitored underpasses; at all locations, animals had the option of crossing at-grade if they preferred. Although the results of the underpass monitoring could not be quantitatively evaluated (see Appendix A), a qualitative assessment indicated the following:

- A wide variety of culvert and bridge designs were used frequently by a wide variety of species, including mule deer, coyotes, mountain lion, bobcat, fox, American marten, rabbits, and small mammals.
- Deer were most likely to use underpasses at least 2.5 m in height and with a natural bottom.
- The surrounding habitat, as well as the design of the structure, played a role in which underpasses were used most frequently.
- The evidence suggests that mid- and large-sized mammals species may prefer to use high quality below-grade crossing opportunities instead of crossing at-grade, in locations where they have a choice.

Part 2. The Habitat and Roadway Features Correlated with Crossing

Study results indicate that mid- and large-sized mammals select road-crossing locations based on features from both the landscape scale and the local (roadside) scale. Concentrated crossing activity by these species was evident at both scales. At the landscape scale, there were long (> 2km) segments of roadway that were crossed more often then other segments. This pattern occurred even where the highway was entirely surrounded by suitable habitat. The highway segments that were crossed most often can be thought of as *conflict zones*, because animals on the roadway risk being hit by vehicles and they create a safety hazard for highway users. At the local scale, there were crossing hotspots, i.e., the locations within a highway segment that had the highest rates of crossing, relative to the rest of the segment. Hotspots occurred both within conflict zones and in segments with lower crossing rates. However, there were more hotspots within conflict zones. Because hotspots varied in length from about 30 up to 600 m in length, it is best to think of them as *crossing zones*, rather than point locations. The features correlated to crossing activity within both types of zone are discussed below.

Features Correlated with Conflict Zones

The study indicated that certain qualities of the landscape were correlated with conflict zones. They include suitable habitat, linear guideways, and slope steepness and complexity. These qualities are discussed in detail below.

Suitable Habitat: The presence of suitable habitat on both sides of the road was the baseline condition required for animals to cross the roadway on a regular basis. The better the habitat, the higher the rates of crossing. This may be the single most important factor for species that have narrow habitat preferences. Species that have broad habitat preferences (e.g., deer, elk, coyotes) have a greater opportunity to be affected by other factors.

Linear Guideways: Linear guideways can either encourage or discourage crossing, depending on their orientation to the roadway. Highway segments located in landscapes that contained guideways oriented perpendicular to the roadway had higher rates of crossing than segments located in landscapes where guideways ran parallel to the roadway. Guideways that lead animals through the landscape included drainages, ridgelines, and sharp breaks in cover type. Other potential guideways include fence lines, sharp changes in land use, and side roads that receive low rates of human use.

Slope Steepness/Complexity: Highway segments located in landscapes comprised of relatively moderate slopes with low complexity (i.e., landforms are not too rugged) adjacent to the roadway had higher crossing rates. This effect was most pronounced in large areas of suitable habitat where animals had the opportunity to pick the easiest travel routes. If a species preferred rugged terrain (e.g., bighorn sheep, mountain goats) the opposite effect would be expected

Features Correlated with Crossing Zones

Results of the study indicate that features from the roadway itself and the habitat immediately surrounding the roadway were correlated to crossing zones. They include barriers, the distance to cover, and linear guideways and are discussed in detail below.

Barriers: Deer, elk, and coyotes avoided barriers (Jersey barrier, guardrails, walls, and steep road cuts) when entering a roadway, although they readily jumped Jersey barrier and guardrail to exit. Animals commonly entered the roadway at the ends of barriers, and rarely wandered along between the barrier and the road before crossing, if the space was narrow. However, animals sometimes walked hundreds of meters along roadsides before crossing if a barrier did not confine them. Other researchers report similar results (Carbaugh et al., 1975).

Distance to Cover: The species that commonly crossed the road in this study were most likely to approach the roadside in areas where a moderate amount of cover (i.e., suitable habitat) was present. However, they did not require cover up to the road's edge in order to approach the roadside. The amount cover within 90 m of the roadside was not correlated with the location of crossing zones. Instead, crossing zones tended to be located along highway segments that had smaller average distances from the roadside to the cover's edge throughout the segment. The characteristics of crossing locations of species that prefer dense cover or no cover at all are expected to vary accordingly.

Linear Guideways: The intersection of linear guideway with a roadway often created a well defined, intensely used crossing zone. This effect is most pronounced for drainages, because drainages tend to be well defined. Ridgelines also guided animals to the roadside, but tended to create more diffuse crossing zones, as the ridgelines themselves are less discrete. In addition, when a ridgeline and a roadway intersect, extensive cutting is often required, and the slopes that are created may be steep, further diffusing the crossing activity at that location.

Underpass Use

For all species, both the characteristics of an underpass itself and the surrounding habitat appeared to play a role in the level of use it received. For example, at Trout Creek Pass, underpasses varied in design, including single chamber CBCs, multi-chamber CBCs, and single span bridges with natural floors. One of the bridges was the most open (height x width/length) structure checked for tracks, and it received the most consistent levels of use, including large numbers of deer, as well as some bobcats and coyotes. However, a high openness value and a natural floor did not guarantee use. A single span bridge located in the north end of the study received lower rates of use then any of the CBCs. Habitat suitability factors limited at-grade crossing at north end of Trout Creek Pass and probably had a similar effect on underpass use.

The underpasses at the Vail Pass study area were all over-sized bridge structures and provided exceptionally high quality below-grade crossing opportunities for wildlife. They ranged from 3.9 to 13.5 m in height and from 21.9 to 218.0 m in width. Because of these generous dimensions, the natural ground cover, including trees, grew underneath many of them. The use of these structures appeared to be most heavily influenced by the pairing of underpasses that allowed animals to cross under both the east- and the westbound lanes of traffic with ease. The two most heavily used underpasses differed greatly in dimension (see Appendix B) but were both located on the west side of the pass, where the east- and westbound alignments were side-by-side. On the east side of the pass, the alignments were separated by a wide (> 200 m) median, and the underpasses along the eastbound lanes were not mirrored in the westbound lanes. The underpasses on the east side of the pass were otherwise similar in construction and dimension to the west side underpasses. Therefore, the ease of crossing the entire highway, rather than an underpass' design and dimensions appeared to play the major role in regulating an underpass' rate of use.

On the east side of the pass, the uneven distribution of underpasses also appeared to influence the rate and location of at-grade crossing. Exactly twice as many at-grade crossing events were recorded in the westbound lanes, which had only a single underpass, as compared to the eastbound lanes, which had four underpasses. Further, the crossing zones in the westbound lanes were roughly aligned with underpasses in the eastbound lanes. These patterns suggest that mid- to large-sized mammals prefer to use high-quality below-grade crossing opportunities when they have a choice.

Part 3. Identifying Crossing Locations for Mitigation

All new highways and highway up-grades located in wildlife habitat should be evaluated for opportunities to reduce wildlife/highway conflicts. Both design- and habitat-based mitigation should focus on conflict zones. These are the locations where animals are most likely to come in contact with the highway. Additionally, the location of discrete design-based mitigation projects, such as under- and overpasses, should focus on crossing zones, the local-scale locations along highway corridors where animals are most likely to cross the roadway.

<u>Methodology Note:</u> Maps depicting the vegetation and topography surrounding a highway project are required for the types of analyses described below. Landscape maps must then be combined with maps that accurately depict features of the existing and/or proposed roadway. Digital data that can be displayed and manipulated with a GIS provides the best platform for analysis.

<u>Animal/Vehicle Collisions and Crossing Locations</u>

Because conflict and crossing zones are crossed more often by wildlife then surrounding segments, they may have higher-than-average rates of animal/vehicle collisions (AVCs) reported. However, because AVC rates are dependent on traffic volume as well as the number of animals crossing the roadway (Roof and Woodling, 1996; Barnum 2000), this effect may not be apparent for low volume roads. Therefore, although AVC data can help identify conflict zones, it cannot replace information about the surrounding habitat and landscape structure into an analysis of crossing locations, as described below. It is also important to note that AVC data is not useful for identifying crossing zones. The primary source of these data is usually State patrol accident reports, which often estimate collision location to the nearest milepost, and rarely more precisely then the nearest tenth of a mile. Therefore, AVC data provides adequate precision to identify conflict zones, which are generally over 2 km in length, but not for crossing zones, which are generally 30-600 m in length.

Identifying Conflict Zones

As described in Part 2, the relative importance of different landscape features in creating conflict zones varies from location to location. For example, deer and elk will travel through steep, rugged terrain that they might otherwise avoid if that area has the most suitable habitat, compared to adjacent areas. However, if they have a choice within the area of suitable habitat, they are likely to choose the easiest travel route. The effect of landscape composition on crossing behavior is also influenced by roadside and roadway features of existing highways. For example, the presence of extensive roadside retaining walls will prevent animals from crossing in locations where landscape structure might otherwise induce them to do so. Finally, local habitat preferences and behavior can play a significant role in how a species responds to landscape structure. For example, the habitat preferences of elk vary across their range and some populations of elk are sensitive to human disturbance, while other populations are not. Determining the effect of recreational activities on habitat suitability near a highway, and the consequent likelihood of elk approaching the roadside in that area requires local knowledge about both the habitat preferences and the behavior of that population. Thus, understanding how landscape composition and habitat preferences effect crossing locations requires familiarity with the landscape in question and the species that are likely to be present.

The information discussed above indicates the following strategy for identifying areas with a high potential to be conflict zones:

- Employ professionals familiar with the landscapes and species of concern.
- Use habitat suitability as the primary indicator of a potential conflict zone.

- Consider how landscape structure may interact with habitat suitability and either increase or decrease the level of use an area receives by a particular species.
- Consider how design of the existing and/or proposed highway affects the expression of habitat preference at the roadside.
- Consider accident data as an auxiliary source of information.

Methodology Note: A variety of commercial digital data products are available to assist with landscape level analyses. These include digital elevation models (DEMs) and national land cover data (NLCD) from the U.S. Geological Survey. Other products, such as digital aerial photography and local or statewide land cover data, are available from local agencies and commercial sources, or can be commissioned through contractors.

Identifying Crossing Zones

Crossing zones are relatively short stretches of highway that have the highest probability of being crossed by wild animals. As discussed in Part 2, features from both the surrounding habitat and the existing highway focus crossing activity, creating a crossing zone. However, as with conflict zones, there was no single suite of variables associated with all crossing zones. Local conditions and interactions between variables mediated the influence a variable exerted at a particular study site.

An important local condition that regulates whether a feature may be useful for identifying crossing zones is the amount of variability in that feature. For example, crossing zones at four out of the six sub-areas studied were positively associated with highway segments that were closer then expected to the cover's edge. In contrast, on the west side of Vail Pass, the design and construction of the roadway resulted in a very consistent distance between the pavement and the forest edge. Consequently, there was little variability that animals could cue on, and distance to forest edge was not correlated with crossing zone locations in this sub-area.

Unique local conditions can also play a key role in determining the influence a feature has on crossing zones. For example, at five of the six study site sub-areas, the locations where drainages intersected the roadway were strongly correlated with crossing zones.

However, at the north end of the Trout Creek Pass the positive association of crossing zones with the forest edge was so strong that it created a negative association with drainages. Reasons for the strength of the relationship with the forest edge include the following: the cover type along the roadside was mostly open grasslands at this site, creating a relatively narrow tongue of forest leading to the roadside; the forest edge was generally a long distance from the roadside in this sub-area, magnifying its effect where it came close to the roadway; there were few other well defined features, such as drainages or barriers, which could also act to focus crossing activity. Additionally, the linear guideways that were present were far away from the highway segment near the forest edge. None of these three conditions existed at any of the other five sub-areas.

Another example of unique local condition overriding other variables that might otherwise act as cues to crossing is the presence of the Copper Mountain ski area at the foot of Vail Pass. In wintertime, the lure of food sources associated with the resort and easy travel on the compacted snow of the ski runs was a strong attractant for coyotes in the area. As a result, neither the locations of barriers nor the distance to the forest edge was important to them when they crossed the road, and they showed a weak negative association with drainages. Additionally, coyotes crossing I-70 near Copper Mountain used all slope classes consistent with their availability, even though animals crossing I-70 in the rest of the Vail Pass study area in winter showed a strong preference for shallow slopes.

As with landscape-scale variables and conflict zones, the relationships of the local-scale variables to crossing zones differed by location. However, they made sense to someone familiar with the resources available in the landscapes in question, as well as the habitat preferences and behavior of the species under consideration. In summary, the information discussed above suggests the following strategy for identifying locations with a high potential to be crossing zones:

- Employ professionals familiar with the landscapes and species of concern.
- Locate and map features likely to be associated with crossing zones and known to be important to the species present. Pay special attention to the

location of drainages, barriers, special habitat features (e.g., food sources), and the distance to cover (for species that use cover).

- Using these maps, determine the relative abundance of each feature, and how much variation it exhibits along the roadside.
- Place greater reliance on features that are highly attractive to resident species, especially if those features are rare, and to features that are relatively variable.

Methodology Note: Maps of roadside and roadway features are easy to create by driving slowly along a roadside and identifying features of interest. A handheld GPS devise/data logger and a laser range-finder can be used to collect positional information about these features. These data can then be displayed and analyzed in the office using standard GIS software (see Appendix A, also Carson et al., 2001; Barnum, 2003).

Part 4. Creating Successful Mitigation Projects

The best type of mitigation to help wildlife safely cross a highway and the best location for that mitigation depends on the structure of the surrounding landscape, highway design, and the species in question. After identifying the areas within a highway project that are most likely to be conflict and crossing zones, the next step is to choose a mitigation approach. The three mitigation approaches discussed below are:

- Avoid placing/upgrading highways in landscapes that are likely to create conflict zones.
- Use highway designs that incorporate safe crossing, and guide animals to those locations.
- Manage the landscape surrounding a highway to support mitigation efforts.

Additionally, because highway design plays a crucial role in successful mitigation, it is most likely to be cost- and biologically effective when:

- Mitigation considerations are incorporated into initial project planning and design.

Identify and Avoid High Conflict Locations

As discussed above, some parts of the landscapes are more likely than others to facilitate the movement of animals, consequently bringing them to the roadside. Using the strategy described in the previous section, planners can identify those areas and avoid placing or upgrading highways in them. In practice, a highway alignment must meet a variety of criteria, not only the reduction of wildlife/highway conflicts. Therefore, a least-cost analysis to determine the best location when all criteria are considered could be used to facilitate the process. Least-cost analysis tools, which can incorporate a multitude of considerations, have been developed for highway siting (e.g., Innes and Pugh, 1996; Jha, 2000).

The "identify and avoid" approach is most effective when implemented prior to construction as part of the process for choosing the best alignment for a new highway. Because few completely new highways are likely to be built in the US, potential to avoid high conflict areas altogether is limited. However, upgrades and realignments of existing roadways provide opportunities to implement this approach on a limited basis. Additionally, upgrades may have fewer constraints, as compared with a brand new alignment, especially in non-urbanized areas where wildlife populations tend to be larger. Therefore the opportunity to (re)design and (re)align with wildlife in mind might also be comparatively greater in these situations.

Design-Based Approaches to Reduce Conflicts

As detailed in Part 2, habitat features at the roadside and the design of the highway itself combine to determine the locations of crossing zones. Therefore, roadway design at the locations where wildlife naturally approach the roadside plays a major role in how easily and safely animals will be able to cross the roadway. With this in mind, design-based approaches for mitigating wildlife/highway conflicts include:

- Where traffic volumes are low, maximizing at-grade crossing opportunities by minimizing the barrier effect of the highway itself.
- Using crossing structures to accommodate animal movements above- or below-grade.

Minimizing the Barrier Effect of the Highway: For low-volume highways where AVCs do not present a significant safety hazard to animals or to the occupants of vehicles, the most cost- and biologically-effective strategy for reducing wildlife/highway conflicts is simply to encourage animals to cross freely at-grade. Limiting steep cuts and fills, Jersey barrier, guardrails, retaining walls, and the width of the road will minimize the barrier effect of the roadway. Where barriers are required, keep in mind that barrier ends can funnel animals onto the roadway. This effect may create a crossing zone in a highway segment where crossing would otherwise be diffuse. Therefore, if barriers are required, the ends should be located where there is a good line of sight to give motorists adequate time to avoid animals that enter the roadway at these locations.

Crossing Structures: Roadway designs that discourage at-grade crossings and guide animals to locations with above- or below-grade crossing opportunities may be the preferred mitigation approach under a variety of circumstances. These include high-volume roads, high AVC areas, and areas where a highway conflicts with heavily-used migration routes or the movements of threatened or endangered species. Structural components of a highway that create safe crossing opportunities include underpasses and overpasses built especially to provide highway crossing for wildlife. However, the study results suggest that adjustments to design features, which would be part of a project for other reasons, can also meet mitigation needs. Generously sized drainage culverts, bridges with adequate headroom, and alignments that include either elevated sections of roadway or contain the roadway in a tunnel can also act as under- or overpasses, respectively.

Existing research examining the effectiveness of different under- and overpass designs is summarized in the recent book *Road Ecology* (Forman et al., 2003). Although there is probably no single design that would be preferred by all species under all circumstances, this reference provides an excellent source of background material to guide design decisions. In general, the following four consideration will maximize use of crossing structures by wildlife: 1) maximize underpass openness (width x height/length); 2) use natural floors; 3) maintain natural vegetation around underpasses or on overpasses; and 4) when modifying standard drainage structures to do double duty as an underpass, provide a dry path for animals to use. Lack of dry footing may discourage some species from using the structure and can create serious icing problems during cold weather.

Barriers that discourage animals from crossing at-grade and/or guide them to crossing structures probably also increase structure effectiveness. Although these barriers may also be constructed specifically for mitigation purposed (i.e., animal-proof fencing), other project features may serve the same purpose. For example, extending roadside barriers (e.g., guardrails, Jersey barrier) placed to meet safety requirements where drainage bisects the roadway may then help guide animals to an over-sized box culvert.

Crossing structures are unlikely to be used if placed in a location where the surrounding landscape does not naturally bring animals to the roadside. Conversely, barriers should not be placed within crossing zones without accompanying safe crossing opportunities. Despite the presence of barriers, animals will continue to approach the roadside in locations where landscape structure combines with resource distribution to encourage crossing behavior. Animals approaching the roadway in these locations will search for opportunities to cross the roadway. Even small breaks in barriers placed in a crossing zone are likely to become a focal crossing location, creating a serious AVC hazard.

In addition to placing crossing structures in the best location, a crucial consideration for this type of mitigation approaches is identifying the location and length of conflict zones and crossing zones relative to the length of highway project. Conflict zones may extend for many kilometers along a roadway and crossing zones may also be many hundreds of meters in length. Therefore, a relatively small project area may only partially overlap with or be completely contained within either type of area. If the barriers used to guide animals to crossing locations within the project area simply end at the project's boundaries, they may funnel animals onto the roadway at these locations, potentially creating a more intense source of conflict than previously existed. In such cases, it may be necessary to extend the mitigation project beyond the boundaries of the highway project for design-based mitigation to be successful.

Manage the Surrounding Landscape to Support Mitigation Efforts

Management of the surrounding landscape can support mitigation efforts in two ways. First, it may be possible to reduce the frequency of crossing in some locations by improving the resources available to wildlife on one or both sides of the road. Second, in locations where safe crossing opportunities are provided to wildlife, the cues from the landscape that guide animals to those locations must be maintained. Transportation agencies, however, generally only have direct control over the narrow strips of habitat in their right-of-ways (ROWs). Therefore, this approach requires cooperation with the entities that control the property adjacent to the highway.

Wild animals cross roads to escape unfavorable conditions, or to access resources. In some cases, it may be possible to remove the negative stimuli or provide the resource on both sides of the roadway, reducing the need to cross. Agreements to protect habitat areas from disturbance and development, and/or to implement specific habitat improvement plans can be effective mitigation tools. However, when considering this approach, it is important to keep in mind that many resources exist as an integral part of the landscape and it is not possible to provide them artificially. For example, there is no way to duplicate the qualities of a low elevation wintering area with predominately southern exposures at a high elevation location with predominantly northern exposures. Wildlife movements that are unlikely to be reduced by managing the surrounding habitat include finding mating opportunities, accessing traditional birthing grounds, and seasonal migrations to summering and wintering habitat.

Agreements to protect habitat areas from disturbance and development may also be an essential component for the success of design-based mitigation. In the locations where safe crossing opportunities are included in the roadway, the cues from the landscape that guide animals to those locations must be maintained. For example, recreational development in a drainage area that acts as a linear guideway to bring animals to an underpass could cause them avoid that area altogether. A result, animals would be far less likely to find and use the underpass, wasting that mitigation effort.

Integrate Mitigation Planning into Highway Planning

Mitigation to reduce wildlife/highway conflicts is most likely to be cost- and biologically-effective when mitigation planning is integrated into the initial stages of project planning. Including wildlife concerns as a baseline design consideration promotes cost-effectiveness because it maximizes opportunities to find engineering solutions that combine the project's purpose and need with wildlife considerations. This approach is also more likely to lead biologically-effective mitigation because mitigation can be placed in the most sensible locations from an animal's point of view, rather than simply where possible from an engineering point of view.

Including wildlife concerns as a baseline design consideration allows project designers to purposefully include engineering solutions that do double duty. Examples include a steep cut-slope that also serves as a barrier to guide animals to a safe crossing location, or bridging, rather than filling and culverting, drainages that intersect with the roadway. Additionally, within a project there is usually flexibility in choosing alignments and curve geometry. Both these design elements have a strong influence on size and placement of cuts, fills, and retaining walls, as well as the need for and placement of drainage structures. Choosing of alignments that "naturally" include design elements that can act as barriers or crossing structures may be cheaper then adding them to plans completed without consideration for wildlife mitigation. Further more, "adding-on" mitigation after the initial design phase is complete is likely to incur extra costs as a result of delays due to the redesign process. Even if the final wildlife friendly design deviates only minimally from the original plans, the evaluation process may cause significant delays and added cost.

Including wildlife concerns as a baseline design consideration facilitates biologically effective mitigation because mitigation structures are more easily placed in the most sensible locations from an animal's point of view. For example, choosing an alignment that intersects with drainage provides the opportunity to put an underpass in a location where the configuration of the landscape naturally guides animals to that underpass. Additionally, if the roadway and the drainage intersect at roughly right angles, it will minimize the underpass' length, creating a more open structure. Conversely, the configuration and location of mitigation incorporated after the primary design phase is over may be a compromise between biological considerations and engineering necessity in order to avoid redesigning the project entirely.

Conclusions and Recommendations

Some of the negative impacts of highways on wildlife can be eliminated if animals can safely and easily cross the highway. Because both landscape structure and features of the highway itself influence where animals naturally come to the roadside, a strategy that considers both types features is needed to effectively identify crossing locations. The primary components of such a strategy are to:

- Use habitat suitability as the primary indicator of crossing activity.
- Consider how landscape structure interacts with habitat suitability to either increase or decrease the level of use an area of suitable habitat receives by a particular species.
- Consider how the design of the existing highway interacts with habitat suitability and landscape structure to influence crossing behavior.
- Synthesize this information by mapping the landscape and roadway features/conditions known to be associated with crossing or to be attractive/repellant to the species present. Use these maps identify the most likely crossing locations.

In addition to identifying the most likely crossing zones, highway planners and designers should incorporate the following principles into their planning process to reduce highway wildlife conflicts:

- Evaluate each highway project individually. Not all crossing locations are associated with the same set of variables.
- Incorporate wildlife considerations into initial project planning and design to maximize cost- and biological-effectiveness,

- Because of local variation, employ professionals familiar with the landscapes and species of concern on the design team.
- Work with the entities that manage landscapes surrounding project areas to minimize animal crossing and/or maintain the landscape structure cues that bring animals to mitigated crossing locations.

Appendix A. Methods

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Table of Figures

Introduction

To determine if the locations where animals cross the highway are different from random locations, I selected two study sites in the Southern Rocky Mountains of Colorado. One was located along US 24 at Trout Creek Pass and the other along I-70 at Vail Pass. I recorded where wild animals crossed the road at both locations, then measured characteristics of the habitat at crossing locations and at random location both from digital data layers that were created from field measurements and remote photography. Depending on the type of data collected, I analyzed the data by comparing average values, using a Monte Carlo approach to generate an expected distribution to compare to actual distributions, or by comparing used habitat to available habitat. I also collected data about underpass use and summarized it with simple counts.

Study Site Descriptions

Trout Creek Pass

The Trout Creek Pass study site (TCP) was located predominantly in Chaffee County, and encompassed 11.0 miles (17.8 km) of narrow, two-lane highway that simultaneously serves as US 24 and US 285. The mile postings range from MP 216.0 approximately two miles east of Johnson Village, to MP 226.0, approximately one mile east of Trout Creek Pass (Figure 1.1, 1.2). A small section of the study area, to the east of the Pass, was located in Park County. US 24 is a two-lane road throughout the study area, except for the east side of the Pass where a climbing lane creates a short section with three lanes. Lanes are 3.7 m wide and shoulders are unpaved. The average annual daily traffic volume is 4000 vehicles (CDOT 2000).

The northern part of this study area was rolling, and cover type consisted of grasslands communities west of US 24, and mixed coniferous forests to the east. The terrain in the south end of the study area was rugged and highly dissected by dry washes and rocky

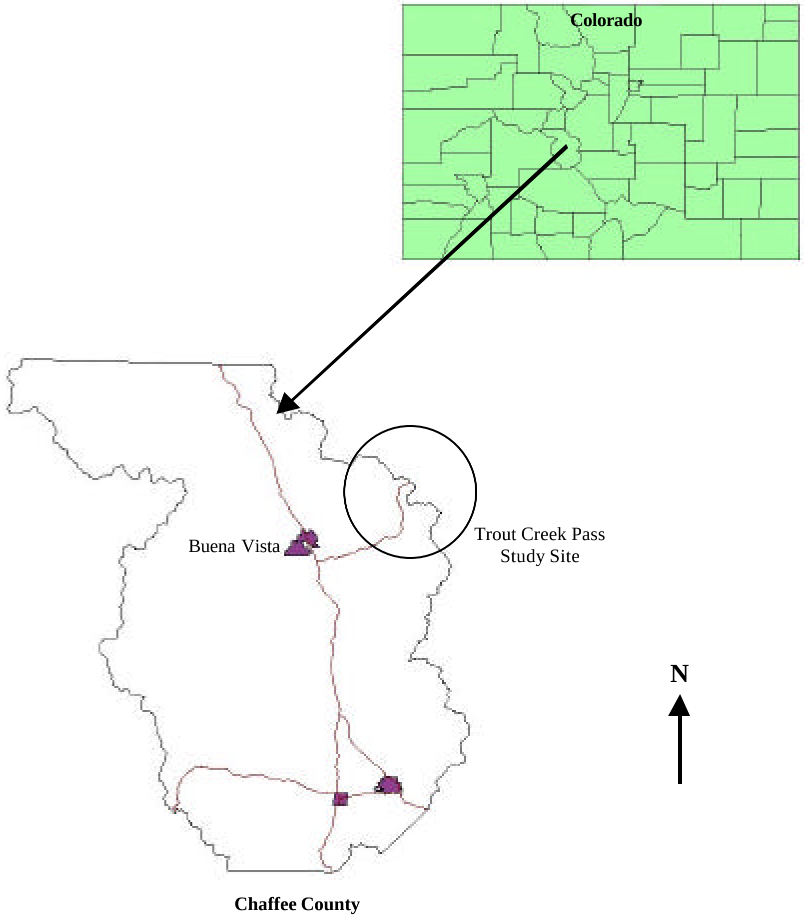

Figure 1.1 The location of the Trout Creek Pass study site (TCP) in Chaffee County, CO.

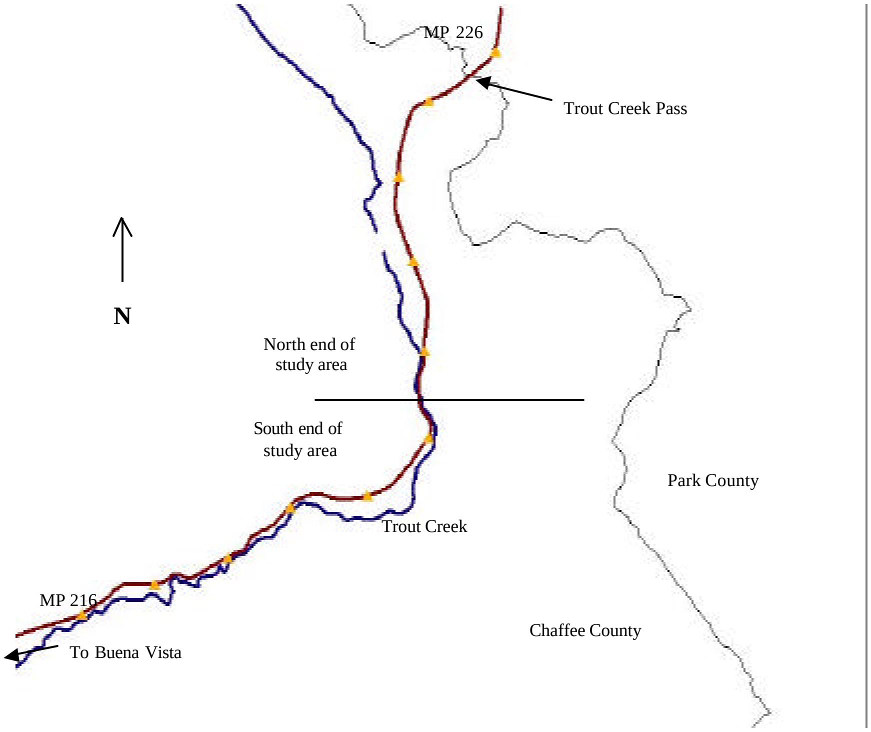

Figure 1.2 Detail of the Trout Creek Pass area, location of TCP.

Elevations in the study area range from 2830 m at the Pass to 2420 m at MP 216.0, and the main source of human disturbance, apart from the highway itself, was about 20 homes located mainly in the southern end of the study area. US 24 intersected six major drainages in the study area that were bridged by large, three-chambered concrete box culverts with concrete floors or by smaller bridge structures with natural floors. This area acted as both summer and winter range for mule deer and elk. Other common terrestrial species included red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), coyote (*Canis latrans*), mountain lion, bobcat, long-tailed and short-tailed weasel (*Mustela frenata, M. erminea*), and mountain cottontail (*Sylvilagus nuttallii*).

Vail Pass

Straddling Summit and Eagle Counties, the Vail Pass study site encompassed 12.0 miles (19.4 km) of I-70, from MP 183.0 to MP 195.0 (Figure 1.3, 1.4). Because of the heavy winter snows this site receives, the animal species present (described below) and their behavior differs substantially between the times of the year when snow is present compared with when snow is not present. Therefore, I considered the Vail Pass area to be two different sites, based on snow depths. I refer to the site as Vail Pass (VP) when the ground was snow-free and as Vail Pass Snow (VPS) when there was snow on the ground.

Vail Pass, located at approximately MP 190, divides the study area into an east side and a west side. The section of I-70 encompassed by the study site contained two 4.1 m-wide lanes and 4.7 m of associated paved shoulders for a total width of 12.9 m in each direction. The alignments of the east- and westbound lanes were independently sited and varied in location and elevation. The median separating the east- and westbound lanes varied in width from less then a meter in some places on the west side of the Pass, up to 260 m on the east side of the Pass. To a large extent, the natural cover and topography was maintained within the wide median area on the east side. On the west side, Jersey barriers separated the east and westbound lanes in locations where they were at the same elevation. Stepped retaining walls were used to separate the lanes in locations where one lane was at a higher elevation then the other. On both the east and west sides, additional

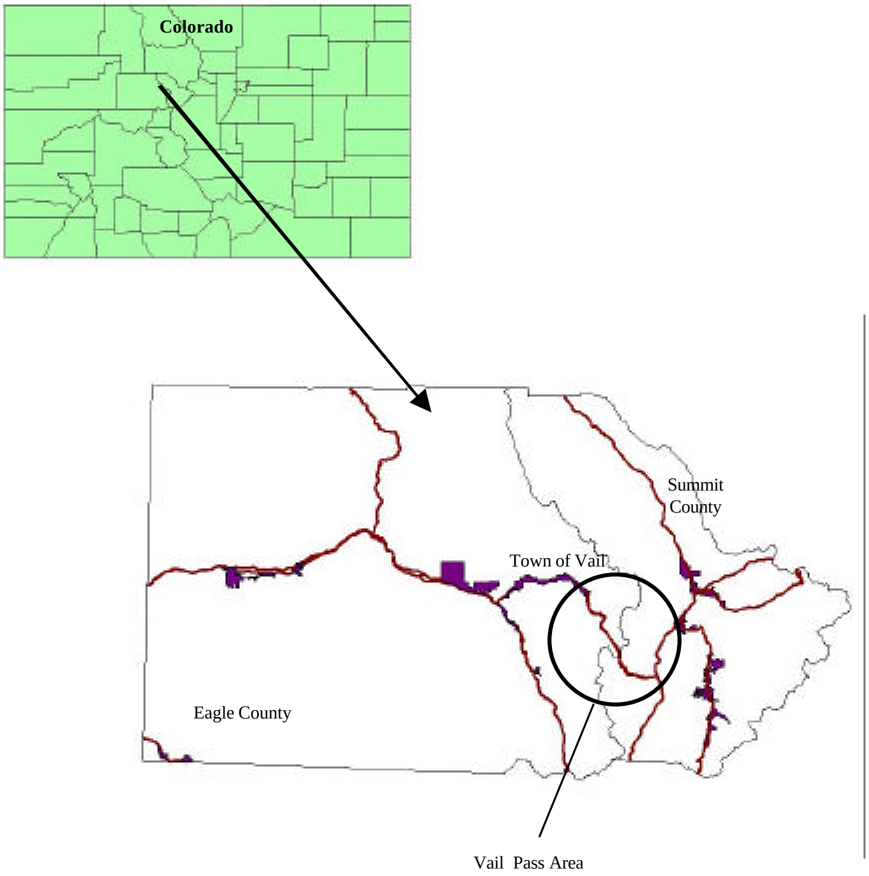

Figure 1.3 Location of the Vail Pass (VP) and Vail Pass Snow (VPS) study sites, straddling Eagle and Summit Counties in Colorado.

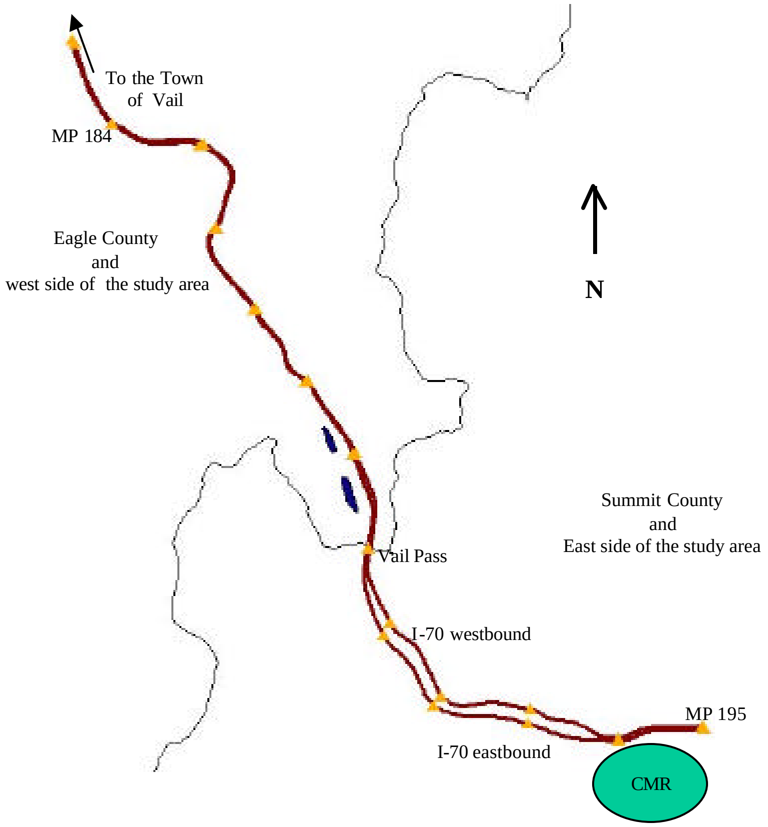

Figure 1.4 Detail of the Vail Pass area, location of both VP and VPS, including the location of Copper Mountain Resort (CMR).

Jersey barriers were used along the outer shoulder in locations where steep drop-offs occurred. In general, there were far fewer vertical roadside and median barriers on the east side than on the west side of the study site (Figure 1.5).

I-70 intersected 18 large drainages in the study area, and bridges spanned 11 of them (Figure 1.5). These bridges provided high quality highway crossing opportunities for wildlife as the drainages they spanned are wide (up to 230 m), and the natural cover below most was largely undisturbed. The primary cover type in this study area was mixed coniferous forest interspersed with aspen stands, sub-alpine meadows, and willow carrs. The elevation of the study site ranged from 2730 to 3165 m, and sources of human-induced disturbance, aside from the highway itself, included a rest area, truck turn out and maintenance shed at the summit and the Copper Mountain Resort at the base of the east side. Common terrestrial wildlife species in this study area included red fox, bobcat, mule deer, elk, and mountain lion during the snow-free months. Snowshoe hare (*Lepus americanus*), coyote, long-tailed and short-tailed weasels, and American marten (*Martes americana*) were present year-round.

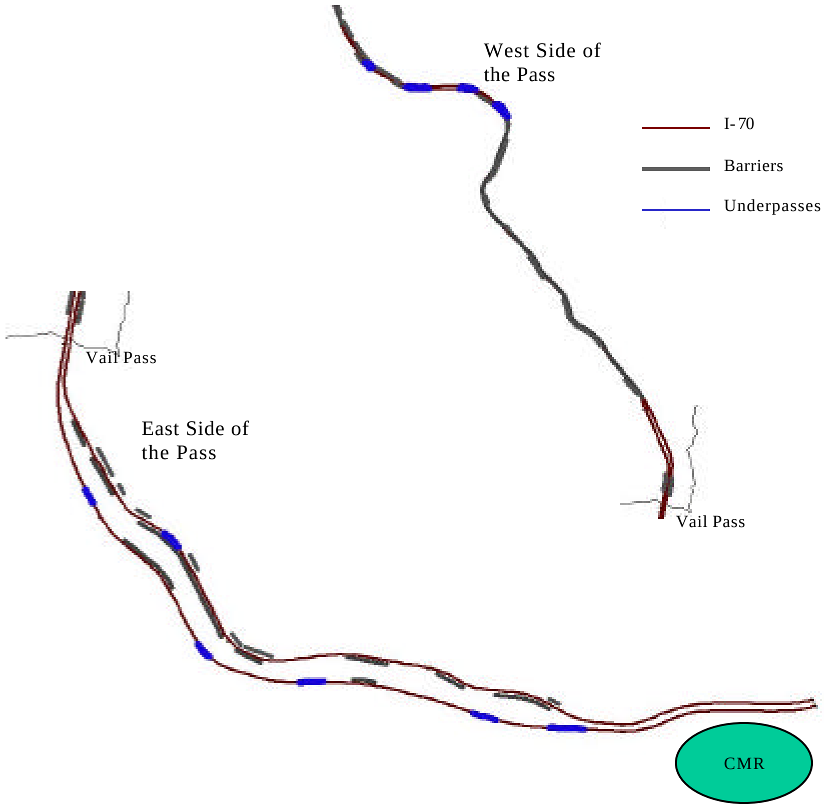

Figure 1.5 The locations of all barriers and underpasses on I-70 at Vail Pass. Note the distribution of barriers and the alignment of the underpasses on the two sides of the Pass.

Data Collection

Tracking Methods

I recorded locations throughout all three study areas where medium- and large-sized mammals (mule deer, elk, coyote, fox, bobcat, mountain lion) crossed the highway, as indicated by their tracks. At TCP and VP I checked 10 roadside transects 200 m in length for tracks during each field session. To ensure transects were distributed throughout a study area and did not overlap, I used a stratified random selection approach, varying transect location for each data collection session. At each transect, a field assistant or I walked along the highway at the pavement's edge and looked for animal tracks left in the unpaved shoulder. At TCP, traffic was light and I crossed the highway to walk along both sides of it, recording tracks from both sides. At VP however, I only walked along the outer edges of the west- and east-bound lanes. Due to high traffic volumes and speeds, I considered crossing the highway to access the median-side roadside unsafe.

I recorded track locations using a hand-held GPS device\data logger (Geo Explorer II, Trimble) that automatically recorded location while I entered information through a menu-driven interface. All tracks of the same species observed within a 5-meter stretch were recorded as a single track record (TR). Each TR included species of animal, number of animals, location (UTM coordinates) and date. I downloaded data files from the data logger and used Trimble's proprietary software to convert them to Excel spreadsheet and ArcView shapefile formats for analysis.

I interpreted the activity of an animal from the pattern of tracks it left behind. At TCP, I only classified a TR as "crossing" if a matched set of tracks was found on both sides of the road. At VP, I did not confirm crossings in this way because I considered it unsafe to cross the roadway. Instead, I classified track sets that were perpendicular to the road and did not have a matched set within 20 m going in the opposite direction as "crossing." Because the swath of tracking medium (road sand) along the roadside was wide at VP, it was usually possible to "read" an animal's behavior at the roadside quite clearly and I only designated a TR as "crossing" when I was reasonably sure the animal had indeed passed to the other side of the roadway.

Snow tracking was conducted at VPS December through March during both 2000/2001 and 2001/2002. I did not implement snow-tracking protocols at TCP because sufficient snow cover at this site was infrequent, unpredictable, and ephemeral. Thus, even on the few occasions when there was snow on the ground at TCP, the standard tracking procedures described above were followed. Using snow-tracking methods, I observed the entire VPS study area, as opposed to a subset of transects, for tracks. Due to the snow depths, far fewer animals are present in the Vail Pass area during winter than during the summer. Thus, finding and recording all trails present was a reasonable task. A field assistant or I located all animal trails that entered the roadway within the study area by driving slowly (< 25 km/h) along the shoulder. When a trail was observed it was identified by species, and crossing success determined. Using the GPS device/data logger, I recorded species, number of individuals, date, and the UTM coordinates of the trail's intersection with the highway.

Underpass Monitoring

In addition to monitoring the roadside for tracks, I monitored some highway structures (bridges, oversized concrete box-culverts) at both study sites for use by animals to cross under the highway. Although only one of the monitored structures was constructed specifically to act as a highway underpass for wildlife, I will refer to all these structures as "underpasses." All underpasses monitored spanned either narrow perennial streams or intermittent drainages that only carried water during spring run-off or during storm events, and offered plenty of dry substrate for animals to use when they passed through. I created track beds from locally available sand and soil at both ends of each monitored structure. An animal was recorded as passing through a structure only when I observed a matched set of tracks at both ends.

At TCP, a field assistant or I monitored a subset of 10 underpasses, chosen based on accessibility and safety considerations. At VP, I monitored four of the 17 underpasses; the other 13 were deemed unsuitable for monitoring due to safety considerations, high levels of human use, or excessively large size, which made maintaining the trackbed difficult. I checked track beds and the roadside within 50 m of either side of each underpass for tracks to record if animals crossing at that location had crossed at-grade or used the structure. Additionally, I monitored five underpasses at VPS for animal use during the winter, as weather permitted. The trails of all animals entering the space underneath these structures were observed in the snow, and each animal's behavior was recorded as either passing through or not passing through.

Habitat Measurements

I made all measurements of landscape structure for landscape-scale comparisons from digital data layers, using the ArcView software package. These data layers were generated from aerial and satellite photography, and I used coverages created by the U.S. Geological Survey (USGS) when available, including the National Land Cover Data (NLCD) for TCP, and 10-meter contour resolution Digital Elevation Models (DEMs) at VP and VPS. Because my field experience suggested that the NLCD coverage of the Vail Pass area misclassified the cover type of large areas, I used a digital vegetation map created by the Forest Service for vegetation measurements at VP and VPS. For the TCP area, 10 m resolution DEMs were not available from the USGS. I commissioned the Remote Sensing and Geographic Information Group located in the Denver, CO, office of the U.S. Bureau of Reclamation to create a 10 m DEM of the TCP site specifically for my project.

At all three study sites, the landscape I measured was the area encompassed by the ridgelines that provided visual boundaries surrounding the highway. I derived the vegetation patterns of these landscapes from the digital cover maps and the topographic patterns from the DEMs. The NLCD is divided into 21 cover type classes in Colorado, and I reclassified the Forest Service data layer to match those classes. I used the ArcView extension Spatial Analyst to process the DEMs into 19 slope classes and nine aspect classes. I classified topographically level areas as "flat," then divided slope by 5-degree increments for 18 additional classes and aspect by increments of 45 degrees for eight additional classes.

I was careful to choose digital base maps that adequately reflected actual land cover classes and their boundaries. I based my assessment on my familiarity with the study sites. I wanted to be confident that the maps reflected variations animals could perceive and respond to. The NLCD is divided into 21 classes in Colorado, 10 of which are naturally occurring land cover types. Because these classes are broadly defined, I believe medium- to large-sized mammals can readily perceive the variation they represent, and this classification scheme was reasonable for my analysis. Similarly, I chose the slope and aspect increments because my experience with animal behavior and habitat selection suggests that animals respond to topographic variation at those levels.

The second type of data I collected in the field was the locations of features along the roadside, including bridges (representing the locations of both underpasses and drainages) and roadside barriers (cliffs, walls, guardrails, Jersey barriers). I collected these data using the GPS device's setting for recording continuous data along a line. Using a roof-mounted antenna, I drove slowly (20-25 km/h) along each feature of interest and collected positions for the entire length of each feature, then converted the positions into ArcView shapefiles using Trimble's proprietary software package.

In addition to making field measurements of the roadside habitat, I also used aerial photos and existing digital data layers to make some local-scale measurements. I digitized lines representing the forest boundaries from aerial photos, then used that data layer to measure the distance of crossing location to the nearest forest edge with ArcView. Additionally, I used the digital vegetation and topographic data layers described above to compare the cover, slope and aspect classes associated with crossing locations to what was available along the entire roadside.

Data Analysis

I considered the data in three separate sets, based on study site and snow depth: Trout Creek Pass (TCP), Vail Pass snow-free (VP), and Vail Pass with snow cover (VPS). I calculated the total number of TRs recorded at each site, counted them by activity and species, and created maps depicting the TR locations. I further divided these primary data sets into subsets, as described below, based on the spatial patterns of the TRs within each study site, and landscape characteristics of the study sites. This approach was necessary because visual analysis of the maps indicated that the density of TRs throughout each study site was uneven.

Identifying Patterns

The maps suggested that both first order (large-scale) and second order (small-scale) patterns were present. Because variations in first order patterns can mask or swamp second order patterns, small-scale spatial patterns must be studied over scales at which the first order effects remain homogenous. Therefore, I divided each of the three primary data sets into sub-areas, based on the extent of homogenous first order patterns. I used visual analysis and simple counts of the crossing TRs at each study site to demark their first order patterns. I confirmed the presence of these first order patterns by using SPSS v.10.1 for Windows to perform chi-square tests to determine if the observed distributions between sub-areas of apparent high and low density TRs did indeed differ from an even distribution.

I confirmed the presence of second order (small-scale) patterns within the sub-areas by identifying groups of TRs that were closer to one another than expected. I used these clusters of TRs to indicate crossing hotspots. I defined a TR as part of a cluster if the median distance to its *n* nearest neighbors was less then expected by chance. The median, rather than the mean, distance between a point and its *n* nearest neighbors was chosen as the metric of comparison for identifying CZs because the distribution of nearest-neighbor distances was skewed to the right. The median is less influenced by outliers, providing a more conservative estimate of the data’s central tendency.

Because first order patterns affect the expression of second order patterns, the number of nearest neighbors I considered varied with the total number of TRs in each sub-area. For sub-areas with fewer then 100 TR, I considered the median distances of a point to its three nearest neighbors. For sub-areas with 101 to 199 TR, I considered the median distances of a point to its five nearest neighbors, and for sub-areas with 200 to 299 TR, I considered the median distances of a point to its seven nearest neighbors. I defined an *n* nearest-neighbors distance smaller than three standard deviations from the expected median distance as not occurring by chance, and therefore, an indication of clustering.

To determine the expected nearest neighbors distance for each data set, I used a Monte Carlo approach. I distributed points randomly along a line representing the roadway of interest to simulate a possible distribution of crossing TRs along it, and then measured the *n*-nearest-neighbors distance for each point. I used 1000 simulations to generate the expected distribution of nearest-neighbors distances. A script written for ArcView in the Avenue programming language was used to perform all simulations automatically, based on user-defined input parameters. After the simulations were completed, I exported the spreadsheet to Excel and calculated summary statistics of each value.

After identifying the TRs with *n* closer-than-expected nearest neighbors on a map of the TRs, I buffered them with a radius the length of the expected median *n*-nearest-neighbors distance, and dissolved the boundaries of all overlapping buffers. I chose this buffer size as it should include all the points that contributed to a given TR's nearest neighbor measurement, on average. I designated all TRs contained within each buffer as part of that crossing zone and used ArcView functions to measure the distance between the two outer-most TRs. Measurements are accurate to ± 10 m. A group of TRs was only considered a crossing zone if it contained at least as many TRs as were used in that data set's nearest neighbors calculation (e.g., three nearest neighbors required considering four TRs). Finally, I inspected the TRs that comprised a CZ to determine if they represented independent events. TRs of the same species recorded the same day and within 50 m of each other were not considered to be independent.

Underpasses Use

I calculated the frequency of underpass use in two different ways. First, I compared the number of times at least one set of tracks, of any species, was recorded as passing through to the total number of times the structure was checked for tracks. Although it was common for me to find multiple track sets each time I checked an underpass, I could not determine if one animal passing through an underpass many times or many animals passing through once created the multi-track track sets. Because a group of *n* animals crossing together may be regarded as one crossing event, rather then *n* independent events, I grouped these data.

However, because the first approach lumps data, important information about species use is masked. Therefore, I also compared the number of times at least one individual, by species, was recorded as passing through to the number of times the structure was checked for tracks. For example, if I checked an underpass and recorded a bobcat and three rabbits as passing through, I counted the underpass as used once by bobcat and once by rabbit. Using this counting method, it is possible that I could record more through passes then the number of times the underpass was checked. Therefore, I report the frequency of use calculated with this approach as a ratio. Finally, at VPS I also counted the total number of animals passing through the underpasses. Snow is an excellent tracking medium, and few animals are present in the Vail Pass area when the snow is deep, making it possible to accurately count every trail.

Quantifying the Relationship of First Order Patterns to Landscape Structure

As detailed above, I split each of the three study sites into two sub-areas, based on the first order patterns of TR density along the roadside. I evaluated the influence of the surrounding landscape on this first order pattern of TR distribution by comparing the landscape structure of the each study site's two sub-areas. Metrics of landscape structure that I considered included the average size and edge-to-size ratio of patches defined by different classes of cover type, slope, or aspect in each study site sub-area. I used the ArcView extension Patch Analyst to count the total number of patches created by variations in cover, slope, or aspect, as well as to calculate the area of each patch and the length of its perimeter. I defined a "patch" as a contiguous area comprised of a consistent class. Although some of the samples I compared were neither normal nor homogenous in their distributions, I chose a two-sample t-test (SPSS 10.1) to compare the mean values of each variable. SPSS offers a correction for heterogeneous distributions, and my sample size were very large, relaxing the need for normal distributions.

Quantifying the Relationship of Second Order Patterns to Local-Scale Features

The approach I used to quantify the local-scale habitat characteristics associated with crossing zones varied according to type of feature under consideration and the data's source. For variables measured in the field, I calculated the average value of each variable measured within CZs and the average value measured at random points. I then compared these two values to determine if there was a difference between CZs and random locations. Because these data were non-normal and often had significantly different variances, I used the non-parametric Mann-Whitney U test (SPSS 10.1) to determine if the means differed from one another.

For the cover, slope, and aspect variables measured on GIS data layers, I used the ArcView extension Patch Analyst to calculate the total area of each cover, slope, and aspect class within 100 m of the CZs and within 100 m of the entire roadway. I used Excel spreadsheet functions to run a chi-square test to compare the proportion of cover, slope, and aspect classes contained in each of the paired data sets.

I also used a GIS-based approach to evaluate if the distribution of CZs in relationship to drainages, roadside barriers, and the forest boundary deviated from what would be expected. I used scripts written for ArcView in the Avenue programming language to measure the actual distance of each TR to the feature of interest, and to implement a Monte Carlo simulation (*n* = 1000) to generate an expected distance for comparison. A single simulation consisted of distributing points randomly along a line representing the road, measuring the distance of all points to the nearest feature of interest, then calculating the average point-to-feature distance. The number of points used corresponded to the number of TRs that made up the CZs in the study site sub-area being evaluated.

The script carried out the Monte Carlo simulations automatically, based on user-defined input parameters, including ArcView shapefiles representing the feature of interest and the roadway, the number of points to use, and the number of simulations to run. The script then executed the number of simulations requested, calculated the mean, median, maximum, and minimum distance, and stored these values in a spreadsheet. After the simulations were complete I exported the spreadsheet to Excel and calculated the summary statistics of each value. I used a two-sample t-test, implemented with Excel spreadsheet functions, to compare the actual mean TR-to-feature distance to the expected mean. If the two means were not significantly different at $\alpha = 0.05$, I concluded that the TRs were randomly distributed in relationship to the features of interest. Additionally, the script counted the number of points in each simulation that were placed adjacent to a barrier so I was able to calculate an expected value. I compared the proportion of TRs that were expected to be adjacent to a barrier to the actual proportion of TRs located adjacent to a barrier with a chi-square test.

To examine if the presence of underpasses had any effect on the locations where animals crossed at-grade, I graphed the relationship between meters of underpass along a kilometer of highway against the number of crossing TRs along that kilometer of highway. I estimated both values using a moving windows analysis. Each window along the roadway was one km in length and was shifted in 100 m increments.

Appendix B. Results

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Introduction

In Appendix B, I report the results of my data collection and analysis efforts. The discussion is organized according to the order of the analysis descriptions followed in Appendix A. Simple summaries of the track record (TR) data are reported first. Results of the analyses that correlated first order TR patterns to characteristics of the surrounding landscape are followed by results of the analyses that correlated second order TR patterns to characteristics of the roadside. Finally, I summarize the underpass use.

Are the Results of this Study Useful?

My results indicate that animals do not cross highways at random, either at the local or the landscape scale. However, the differences between the low and the high permeability landscapes, as well as between crossing zones and random location were inconsistent across the three study sites. These results were not surprising. As discribed in Appendix A, my three study sites differed from each other in multiple ways, including the species present, snow depths, traffic volume, highway design, and roadway footprint. Nor do the these inconsistencies imply that an assessment of the surrounding habitat and highway characteristics are useless for informing the process of reducing wildlife/highway conflicts, as I will discuss below.

Given the large scale and unique nature of landscapes, opportunities to utilize strict experimental designs with them, that vary only a single component of the systems under comparison, in order to draw cause/effect conclusions, are rare (Turner et al. 2001). Because of this basic problem, people who need information about landscape-scale process must often rely on thoughtful, qualitative assessments of data about systems of interest, in place experimental assessments. Additionally, my results serve to illustrate the importance of considering the unique variation offered by natural systems in order to properly understand how they function.

There is an increasing realization among environmental scientists that natural systems are complex and non-linear. Therefore, making generalization about their function is difficult. Rather than try to formulate a simple rule about how a natural process works, it is usually more accurate to answer, "it depends" (Soulé and Orians, 2001). This is not to say that natural systems are chaotic, making management decisions based on their functions impossible. The variables upon which a system's function depends are accessible to professionals familiar with the system. If these professionals combine data about the system with common sense born from their experience, good management decisions can be made (Soulé and Orians, 2001).

Descriptive Summary of Tracks

I collected track data 130 times at Trout Creek Pass (TCP) between 28 January 2000 and 4 July 2001, recording a total of 535 TRs, representing 832 individual animals. I conducted a total of 91 tracking sessions when there was no snow cover at Vail Pass (VP), comprised of 40 sessions during 2000 and 51 sessions during 2001. I recorded a total of 778 TRs, representing 1155 individuals, at VP. When there was snow on the ground at Vail Pass (VPS) I collected track data on 18 occasions during 2000/01 and on 30 occasions during 2001/02, for a total of 48 snow tracking sessions, and I recorded a total of 771 TRs, representing 978 individuals. The TRs are summarized by species and activity for each study site in Tables 1.1, 1.2, and 1.3.

Table 1.1 Summary of TR by species and travel at TCP

Species	Crossing (% crossing, by species)	Not Crossing (% not crossing, by species)	Total (% of all TRs, by species)
Mule Deer	219 (53.0 %)	194 (47.0 %)	413 (77.2 %)
Elk	40 (71.4 %)	16 (29.6 %)	56 (10.5 %)
Coyote	10 (27.8 %)	26 (71.2 %)	36 (6.7 %)
Rabbits/Hares	7 (70.0 %)	3 (30.0 %)	10 (1.9%)
Fox	1 (25.0 %)	3 (75.0 %)	4 (0.7 %)
Mountain Lion	1 (100 %)	-	1 (0.2 %)
Bobcat	-	1 (100.0 %)	1(0.2 %)
Other	2 (40.0 %)	3 (60.0 %)	5 (0.9 %)
Unknown	-	7 (100.0 %)	7 (1.3 %)
Total	278	257	535

Table 1.2 Summary of TRs by species and travel at VP

Species	Crossing (% crossing, by species)	Not Crossing (% not crossing, by species)	Total (% of all TRs, by species)
Mule Deer	191 (34.9 %)	284 (65.1 %)	475 (61.0 %)
Elk	117 (43.2 %)	154 (56.8 %)	271 (34.8 %)
Coyote	8 (28.6 %)	20 (71.4 %)	28 (3.6 %)
Mountain Lion	1 (100.0 %)	-	1 (> 0.1 %)
Moose	1 (100.0 %)	-	1 (> 0.1 %)
Other	-	1 (100.0 %)	1 (> 0.1 %)
Unknown	1 (100.0 %)	-	1 (> 0.1 %)
Total	319	459	778

Table 1.3 Summary of TR by species and travel at VPS

Species	Crossing (% crossing, by species)	Not Crossing (% not crossing, by species)	Total (% of all TRs, by specie
Coyote	433 (74.5 %)	148 (25.5 %)	581 (75.3 %)
American marten	12 (35.3 %)	22 (64.7 %)	34 (4.4 %)
Weasel species	23 (45.1 %)	28 (54.9 %)	51 (6.6%)
Snowshoe hare	39 (76.5 %)	51 (23.5 %)	90 (11.7 %)
Red fox	-	2 (100.0 %)	2 (0.3 %)
Elk	-	8 (100.0 %)	8 (1.0 %)
Total	507	264	771

The species that I recorded most often at TCP and VP was mule deer (77.2 and 61.0 %, respectively), and I also recorded a substantial number of elk at VP (34.8 %). Coyotes were the species that I recorded most commonly at VPS (75.3 %). The proportion of tracks indicating crossing varied among the three study sites, as did the animal species that crossed most frequently. Animals were most likely to cross at VPS (65.7 % of all tracks) and least likely to cross at VP (41.0 %). The crossing rate at TCP was intermediate (52.0 %). The crossing rate at TCP was not significantly different from either VP (?^{2} = 2.289, $p > 0.10$) or VPS (?^{2} = 3.669, $p > 0.05$), but animals were significantly more likely to cross the highway at VPS, as compared with VP (?^{2} = 9.286, $p < 0.05$).

Distribution of Tracks

Animals are more likely to cross highways at certain locations at both the landscape and the local scale. Quantitative as well as visual analyses of the patterns created by the distribution of track records (TRs) along the roadside indicated that both first order and second order clustering existed at all three study sites. I interpreted the second order TR clusters as indicators of locations where animals preferred to cross the road, and designated such locations as crossing zones (CZs). The results of my spatial pattern analysis of the TRs are described in detail below.

First Order Patterns

Mapping the locations of crossing TRs within their respective study sites revealed that crossing TRs were not evenly distributed throughout any of the study sites. At each of the three sites, I observed more crossing TRs located in a definable sub-area of the site. At TCP I recorded far fewer TRs along the portion of US 24 located north of where Trout Creek intersects the highway. The resulting low- and high-density TR areas corresponded with differences in both topography and land cover north and south of Trout Creek, and I divided the data into two sub-areas, north (MP 221.5-226.0) and south (MP 216.0-221.5), accordingly.

At VP, I recorded less than half as many TRs on the west side of the Pass than the east side. As discussed in Appendix A, the design of the highway differs substantially between the two sides of the Pass. Therefore, the Pass was a reasonable dividing line between the differing first order patterns, and I subdivided the data into two sub-areas, east (MP 190.0-195.0) and west (MP 183.0-190.0).

When snow is present in the Vail Pass area, large, steep snowdrifts along the roadside are created throughout the study site by snowplows. These drifts masked some of the structural differences of the roadway between the east and west sides of the Pass, and it became less of a natural dividing line. Additionally, the distribution of TRs when snow was on the ground was consistent throughout the VP study area, except for the 2.5 miles of roadway closest to Copper Mountain Resort ski area (CMR). During the months with snow cover I recorded a clearly disproportionate number (75.0 percent of total) of TRs in the portion of the study area closest to CMR. Therefore, I divided VPS into two sub-areas, CMR (MP 192.5-195.0) and Not CMR (MP 183.0-192.5), based on the location of the resort.

Chi-square tests indicated that the proportion of crossing TRs located in each paired set of sub-areas departed significantly from either an even or a random distribution, based on the linear distance of the roadway at each study site sub-area (Table 1.4).

Table 1.4 Distribution of crossing TRs within the sub-areas of each study site

Study Site	Sub-Area	Number of Crossing TRs	Linear Length of Sub-Area	TRs/km	Chi-Square Comparison
TCP					
	South	219	8.9 km	24.6	$\chi^2 = 19.13$, $p < 0.00$
	North	59	7.3 km	8.1	
VP					
	East	227	8.8 km	25.8	$\chi^2 = 80.20$, $p < 0.00$
	West	92	11.3 km	8.1	
VPS	CMR	401	4.0 km	100.2	$\chi^2 = 214.06$, $p < 0.00$
	Not CMR	106	15.4 km	6.7	

Second Order Patterns

Visual analysis of the mapped crossing TRs in the sub-areas of each study site suggested that additional small-scale, or second order, clustering of TRs was present within the first order clustering discussed above. Nearest neighbors analyses confirmed my impression of second order patterns at all three study sites. At TCP south the nearest neighbors analysis indicated that 60.4 % of TRs were more clustered than would be expected by chance. At TCP north 58.6 % of TRs were more clustered than expected by chance. At VP and VPS, I analyzed clustering separately in the west- and eastbound lanes. At VP, TRs recorded along the westbound lanes were more likely to be clustered together than those recorded along the eastbound lanes. This was true at both VP east (71.8 versus 47.

8 %) and VP west (66.7 versus 34.4 %) of the Pass. At VPS, 42.9 of the TRs in the westbound lanes and 57.1 % of TRs in the eastbound lanes were closer to one another than expected adjacent to CMR. In the rest of the study area, 63.9 % of TRs along the westbound lanes and 72.9 % of TR along the eastbound lanes were more clustered than expected by chance.

Crossing Zones

I identified CZs based on the second order patterns of crossing TRs. I interpreted groups of crossing TRs that were more clustered than expected by chance as an indication that animals focused crossing activity along that stretch of highway. At TCP north I identified five distinct CZs ranging from about 80 m to 300 m. Distance between them ranged from 240 m to 2630 m. At TCP south, I identified 10 CZs ranging in length from about 30 m to 600 m. The distance between them ranged from 200 m to 1120 m.

At VP east, I identified five distinct CZs along the westbound lanes and four along the eastbound lanes ranging in length from 100 to 760 m. The intervals between them ranged from 140 to 1510 m in length. CZs along the west- and eastbound lanes were not strongly aligned with one another. At VP west, I identified five distinct CZs along the westbound lanes and three along the eastbound lanes, ranging in length from 50 to 490 m in length. The intervals between them ranged from 650 to 2480 m in length. All three of the CZs identified along the eastbound lanes are strongly aligned with CZs along the westbound lanes.

At VPS CMR, I identified seven distinct CZs along the westbound lanes and four along the eastbound lanes, ranging in length from 40 to 310 m in length. The intervals between CZs ranged from 70 to 760 m in length. CZs along the west- and eastbound lanes were somewhat aligned with one another. In the At VPS Not CMR, I identified five distinct CZs along the westbound lanes and nine along the eastbound lanes, ranging in lenght from 60 to 530 m in length. The intervals between them ranged from 310 to 4290 m in length. The CZs identified along the eastbound lanes are not strongly aligned with CZs along the westbound lanes.

The Relationship of First Order Patterns to Landscape-Scale Features

At the landscape scale the different densities of TRs in each of the paired sub-areas was correlated to significant differences in the composition of the cover type, slope, and aspect classes of the surrounding landscape. The edge/size ratio of contiguous patches with a consistent slope was also significantly different between the sub-areas at all three study sites, but not the average patch size. The results are presented in tables and discussed in detail below.

Landscape Composition and Complexity

At all three sites, the sub-areas with higher densities of TRs in general, and crossing TRs specifically, corresponded to landscape composition and to a lesser degree, complexity (Tables 1.5, 1.6). At TCP, significantly more TRs were located in the south end even though CDOW estimates that both deer and elk populations should be consistent throughout this study area. At VP, more TRs than expected were recorded at VP east even though CDOW estimates that both deer and elk populations are lower there, as compared with VP west.

Table 1.5 Comparisons of composition sub-area pairs, p-values indicate the likelihood that pairs are different from each other by chance

	Dominant Cover Type Class	Dominant Slope Class(es)	Dominant Aspect Class(es)
TCP			
South	Forest + shrub (36 + 36 %)	11-30° (62 %)	SE - NW (65 %)
North	Grassland (52 %)	0-10° (63 %)	N/NE,/E, SW/W (73%)
	p = 0.000	p = 0.000	p = 0.000
VP			
East	Forest (63 %)	10-25° (80 %)	N - S (74%)
West	Forest (74 %)	15-30° (79 %)	N/NE, SW/W (78 %)
	p = 0.000	p = 0.000	p = 0.00
VPS			
CMR	Forest (65 %)	6-15° (55%)	NW/N/NE, S/SW (66 %)
Not CMR	Forest (74 %)	16-25° (53%)	NE/E, SW/W (70 %)
	p = 0.000	p = 0.000	p = 0.000

Note: the values in parentheses indicate the percent of the landscape comprised pf the dominant class(es). The reported p-values are derived from chi-square test comparing the distributions of cover classes of each sub-area pair.

Table 1.6 Comparison of landscapes metrics associated with first order patterns. The likelihood that the paired values are different from each other by chance is indicated by the p-values

	Cover		Slope		Aspect	
	Mean Patch Size (ha)	Patch Area to Edge Ratio*	Mean Patch Size (ha)	Patch Area to Edge Ratio*	Mean Patch Size (ha)	Patch Area to Edge Ratio*
TCP						
South	92.4	10.76	12.4	2.53	6.4	2.44
North	170.4	11.29	26.2	2.68	7.5	2.27
	p = 0.25	p = 0.078	p = 0.344	p = 0.00	p = 0.485	p = 0.00
VP						
East	1701.1	37.53	38.8	4.72	79.7	6.00
West	1632.1	34.52	16.5	4.08	70.9	5.60
	p = 0.831	p = 0.424	p = 0.00	p = 0.00	p = 0.534	p = 0.68
VPS						
CMR	1318.6	33.17	31.7	4.45	73.3	5.97
Not CMR	1712.5	37.29	22.4	4.26	76.5	5.76
	p = 0.32	p = 0.21	p = 0.58	p = 0.00	p = 0.84	p = 0.33

The reported p-values are derived from an independent samples t-test comparing the paired values
*The larger the value, the less complex the shape of the patch

All high density TR sub-areas occurred in landscapes with at least 70 % woody cover, as would be expected when dealing with cover-associated species such as deer, elk and coyote. This result supports previous research that indicates animal activity at the roadside is highest adjacent to cover (Lyon, 1979; Rost and Baily, 1979; Finder et al., 1999). However, cover type complexity did not appear to play a role, as it differed significantly only for edge/size ratios at TCP, and only marginally so. Both slope composition and slope complexity were also linked to TR density. At VP and VPS, the higher densities of TRs were associated with significantly shallower slopes and lower edge/size ratios. This makes sense, as landscapes comprised of shallow, consistent slopes are easier to travel through, and animals should therefore be more likely to use these landscapes and come into contact with the roadside. These results also mirror the findings of Alexander and Waters (2000).

At TCP, the opposite relationship to slope composition and complexity was statistically significant. However, rather then negate the importance of topography as described above, this result serves to bolster the role of preferred cover. Although TCP south had more then twice as much area over 20° in slope as compared to TCP north, 76 % of TCP south was still under 20°, providing plenty of easy travel terrain. Meanwhile, TCP south had half again as much shrub cover as TCP north, the preferred forage of deer. Along the roadside, the shrubby areas were well interspersed with grass and forest patches, providing the mix of food and cover that deer prefer (Fitzgerald et al., 1994). At TCP north, a few large blocks of grass, shrub, and forest dominated the landscape. Directly adjacent to the highway, the land cover is mainly grass, and on the west side of US 24 the forest edge is about 1.5 km away. Mule deer, the species that most commonly crossed US 24 during the study, generally avoid open areas of that size.

The primary role of preferred cover type, and the secondary role of slope in creating landscapes that bring animals to a roadside make sense from a biological point of view, considering the species present at my study sites. However, the role of aspect is more difficult to reconcile. The dominant aspects of the landscapes surrounding the roadways with higher crossing rates differed at all three study sites. Around the sub-areas with lower crossing rates northeastern, southwestern, and western facing slopes dominated, but this association was not clear-cut either.

However, the fuzzy relationship between aspect and TR density is not surprising. The predominant direction of a roadway that runs in a relatively straight-line direction along a valley bottom, like US 24 and I-70 in the study site sub-areas, will dictate the aspect of the surrounding landscape to a large extent. The roadway cannot have this same effect on cover type or slope composition. Thus, even if animals are cueing on aspect as they choose habitats surrounding roads, the presence of the aspect they prefer may be swamped by the overall influence of roadway orientation. As a result, only very general differences between the landscapes of low and high rates of use may be apparent, and the difference may have no biological significance at all. Thus, it was impossible to determine the significance of aspect in mediating the use of the surrounding landscape at my study sites.

Other Influences from the Landscape

In addition to cover type and slope, four other variables influenced the first order distribution of TRs. These variables were: the number and quality of underpasses within an entire sub-area; the configuration of those underpasses; the orientation of landforms that can act as linear guideways; and at VPS, the presence of CMR. The influence of these four variables is discussed in detail below. Although I was able to quantitatively assess the influence of underpasses and of CMR on TR distribution, my examination of linear guideways is strictly qualitative because I had no objective methodology for identifying what constituted a linear feature.

At VP there was a strong relationship between number of at-grade crossings and the meters of underpass/km of highway. The number of animals crossing at-grade was higher along the stretches of roadway with fewer meters of underpasses/km roadway. The opposite relationship between rate of at-grade crossing and meters of underpass available occurred at TCP. However, this was expected. At VP, mule deer readily used the underpasses that were present, while at TCP they did not. Instead, the deer followed the drainages to the road, and then crossed at-grade. At VPS, the distribution of TRs was not negatively or positively associated with underpass location.

The configuration of underpasses was also important along I-70. At VP west and VPS Not CMR, only 8.2 and 5.1% of all crossing TRs, respectively, were located along the portion of the highway where underpasses in the east- and west-bound lanes were aligned with one another (MP 183.0 – MP 185.5). In this area, animals could pass directly under the entire roadway, and they were far less likely to make an at-grade crossing. Additionally, on the east side of the Pass the five underpasses in the eastbound lanes were not mirrored by underpasses in the westbound lanes. Animals that passed through an underpass in the eastbound lanes were forced to cross the westbound lanes at-grade if they wanted to continue on in the same direction. At VP east there was a clear spike in crossing rates along the westbound lanes, related to where the underpasses are located along the eastbound lanes. At VPS, the influence of CMR made it difficult to discern the relationship of TR distribution to underpass location in this area.

Wildlife professionals commonly assert that drainages and ridgelines act as guideways for animals moving through the landscape. A visual analysis of mapped TRs at TCP and VP suggests that the first order patterns of TR distribution could have been influenced by the orientation of such guideways. At TCP north and VP west, which had lower densities of TRs, most of the predominate ridgelines and drainages ran parallel to the road and did not act to bring animals to the roadside. Additionally, the four major drainages that did bisect the highway at VP west were spanned by large bridges that provided exceptional opportunities for animals to cross under the highway, further reducing the likelihood of at-grade crossing in this sub-area. Conversely, at the south end of TCP, box culverts which deer were reluctant to enter spanned the major drainages that guided animals to the highway. Consequently, the number of at-grade crossings in these locations was high. At VPS, the relationship of TR distribution to drainages and ridgelines was unclear. Snow depths associated with both types of features vary with the prevailing wind and may have the greatest influence on animal movement in wintertime.

At VPS, the location and frequency of animals crossing at-grade was strongly correlated to CMR (68.4 % of all crossing occurred adjacent to CMR). In winter, snow depths restrict both mobility and the food availability for wild animals in the Vail Pass area. This effect is pronounced for coyotes, which are not adapted to moving though deep snow. However, the packed ski trails at CMR and the plowed access roads allow wild animals as well as humans to move through the winter environment with relative ease. Additionally, in winter the availability of trash, birdfeeders, and pet food at CMR may act as a strong attractant to coyotes, the most common species recorded at VPS.

Local Scale Features

Variables from the roadside that were significantly correlated to CZ location included the aspect, cover type, distance to the nearest drainage, and the distance to the forest boundary. The results are presented in tabular formats below. Additionally, CZs were not located along portions of the road that were obstructed by barriers such as Jersey barriers, guardrails, or cliffs. The relationship of CZ locations to all the measured local-scale variables is discussed in detail below.

The comparisons of the cover type, slope, and aspect classes within 100 m of CZs with the distribution of classes available within 100 m of the entire roadside indicated that cover type differed at four sub-areas, aspect differed at five, but slope only differed at one (Table 1.8). The mostly non-significant results for slope were not surprising. My experience with the study sites suggests that the 10 m resolution DEMs did not capture the fine-scale variations that animals responded to when choosing a pathway from the adjacent habitat to the roadside. I observed many well-worn roadside game trails that picked a low-angle path through relatively steep slopes. The one significant result was at VPS Not CMR, where CZs were positively associated with slopes of 15° or less. Snow cover increases the attractiveness of shallow slopes for travel because it obliterates narrow game trails that pick through otherwise inhospitable slopes. Additionally, steep slopes become slippery and/or an avalanche hazard with snow cover.

Table 1.8 Results of chi-square tests comparing the distribution of cover, slope, and aspect classes within 100 m of the CZs to what is available throughout the highway corridor within 100 m of the roadside

Study Area	Sub-area	Cover Type	Slope	Aspect
TCP	South End	$\chi^2 = 1.02$, $p > 0.25$	$\chi^2 = 13.73$, $p > 0.25$	$\chi^2 = 7.84$, $p > 0.25$
	North End	$\chi^2 = 8.39$, $p < 0.05$	$\chi^2 = 10.51$, $p > 0.25$	$\chi^2 = 76.94$, $p < 0.001$
VP				
	East Side	$\chi^2 = 33.04$, $p < 0.001$	$\chi^2 = 3.51$, $p > 0.25$	$\chi^2 = 20.01$, $p < 0.05$
	West Side	$\chi^2 = 25.77$, $p < 0.001$	$\chi^2 = 6.70$, $p > 0.25$	$\chi^2 = 15.43$, $p < 0.10$
VPS				
	CMR	$\chi^2 = 7.92$, $p < 0.05$	$\chi^2 = 5.36$, $p > 0.25$	$\chi^2 = 24.49$, $p < 0.001$
	Not CMR	$\chi^2 = 0.92$, $p > 0.25$	$\chi^2 = 40.24$, $p < 0.001$	$\chi^2 = 45.75$, $p < 0.001$

Across the five sub-areas that had a significant relationship with aspect, there was no consistency in the aspect classes that were either positively or negatively correlated with CZs. Like at the landscape-scale, the effect of roadway direction probably swamped any effect of animal preference. The four sub-areas with significant relationships to cover also had inconsistent associations with cover type classes, and there was no clear source of biological significance to explain the observed patterns. Like with slope, it is likely that the variations in cover type that animals respond to at this scale are too fine-grained to be detected at the resolution of the digital data layers.

The association of CZs with barrier ends appeared strong, despite inconsistencies across the six sub-areas. Crossing zones were positively associated with barrier ends at both at TCP south and VP east (Table 1.9). At VP west there were so many barriers that nearly every location was near to a barrier end. Thus, there was little variability related to barrier ends that could be measured. At VPS, most barriers disappeared under the roadside snowdrifts created by the plows. In essence, these drifts became one continuous barrier along the entire roadway, and once again, there was little variability associated with barrier ends to measure. However, it is important to note that on the west side of Vail Pass, where both median and outer-edge barriers are present in many places, all CZs were located along the stretches of road with the fewest barriers, regardless of snow cover. Animals focused crossing activity on locations with either no barrier at all, or just a median side barrier.

Table 1.9 Actual distances compared with expected distances of CZs to barrier ends and the results of the chi-square test comparing the actual with the expected number of TRs located mid-barrier

Study Area	Sub-area	Actual Mean Distance (m)	Expected Mean Distance (m)	t-test Results	Mid-Barrier Chi-Square Results*
TCP	South End	43.1	52.2	$t = 1.63, p < 0.10$	$\chi^2 = 8.39, p < 0.01$
	North End	618.8	-	-	-
VP	East Side	202.31	259.64	$t = 2.54, p < 0.001$	$\chi^2 = 8.67, p < 0.01$
	West Side	232.48	201.99	$t = 0.94, p > 0.25$	$\chi^2 = 10.57, p < 0.01$
VPS	CMR	286.75	302.87	$t = 0.67, p > 0.25$	$\chi^2 = 13.26, p < 0.01$
	Not CMR	208.8	196.78	$t = 0.48, p > 0.25$	$\chi^2 = 8.39, p < 0.01$

* p-values indicate the likelihood that the actual number of points located mid-barrier is different from the expected number by chance.

Additionally, at all three study sites there were no CZs, and very few crossing TRs, located within the space between a roadside barrier and the roadway. This distribution of crossing TRs differed significantly from expected (Table 1.9). These results suggest that animals do not jump over Jersey barriers or guardrails to enter the roadway, a conclusion that agrees with the results reported by Carbaugh et al. (1975). Although my own results indicate that animals occasionally wander along the roadside in some places, they apparently do not walk into the narrow space between a barrier and the hardtop before crossing.

Previous research indicates that the locations where wild animals interact with highways are positively associated with drainages (Romin and Bissonette, 1996; Finder et al., 1999; Hubard et al., 2000), and my results support these findings. The CZs in my study were positively associated with drainages at TCP south, on VP east, and VPS Not CMR (Table 1.10). However, CZs were negatively associated with drainages at TCP north and VP west, and did not have a significant relationship at VPS CMR. These negative associations were not surprising and do not negate my support for a general positive association between CZs and drainages. The CZs at TCP north were strongly associated with the forest edge (see below), which was far away from the few locations where drainages intersected the roadside. At VP west, the large bridges that spanned the drainages created exceptional opportunities for animals to pass under the road. Thus, most animals following these drainages passed under the highway, and only a few at-grade crossing TRs were created near these drainages.

Table 1.10 Actual distances compared with expected distances of CZs to a drainage that intersects the road

Study Area	Sub-area	Actual Mean Distance (m)	Expected Mean Distance (m)	t-test Results
TCP	South End	216.58	447.09	t = 3.509, p < 0.001
	North End	3402.85	2299.17	t = 3.650, p < 0.001
VP	East Side	188.53	463.77	t = 6.89, p < 0.001
	West Side	3076.09	1583.11	t = 0.84, p < 0.25
VPS	CMR	666.78	601.10	t = 1.14, p < 0.10
	Not CMR	654.38	1258.14	t = 3.70, p < 0.001

Previous research also indicates that the locations where wild animals interact with roadways are positively associated with woody cover (Lyon 1979, Rost and Baily, 1979, Rodriguez at al., 1995, Yanes, 1995; Romin and Bissonette, 1996; Finder et al., 1999; Hubard et al., 2000), and my results support these findings as well. CZs were associated with the forest boundary in four out of six of the sub-areas, and the relationship was very strong for three of them (TCP north, TCP south, VPS Not CMR; Table 4.10). No significant difference from the expected distribution was apparent at VP west because the forest boundary is a very consistent distance from the roadside, and consequently, there was no significant variation to measure. The reason for the non-significant relationship at CMR VPS is probably because the attraction of CMR itself overrode any preference for crossing near forest cover.

However, the relationship of CZs to woody cover bears some additional discussion. The total amount of forest cover in the landscape (see previous section) and distance to the forest edge were significantly related to CZ location. Specifically, my results suggest that forest animals in the Southern Rocky Mountains prefer to cross a highway when at least 70 % of the surrounding landscape is woody cover (Table 1.5) and when the forest edge is no more then about 50 m away (Table 1.11). However, neither the amount of nearby woody cover, as measured by a GIS, nor the nearest individual stand of cover, as measured in the field, was important. This suggests that the most important quality of forest for forest-associated species may simply be that “its there”, and that it is nearby.

Table 1.11 Relationship of CZs to the forest boundaries

Study Area	Sub-area	Actual Mean Distance (m)	Expected Mean Distance (m)	t-test results
TCP	South End	20.72	26.43	t = 2.17, p < 0.05
	North End	26.15	68.54	t = 3.84, p < 0.001
VP	East Side	49.93	58.60	t = 2.62, p < 0.10
	West Side	43.66	41.44	t = 0.34, p > 0.25
VPS	CMR	57.66	54.39	t = 0.15, p > 0.25
	Not CMR	35.78	47.06	t = 2.14, p = <0.01

Underpass Use

Animals used underpasses to cross under the highway at all three study sites even though roadways at the study sites were unfenced and they were free to cross at grade. Due to the superior tracking medium placed in the underpasses, it was possible to record a greater range of species using the underpasses than crossing at-grade. Animals used the underpasses throughout the year. Although the type of data that were collected cannot be used to indicate a clear preference for certain underpass designs, they do demonstrate that a variety of designs are acceptable to a range of species.

Trout Creek Pass

The characteristics of the structures monitored for use at TCP, the number of times at least one set of tracks was observed passing through, and the number of times at least one animal was recorded crossing at grade next to an underpass (an end-run) are reported in Table 1.12. I checked 10 underpasses a total of 482 times, and at least one set of tracks was recorded passing through 23 % of the time. At least one set of tracks end-running an underpass was found 42 % of the time, and deer made all end-runs.

Table 1.12 Characteristics of monitored underpasses at TCP, number of times the structure was checked, and the number of times at least one through-pass by at least one medium- or large-sized animal was recorded

MP Location	Type*	Height (m)	Chamber Width/Total Width (m)	Length (m)	No. Times Checked**	No. Through Passes (%)	No. of End-runs (%)
215.0	Single Span	14.0	24	11.50	49	45 (91.8 %)	-
216.1	3 Chamber	3.0	3.40/10.20	14.00	23	11 (47.8 %)	11 (47.8 %)
216.5	3 Chamber	3.0	3.05/9.15	18.25	21/85	23 (27.1 %)	15(71.4 %)
216.8	2 Chamber	3.4	2.48/4.96	32.70	16	8 (50.0 %)	12 (75.0 %)
217.1	1 Chamber	2.5	2.50	27.50	19	1(5.3 %)	5 (26.3 %)
218.0	1 Chamber	2.5	2.50	22.10	17	5 (29.4 %)	8 (47.1 %)
218.4	3 Chamber	2.9	3.10/9.30	21.30	27/105	28 (26.7 %)	8 (29.6 %)
219.2	3 Chamber	3.0	3.10/9.30	21.30	29/105	31 (29.5 %)	18 (62.1 %)
221.9	3 Chamber	2.4	3.10/9.30	14.60	29	4 (13.6 %)	7 (24.1 %)
222.60	Single Span	3.1	7.34	11.10	34	1 (2.9 %)	6 (17.6 %)

* Single span bridges have natural floors, all other structures have concrete floors.

**For 216.48, 218.4, and 219.2 the first number in this column is the number of times the road surrounding the culvert was checked for evidence of end-running. The second number is the total number of time the trackbeds were checked for tracks. The at-grade road side at 215.0 was never checked for end-runs.

The ratio of each underpass' use (number of times used/number of times checked) based on the total number of through-passes, by species, is reported in Table 1.13. Because tracks from more then one species were often recorded when an underpass was checked for tracks, this ratio exceeds 1.0 for some underpasses.

Table 1.13 Number of times at least one individual of a species used each underpass at TCP

Species	215.0	216.1	216.5	261.8	217.1	218.0	218.4	219.2	221.9	222.6
Deer	39	4	5	-	-	-	-	-	-	-
Elk	-	-	-	-	-	-	-	-	-	-
Coyote	10	2	9	5	1	2	7	8	4	
Fox		-	7	-	-	1	5	15	-	-
Bobcat	1	1	3	-	-	1	9	6	-	-
Mt. Lion	-	2	1	3	-	2	3	-	-	-
Rabbit	11	12	20	5	5	-	16	49	-	1
Weasel	1	1	2	-	-	-	8	4	1	-
Total	62	24	47	13	6	6	48	82	5	1
Crossing Ratio	1.26	1.04	0.55	0.81	0.31	0.35	0.46	0.78	0.17	0.03

Rabbits, deer, and coyotes were the species most commonly recorded using underpasses. Coyotes and rabbits used the greatest number of different underpasses, but deer used their favored underpass (MP 215.0) most consistently. Multiple track sets from one species, especially deer, rabbits, and coyotes were commonly recorded. In most cases there was no way of knowing if these occasions represented one animal crossing many times or many animals crossing once. Track sets from two or more species were also relatively common, and consisted of both predator and prey species in many cases. In general, underpass use by all species remained consistent throughout the year, although mountain lions were not recorded during the summer months (June-August). The four underpasses that I checked most regularly (MP 215.0, 216.48, 218.4, and 219.2) were used throughout the year. Notable crossing events include a beaver dragging branches through the MP 219.2 structure on four occasions, and deer beginning to use the concrete-bottomed structure at MP 216.15 in late November, 2000, then continuing to use it consistently throughout the remainder of the study.

The single span bridge at MP 215.0 had a natural floor, was very open, and received the most consistent levels of use, including large numbers of deer as well as some bobcats and coyotes. However, although larger structures were generally used more then smaller ones, size did not guarantee use. The single span bridge and the three-chambered culvert located in the north end of the study area received no or very low rates of use.

Vail Pass

The characteristics of the structures monitored for use at VP, the number of times at least one set of tracks was observed passing through, and the number of end-runs are reported in Table 1.14. I checked four underpasses a total of 347 times, and at least one set of tracks was recorded 91 % of the time. At least one set of tracks end-running an underpass was found 29 % of the time. Table 1.15 reports the number of observations by species, when at least one track set was recorded. Each underpass' ratio of crossing, based on the total number of through passes, by species, and the number of times each underpass was checked, is also reported.

Table 1.14 Characteristics of the underpasses monitored for use at VP, including the number of times the structure was checked for tracks, and used by at least one medium- or large- sized animal to cross through

Location	Type	Height (m)*	Length (m)	Width (m)	No. Times Checked**	At Least One Through Pass	At Least One End-run
MP 183.0	Two adjacent 2-lane bridges	3.9	26.0 (both spans)	20.9	90	86 (95.5 %)	24 (26.7 %)
MP 184.9	Two adjacent 2-lane bridges	13.4	26.0 (both spans)	128.0	84	81 (96.4 %)	16 (19.1 %)
MP 190.8	One 2-lane bridge	5.6	12.9	45.0	88	75 (85.2 %)	38 (31.8 %)
MP 191.8	One 2-lane bridge	10.8	12.9	71.1	85	75 (88.2 %)	25 (29.4 %)

**The height of most bridges varied with topography; the maximum height is reported.
***It was not possible to access trackbeds due to highway maintenance and repair work on some occasions.

Table 1.15 Number of times at least one individual used the underpasses at VP

Species	Underpass			
	MP 183.0	MP 184.9	MP 190.8	MP 191.8
Deer	86	81	75	75
Elk	3	6	-	-
Moose	-	1	-	1
Coyote	10	15	1	5
Fox	3	1	6	-
Mountain. Lion	-	1	1	2
Bear	-	2	-	-
Totals	102	107	83	83
Crossing Ratio	1.13	1.27	0.94	0.98

Deer were the species most commonly recorded using all underpasses, and they used the underpasses on the west side of the Pass heavily and consistently. During June, July, and August of both years there were often so many deer tracks in the trackbeds of MP 183.0 and 184.9 that they obliterated one another and I could not count them accurately. Use was high throughout the summer, and then dropped off in the fall, reflecting the shift of deer and elk to lower elevations for the winter months. The less commonly recorded species were most likely to be recorded in June, September, and October, perhaps also reflecting seasonal migrations which were more likely to bring the animals into contact with the road. Coyote tracks were recorded more commonly in early summer and fall both below the roadway and at grade, and the two sets of bear tracks were recorded at almost the exact same location under 184.9 in October 2000 and 2001, just prior to hibernation.

Vail Pass Snow

The characteristics of the structures monitored for use, the number of times at least one trail was recorded passing through, and the total number of trails observed are reported in Table 1.16. I checked seven underpasses a total of 108 times, and at least one set of tracks was recorded 49 % of the time. Only one end-run was recorded, by a marten at MP 190.8. Because the density of trails going through the underpasses was low during winter and snow cover provided an excellent tracking medium, it was possible to count all tracks sets with great accuracy. However, when multiple trails from the same species were observed traveling though an underpass, it was still not possible to determine if this represented one animal passing through multiple times or multiple animals passing through once.

Table 1.16 Characteristics of the underpasses monitored for use at VPS. Includes the number of times the structure was checked for tracks, and the number of times it was used by at least one medium- or large-sized animal to cross through

Location	Type	Height* (m)	Length (m)	Width (m)	No. Times Checked	At Least One Through Pass	Total Number of Trails
MP 183.0	Two adjacent 2-lane bridges	3.9	26.0	21.9	17	5 (29.4 %)	5
MP 184.5	Two adjacent 2-lane bridges	13.5	12.9	218.0	13	10 (76.9 %)	24
MP 184.9	Two adjacent 2-lane bridges	13.4	12.9	128.0	19	13 (68.4 %)	30
MP 190.8	One 2-lane bridge (eb)	5.6	12.9	45.0	17	7 (41.2 %)	13
MP 191.4	One 2-lane bridge (eb)	13.2	12.9		13	5 (38.5 %)	7
MP 191.8	One 2-lane bridge (eb)	10.8	12.9	71.1	17	6 (35.3 %)	11
MP 192.5	One 2-lane bridge (eb)	10.5	13.0	103.5	12	7 (58.3 %)	32

*The height of most bridges varied with topography; the maximum height is reported.

Table 1.17 reports the number of observations when at least one track set was recorded, by species, and Table 1.18 reports the total number of trails that were recorded. Each underpass' ratio of crossing, based on the total number of through passes, by species, and the number of times each underpass was checked, is also reported. The data indicate that coyotes used the greatest variety of underpass most consistently and MP 192.5 and 184.9 were the most commonly used underpass in winter. Additionally, the rate of animal passage through underpasses was higher during March, as compared with the December – February period.

Table 1.17 Number of times at least one individual used the underpasses at VPS

	Underpass						
Species	MP 183.0	MP 184.5	MP 184.9	MP 190.8	MP 191.4	MP 191.8	MP 192.5
Coyote	2	6	7	9	3	4	8
Weasel	1	-	4	-	-	1	-
Marten	1	7	8	-	-	-	6
Hare	1	-	4	1	-	-	9
Elk	-	2	1	-	-	-	-
Totals	5	15	24	10	3	5	23
Crossing Ratio	0.29	1.15	1.26	0.59	0.23	0.29	1.92

Table 1.18 The total number of animals that used the underpasses at VPS

	Underpass						
Species	MP 183.0	MP 184.5	MP 184.9	MP 190.8	MP 191.4	MP 191.8	MP 192.5
Coyote	2	14	12	12	5	10	15
Weasel	1	1	3	-	-	1	-
Marten	1	6	9	-	-	-	5
Hare	1	-	1	1	-	-	12
Elk	-	2	4	-	-	-	-
Totals	5	23	29	13	5	11	32

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