Wildlife Use of Highway Underpass Structures in Washington State

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ABSTRACT:

The impacts of roads on wildlife and the environment have been well documented. Habitat fragmentation and wildlife-vehicle collisions are among the most noticeable and costly effects. To make appropriate management decisions to rectify barriers to wildlife movement and reduce wildlife-vehicle collisions, it is imperative to understand what, when and where wildlife are using existing highway underpass structures to cross highways safely. This study focused on analyzing species composition and temporal patterns of wildlife detections at various crossing structures throughout Washington State. Temporal aspects of species use of different underpass structures along highways were examined to gain insight to factors potentially influencing the permeability of existing highways and structures. Results found that certain species of wildlife were detected most often at particular structure types. Carnivores were detected most abundantly at culverts, while ungulate species were detected most profusely at bridges. Temporal patterns of most species detected were crepuscular, except for bears, elk and raccoons. Wildlife and human detections shared an inverse relationship where wildlife detections peaked before and after both peak human detections. This trend was also found with wildlife detections and traffic volume. Further research is needed to better understand how human presence and traffic volumes might be affecting wildlife use of structures.

INTRODUCTION:

Impacts of Roads on Wildlife

Roads are a main form of development transecting vast areas of the Earth's surface, negatively affecting ecosystems and associated wildlife.[1,2] Effects of roads include increased wildlife mortality rates; as collisions with vehicles are among the most noticeable and in some cases primary causes of mortality for large vertebrates.[2,3] The less obvious effects, but also influential impact of roads on ecosystems is habitat fragmentation. Road networks fragment landscapes and populations by impeding wildlife movement through physical barriers and behavioral avoidance, impacting population viability and resilience to changing environmental conditions .[4] Restriction of movements can reduce migration, dispersal and opportunities for mating, leading to population subdivision and genetic differentiation.[5,6] Characteristics of roads can influence the rate of collisions and habitat fragmentation. Jaeger and colleagues[7] found that road width and speed limit negatively impact wildlife, but not as significantly as traffic volume. This suggests that wider roads and a higher traffic speed result in greater wildlife-vehicle impacts.[1,7] Highways with high traffic volume have higher wildlife-vehicle collision rates and wildlife mortality, which negatively affect wildlife populations.[8,9]

Wildlife-vehicle collisions across the United States are annually estimated to be 300,000, an increase from 200,000 to 300,000 during 1990-2004. [3] Reasons for this increase could be explained by growing deer populations in many regions of the U.S. or an increase in traffic. [3] Collisions on Washington State highways involved at minimum 14,969 deer and 415 elk over the five year period 2000-2004, according to carcass removals.[10] Actual numbers of collisions with deer and elk in Washington State are likely higher since not all collisions with deer and elk result in instant mortality, and some unknown number of animals either survive the collisions or die at some distance from the roadway. Additionally, data are only available for state maintained roads. Local road departments rarely record carcass removals.

These collisions have safety consequences. Large mammals such as elk, deer and bear can cause serious injury to drivers and substantial property damage.[3,11] Large mammals are highly mobile and are more likely to enter roadways than less mobile species, increasing the chance of collision.[12,13] Driver safety is a primary goal for many transportation agencies and reducing or eliminating collisions with large mammals is a common problem for DOT management. Therefore, transportation departments have invested in studies of wildlife-vehicle collisions with the goal of reducing impacts on both humans and wildlife. Studies completed to date underscore the complexity of factors that contribute to these accidents. Wildlife-vehicle collisions are influenced by many factors including road characteristics and human behavior. [14,7,15]

It is therefore of interest to transportation agencies to manage for driver safety in high wildlife-vehicle collision prone areas. Unfortunately, mitigation decisions intended to provide for habitat connectivity and driver safety by transportation departments have historically been a product of analyzing only the wildlife-vehicle collisions.[3] This type of data provides no insight to wildlife successfully crossing roads at safe crossing structures. By analyzing wildlife detections non-invasively through the deployment of game cameras, behavioral responses of wildlife to roads can be obtained and inform mitigation decisions made by transportation planners and wildlife managers.

The Washington State Department of Transportation (WSDOT) is highly invested in considering the impact of habitat and the conservation of wildlife during transportation activities. Research on how roads influence the movement of wildlife, thus habitat connectivity throughout the state, informs transportation planners of areas that are needed to provide for wildlife movement. Part of this research analyzes already existing underpass structures for permeability through the use of game cameras.

This study focused on analyzing temporal patterns of wildlife detections at various crossing structures throughout Washington State. The emphasis was on understanding species use of different underpass structures along highways to better understand the highway's permeability and the characterization of wildlife use prior to any mitigation being constructed. By understanding permeability of structures along state highways, transportation planners can make appropriate mitigations decisions for wildlife, while ensuring driver safety. Once mitigation infrastructure is built, post-construction monitoring can be compared to pre-construction data to better understand how intended improvements affect wildlife use. With these goals in mind, we developed four research questions.

1. What animals, in what numbers, are using these underpasses?
2. What is the temporal variability of use at underpasses? Does it differ with time of day or the occurrence of sunrise and sunset?
3. What is the seasonal variability of each species' use structures?
4. What is the relationship between each species' use of underpasses and varying traffic volumes?

METHODS

Study Sites

I-90 West, North Bend, WA

Structure Description: Steel and concrete bridge on a divided highway
Dimensions: North Structure 12' high x 80' span x 83' long
South Structure 12' high x 80' span x 52' long
Width of fenced area under bridge 15'
Camera Deployment: Year 1: 6/22/2011 to 6/11/2012

Roadway and Site Description:

I-90 West is located along I-90, 30 miles (48 kilometers) east of Seattle (Figure 1). I-90 is the main west – east highway corridor in Washington State. This is a divided interstate (3 lanes in each direction). Annual average daily traffic (AADT) volume consisted of 45,696 vehicles in 2011.[16] There are two crossing structures located here, one for the west bounds lanes and one for the east bound lanes. Each structure along with eight foot tall wildlife fencing was built in 1976. Fencing stretched outward from each structure following I-90 in both directions. Due to the age of fencing, several places along the fence were in disrepair due to fallen trees and snags. Habitat through the structures consisted of seasonal wet areas surrounded by mostly grasses. On either side of the structures habitat consisted of thick vegetation, managed forest dominated by Douglas fir as well as human development. Further south of the crossing structures was an old abandoned road that led to Echo Lake. This abandoned road was heavily trafficked by mountain bikers and hikers.

Two Reconyx PC 900 game cameras were installed in front of both entrances to the structures. Cameras were placed so that the structures entrances were fully captured by the view of the camera in order to record all species utilization. Both cameras, on north and south sides of the interstate were enclosed in protective steel boxes bolted to a tree or fence post.

I-90 East, North Bend, WA

Structure Description: Steel Corrugated arch Culverts with natural substrate
Dimensions: North Structure 12' high x 29' span X 120' long
South structure 12' high x 29' span x 144' long
Camera Deployment: Year 1: 6-23-2010 to 6-23-2011, Year 2: 6-25-2011 to 6-25-2012

Roadway and Site Description:

I-90 East is located along I-90, 30 miles (48 kilometers) east of Seattle (Figure 1). There are two crossing structures located here, one for the west bounds lanes and one for the east bound lanes. An eight foot wildlife fence extends out from the crossing structures, paralleling I-90. However, due to age and lack of regular maintenance, there are several breaches in the fence due to fallen trees and snags. Surrounding habitat included a small creek that flows within these structures form south to north, traveling under ground between the two structures and above within each. On either end and between each structure was thick vegetation and managed forest dominated by Douglas fir and riparian areas associated with the small creek.

Two Reconyx PC 85 game cameras were installed in front of the north and south entrances to the structures. Cameras were placed so the structures entrances were fully captured by the view of the camera in order to record all species utilization. The southern camera was placed in a steel box bolted to a tree at chest height. The northern camera was placed in a metal utility box of a type commonly used for telephone line connections.

FIGURE 1 Monitoring site locations.

US-2 Deadman Creek, Spokane, WA

Structure Description: Steel Corrugated Arch Culvert
Dimensions: 17’ high x 30’ span x 112’ long
Camera Deployment: Year 1: 6/29/2011 to 4/22/2012

Roadway and Site Description:

Deadman Creek is located along US-2 north of Spokane, WA (Figure 1). This road segment is two lanes running north –south. Annual average daily traffic volume consisted of 24,868 vehicles in 2011.[16] In 2010 an existing concrete box culvert, an eight feet wide structure was replaced with a large corrugated steel culvert as a result of a fish barrier replacement project. This structure was not built with wildlife fencing; however natural features including a stream course and tall embankments act as a funnel to the structure. The initial replacement project was based on restoring potential habitat for resident cutthroat trout however, the structure was built wide enough to allow terrestrial wildlife to utilize the dry banks on either side of the creek during low flows. Wetland and riparian habitat next to the structure was improved through wetland mitigation after construction was completed.

Habitat outside of the immediate structure consisted mostly of human development including residential homes and agriculture. During summer months the creek is popular with people.

Two Reconyx PC 900 game cameras were installed on both sides of this structure's entrances positioned to take pictures of any wildlife utilizing the structure. Cameras were locked to cables embedded in concrete inside metal utility boxes intended to disguise them and prevent human tampering.

US-12 Cora Bridge, Randle/Packwood, WA

Structure Description: Steel and concrete span bridge
Dimensions: 22' high x 200' span x 33' long
Camera Deployment: Year 1: 1/26/2012 to 1/24/2013

Roadway and Site Description:

Cora Bridge is located along US-12 between Randle and Packwood, WA (Figure 1). This highway is another main west – east highway corridor in Washington State, however traffic volume is not as high as I-90. This segment of highway had two lanes and was unfenced. Annual average daily traffic volume consisted of 2,910 vehicles in 2011.[16] This bridge spans the width of the Cowlitz River. Multiple concrete support columns support the span of the bridge across the river. On either side on the river is ample bank for terrestrial wildlife to negotiate. On the west side of the bridge there is parking for cars and the area is heavily used by humans. Substrate under the bridge includes large rocks and boulders but there are walkable paths under the bridge. Heavy growth of Himalayan blackberries are present on this side of the bridge except for a path underneath the bridge and along the bank. Under the east side of the bridge there is a grassy path flanked by thick Himalayan blackberries with ample space to pass safely under the bridge. Adjacent to the bridge habitat consisted of large land parcels use primarily for livestock grazing.

Two Reconyx PC 85 game cameras were installed, one on each side of the river. Cameras were positioned so that any wildlife utilizing the area under the bridge along the upper bank is captured. Cameras were locked to cables embedded in concrete inside of metal utility boxes intended to disguise them from human tampering.

US-97 Butler Creek, Goldendale, WA

Structure Description: Steel corrugated culvert
Dimensions: 8' high x 8' span x 33' long
Camera Deployment: Year1: 6/8/2011 to 5/17/2012

Roadway and Site Description:

Butler Creek is located along US-97 outside of Goldendale, WA (Figure 1). This segment of highway during this period of time is a two lane road heading north and south with a low barbed wire right-of-way fence. Annual average daily traffic volume consisted of 4,504 vehicles in 2011.[16] The culvert is embedded in a concrete structure with a concrete apron spill way at the east culvert entrance. The west side entrance to the culvert has large rock rip-rap stabilizing the creek bank. Immediate habitat consisted of grass and ponderosa pine forest. Surrounding ponderosa pine forest was managed by private landowners and DNR.

Two Reconyx PC 85 game cameras were installed, one on each side of the highway near the culvert. Cameras were not positioned at the openings of the culvert but instead monitored habitat adjacent to the culvert. Cameras were placed in metal utility boxes to disguise them from human tampering.

Camera Data Collection, Management and photo analysis:

Once a month cameras were serviced to retrieve cards and replace batteries, ensuring continuous monitoring of sites. Images were downloaded and stored in folders organized by location and date range. Images were analyzed and the results stored in Excel spreadsheets. Data stored in Excel spreadsheets involved detections. A detection was defined to be one or more animals captured by the camera and separated from the any prior or subsequent detection of the same species by at least 30 minutes. The following information was recorded per detection: date of detection, start and end time of detection, whether the detection spanned midnight, detection start and end temperature, whether the animal passed through the structure, time of sunrise and sunset, species detected, sex, age, total number of individuals during detection, whether the animal was repelled by the structure, whether the opposite camera captured the same animal occurrence, and comments.

The VLOOKUP function in MS Excel was used to coordinate time of detection to a table of sunrise/sunset times for various locations in order to analyze detections in relation to sunrise and sunset. To accomplish this, we established a point in time when each detection occurred. This point in time is the midpoint between the time when the first and last photos of an animal, or group of animals, were taken. This time of detection could then be characterized in terms of its relationship to the nearest sunrise and sunset, giving us a sense of the influence of daily cycles on occurrence of each species at our structures. We used National Oceanic and Atmospheric Administration's (NOAA) online sunrise/sunset calculator for times of sunrise and sunset and assigned these to each detection.[17] Each detection was then characterized for its relationship, in number of hours, to the nearest sunrise and sunset. Negative values represent number of hours prior to the nearest sunrise or sunset and positive values represent number of hours after the nearest sunrise or sunset. Graphs were constructed to show numbers of detections by intervals of hours on either side of sunrise and sunset, giving a strong visual description of a species' tendency toward diurnal, nocturnal, or crepuscular behavior at each location.

Data Analysis:

Once all the information was recorded in excel spreadsheets, data from each camera at each location was combined, filtered and sorted. Since all locations had multiple cameras, data from each camera was then combined per location. Duplicated entries were deleted, such that, multiple detections of the camera operator and wildlife detected by both cameras in one day were deleted. Data selected for analysis came from locations monitored for a full annual cycle. Subsets of data representing, as close as possible, an annual cycle were created. If a site had two full years of data, the data were broken out into annual cycle datasets and analyzed separately as year 1 and year 2. Species composition was analyzed and specific species were selected based on abundance (>20) for continued analyses. A single detection sometimes involved multiple individuals and the data summarized in this analysis reflect the expansion of detections to reflect multiple animals in these detections. Species abundance will be used to describe the combination of an event that captures one or more animals and the number of animals capture. Species abundance was graphed against time of day and season. Seasons were defined as winter 12/21 to 3/20, spring 3/21 to 6/20, summer 6/21 to 9/21, and fall 9/22 to 12/20. Traffic volume data were obtained from available traffic data recorders near camera site locations. Species abundance was graphed against traffic data to get a baseline understanding of the relationship between use of structures and traffic volume.

RESULTS

Species Composition

The range of species detected at the monitoring sites varied between 6 and 10 with I-90 East having the greatest number and diversity of species, with a total of 10 detected (Table 1). I-90 East was primarily dominated by carnivore species, with an average 38% of detections consisting of black bears and 30% consisting of coyote. Divergently, a site located 2 miles from I-90 East, I-90 West, displayed only 20% black bear, 7% coyote, and black-tailed deer as the dominate species totaling 35%. The monitoring site with the lowest diversity of species and highest amount of individuals detected was US-2 Deadman Creek with 6 species and 1642 individuals detected. US-2 Deadman Creek detections were dominated by white-tailed deer at 76% and human &/or dog at 23% .Despite the locations of these monitoring sites within the distribution range for elk, only two sites detected elk, I-90 East and US-12 Cora Bridge, with US-12 Cora Bridge having the highest elk abundance at 41 individuals. US-12 Cora Bridge had the greatest percentage of human activity at 58%, while US-2 Deadman Creek detected the greatest abundance of human activity at 383 individuals.

Temporal Analysis

24 Hour Clock

When detections of species were graphed in relation to a 24 hour clock; common trends among monitoring sites emerged. Wildlife abundance showed an inverse relationship to human &/or dog detections. The majority of human &/or dog detections occurred during mid-day hours between 9:00 and 16:00 hours (Figure 2). Peaking of wildlife detections varied between sites and species, usually peaking before and after human &/or dog peaks. I-90 West displayed high abundance of wildlife detections between 3:00 to 7:00 and 18:00 to 21:00 hours (Figure 2A). I-90 West displayed noticeable patterns of detections for raccoon, black bear and black-tailed deer, but not coyote. I-

90 East displayed a fairly high abundance of detections throughout the day, but peaked during morning hours of 6:00 to 9:00 and 18:00 to 19:00 hours (Figure 2B). I-90 East displayed noticeable patterns of detections for only black bears and coyotes, with black bear detections peaking between the hours of 6:00 and 9:00 with lowest amount of detections between 21:00 to 4:00 hours the next day. Coyote detections peaked at 1:00 hours, 5:00 hours and between the hours of 7:00 and 9:00. US-12 Cora Bridge displayed the most staunch inverse relationship pattern between wildlife detections and human &/or dog detections, with wildlife detections peaking at late evening hours and early morning hours (20:00 to 3:00 hours the next day) (Figure 2C). US-2 Deadman Creek displayed a similar trend to US-12 Cora Bridge's inverse relationship between human &/or dog and wildlife detections, however wildlife detections peaked at different hours than what is seen at US-12 Cora Bridge, peaking between the hours of 5:00 to 8:00 hours and 16:00 to 20:00 hours (Figure 2E). Similar patterns of wildlife detections peaking in morning and evening hours were found with US-97 Butler Creek (Figure 2D).

TABLE 1

COMPOSITION OF SPECIES DETECTED AT ALL MONITORING SITE LOCATIONS FOR WASHINGTON STATE.

Camera Sites												
Species	**I-90 West**		**I-90 East** Yr 1		Yr 2		**US-12 Cora Bridge**		**US-97 Butler Creek**		**US-2 Deadman Creek**	
Deer Spp. (*Odocoileusspp.*)	68	34.17%	19*	10.33%	7	1.72%	16*	6.58%	217*	71.85%	1241*	75.58%
Elk (*Cervus elaphus*)	0	0.00%	1	0.54%	1	.25%	41*	16.87%	0	0.00%	0	0.00%
Moose (*Alces alces*)	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	1	0.06%
Black Bear (*Ursus americanus*)	39*	19.60%	67*	36.41%	158	38.73%	0	0.00%	2	0.67%	0	0.00%
Bobcat (*Lynx rufus*)	7	3.52%	3	1.63%	11	2.70%	1	0.41%	2	0.67%	0	0.00%
Coyote (*Canis Latrans*)	13*	6.53%	54*	29.35%	123	30.15%	1	16.46%	7	2.35%	3	0.18%
Raccoon (*Procyon lotor*)	38	19.10%	4	2.17%	16	3.92%	40*	0.41%	0	0.00%	8	0.49%
Human &/or Dog (*Homo sapien* and *Canis familiaris*)	32*	16.08%	36*	19.57%	84	20.59%	141*	58.02%	61*	20.47%	383*	23.33%
Bird Spp. (*Aves*)	1	0.50%	0	0.00%	2	.49%	2	0.82%	6	1.01%	6	0.37%
Rabbit Spp. (*Leporidae)*	1	0.50%	0	0.00%	4	.98%	0	0.00%	1	0.34%	0	0.00%
Virginia Opossum (*Didelphis viginiana*)	0	0.00%	0	0.00%	2	.49%	0	0.00%	0	0.00%	0	0.00%
Skunk Spp. (*Mephitidae*)	0	0.00%	0	0.00%	0	0.00%	1	0.41%	2	.067%	0	0.00%
Squirrel Spp. (*Sciurus spp.*)	0	0.00%	0	0.00%	0	0.00%	0	0.00%	3	1.01%	0	0.00%
Total	**199**	**100%**	**184**	**100%**	**408**	**100%**	**243**	**100%**	**302**	**100%**	**1642**	**100%**

*Species selected for further analyses per site.

Deer spp. is a combination of mule (*Odocoileus hemoinus*), white-tailed (*Odocoileus virginianus*) and black-tailed deer (*Odocoileus hemionus columbianus*).

Bird spp.is a combination of mallard (*Anas platyrhnchos*), wild turkey (*Melegris gallopavo*), American crow (*Corvus brachyrhynchos*), American robin (*Turdus migratorius*), and humming bird spp. (*Trochilidae*).

Squirrel spp. is eastern gray squirrel (*Sciurus carolinensis*) and western grey squirrel (*Sciurus griseus*).

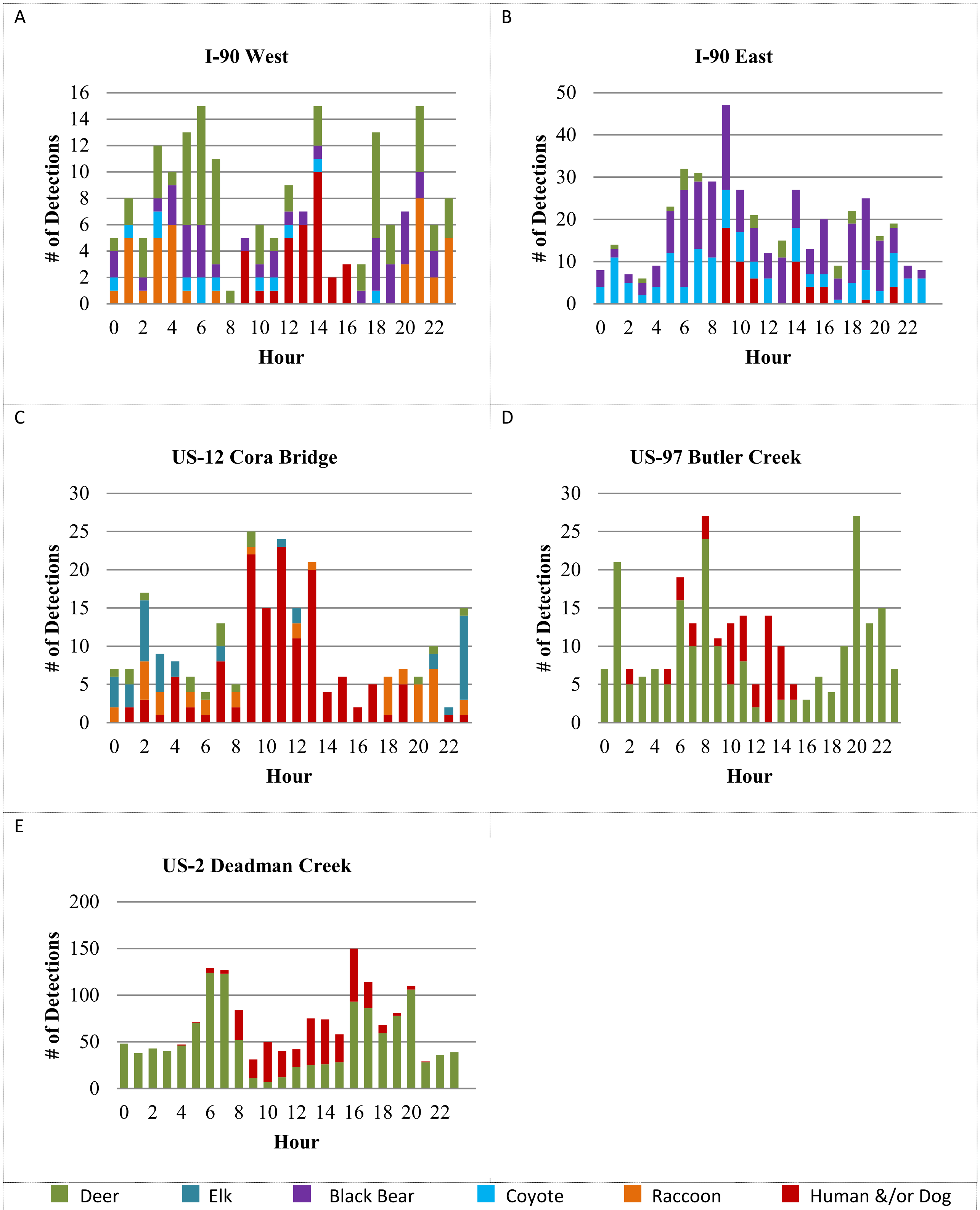


FIGURE 2 Animal abundance hour at all monitoring sites in Washington State.

Seasonality of Detections

Seasonal variation in detections of species was found to occur at every monitoring site, however seasonal patterns of detections differed between sites. For three sites I-90 West, I-90 East and US-97 Butler Creek, deer were most abundant during summer months (Figure 3A,B, and D). However, US-12 Cora Bridge and US-2 Deadman Creek detected deer at greatest abundance during fall months but continuing into the winter time for US-2 Deadman Creek (Figure 3C and E). US-2 Deadman Creek was the only site that document high abundance of deer species during winter months. All other sites detected little to no deer presence during winter months. I-90 West and I-90 East detected the greatest abundance of black bears during summer months. Coyote was detected at highest abundance during summer months at I-90 West and fall months at I-90 East. Raccoon was detected at greatest abundance during summer months at I-90 West and I-90 East and winter months for US-12 Cora Bridge. Elk detections stayed steady throughout the year except for decreasing during spring months. Overall, spring months showed the lowest animal abundance of all seasons.

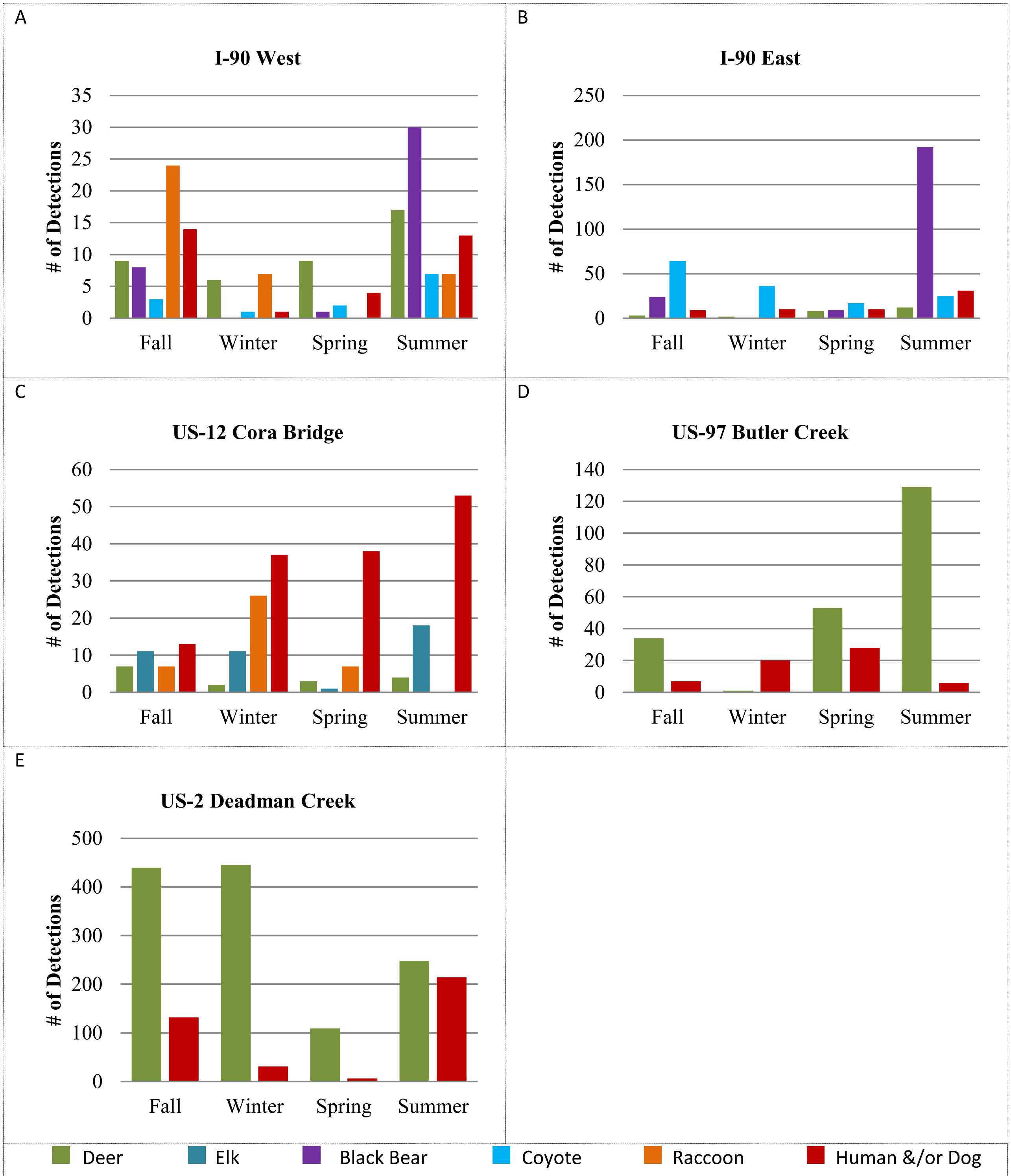
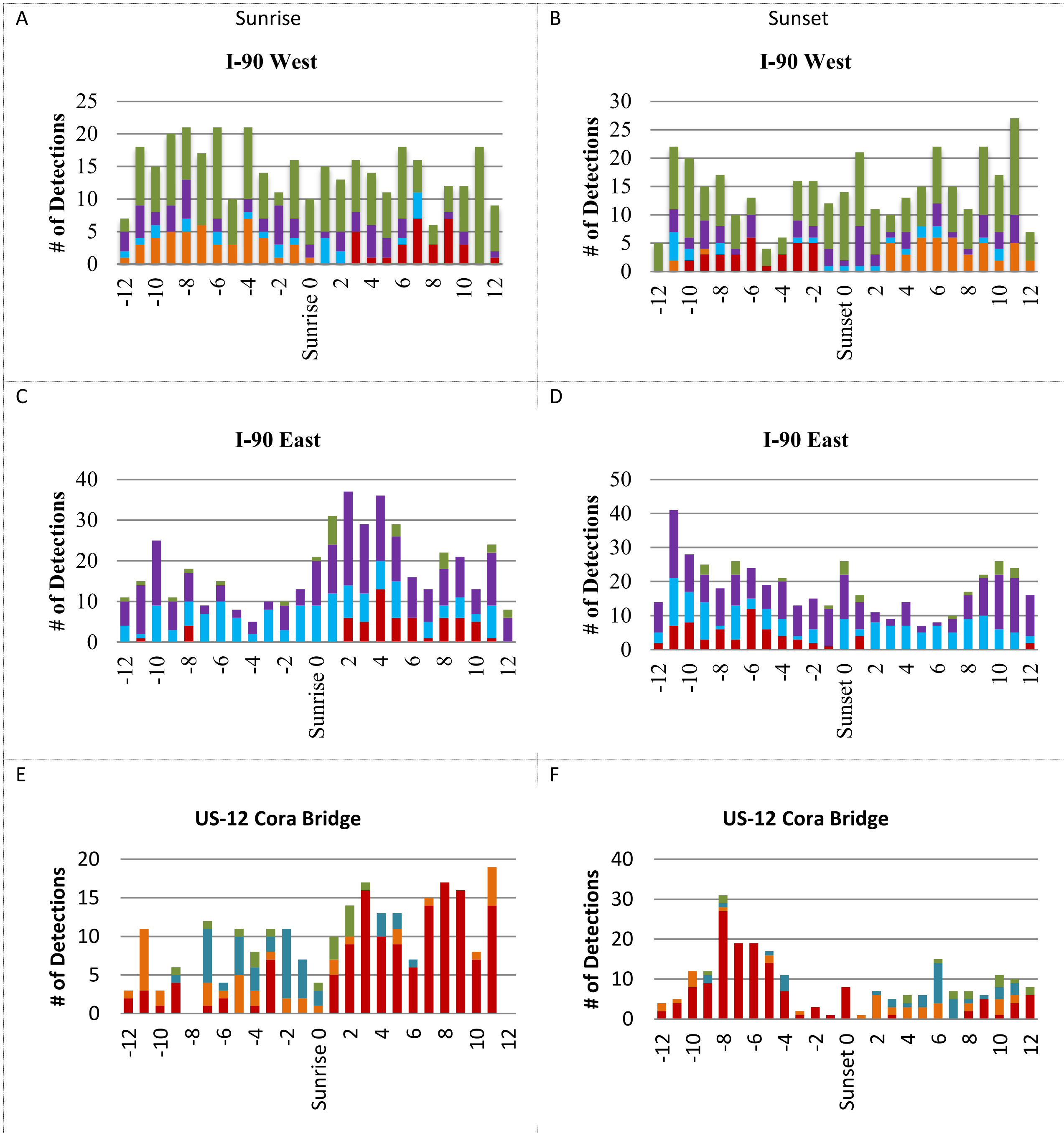


FIGURE 3 Animal abundance detections by season at all monitoring sites in Washington State.

Crepuscular Activity

Most monitoring sites mirrored I-90 West where human &/or dog detections most commonly occurred after sunrise and before sunset while wildlife detections most commonly occurred before sunrise and after sunset (Figure 4). Raccoons showed noticeable patterns in relation to sunrise and sunset, with most detections occurring before sunrise and after sunset. At I-90 West black bear detections were dispersed in no noticeable order in relation to sunrise and sunset (Figure 4A and B). However, at I-90 East, black bear detections peaked and were most abundant after sunrise (2 to 4 hours after) and before sunset, with the lowest amount of detections 2 to 7 hours after sunset (Figure 4C and D). Deer detections displayed variable patterns in relation to sunrise and sunset. Temporal patterns were not evident at I-90 West, I-90 East and US-12 Cora Bridge, however, there were noticeable patterns at US-97 Butler Creek and US-2 Deadman Creek (Figure 4). Deer detections at US-97 Butler Creek peaked after sunrise with several peaks in relation to sunset (Figure 4G and H). Deer detections at US-2 Deadman Creek showed noticeable peaks at sunrise and sunset (Figure 4 I and J).



A
Sunrise
I-90 West
# of Detections
Sunrise 0
B
Sunset
I-90 West
# of Detections
Sunset 0
C
I-90 East
# of Detections
Sunrise 0
D
I-90 East
# of Detections
Sunset 0
E
US-12 Cora Bridge
# of Detections
Sunrise 0
F
US-12 Cora Bridge
# of Detections
Sunset 0

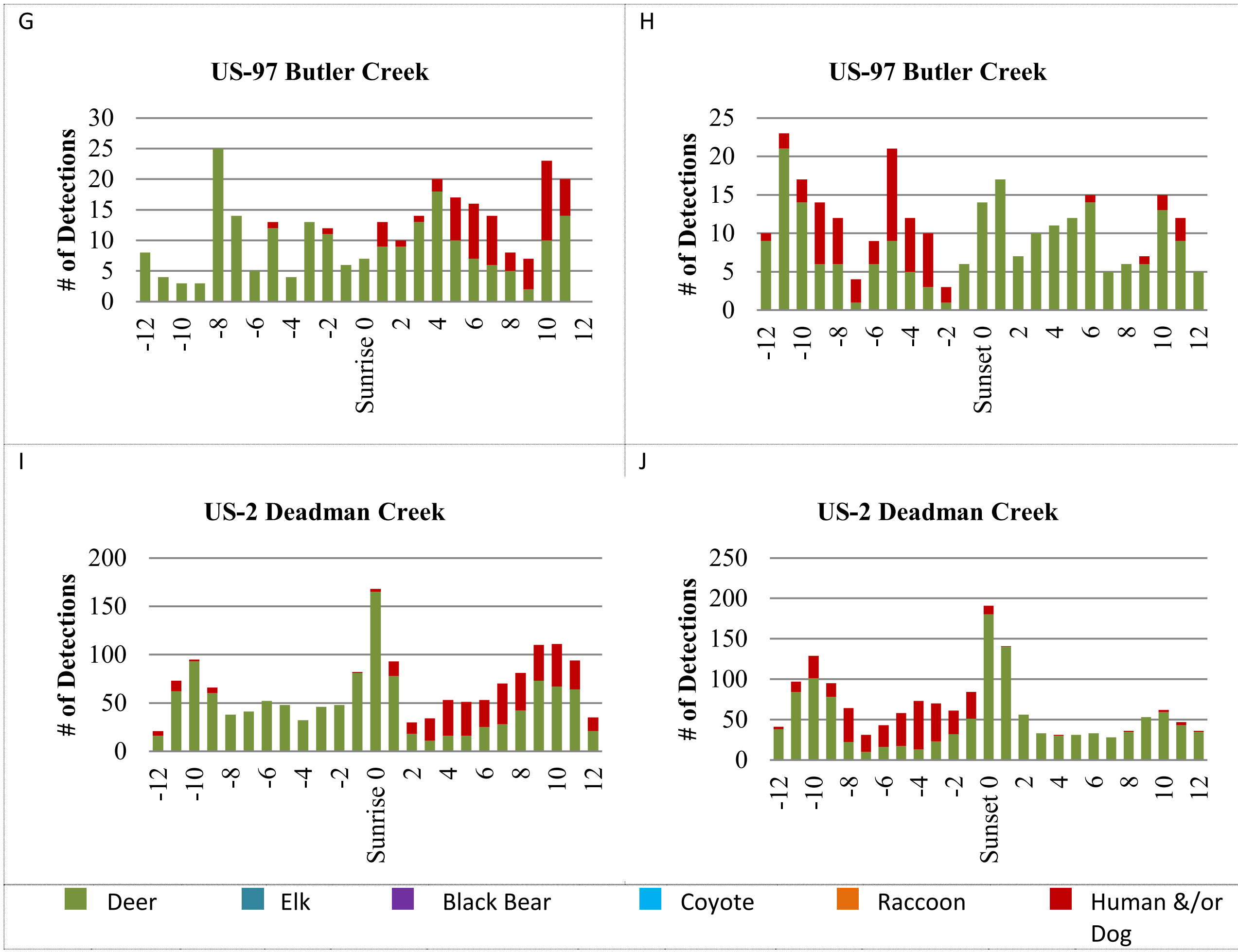
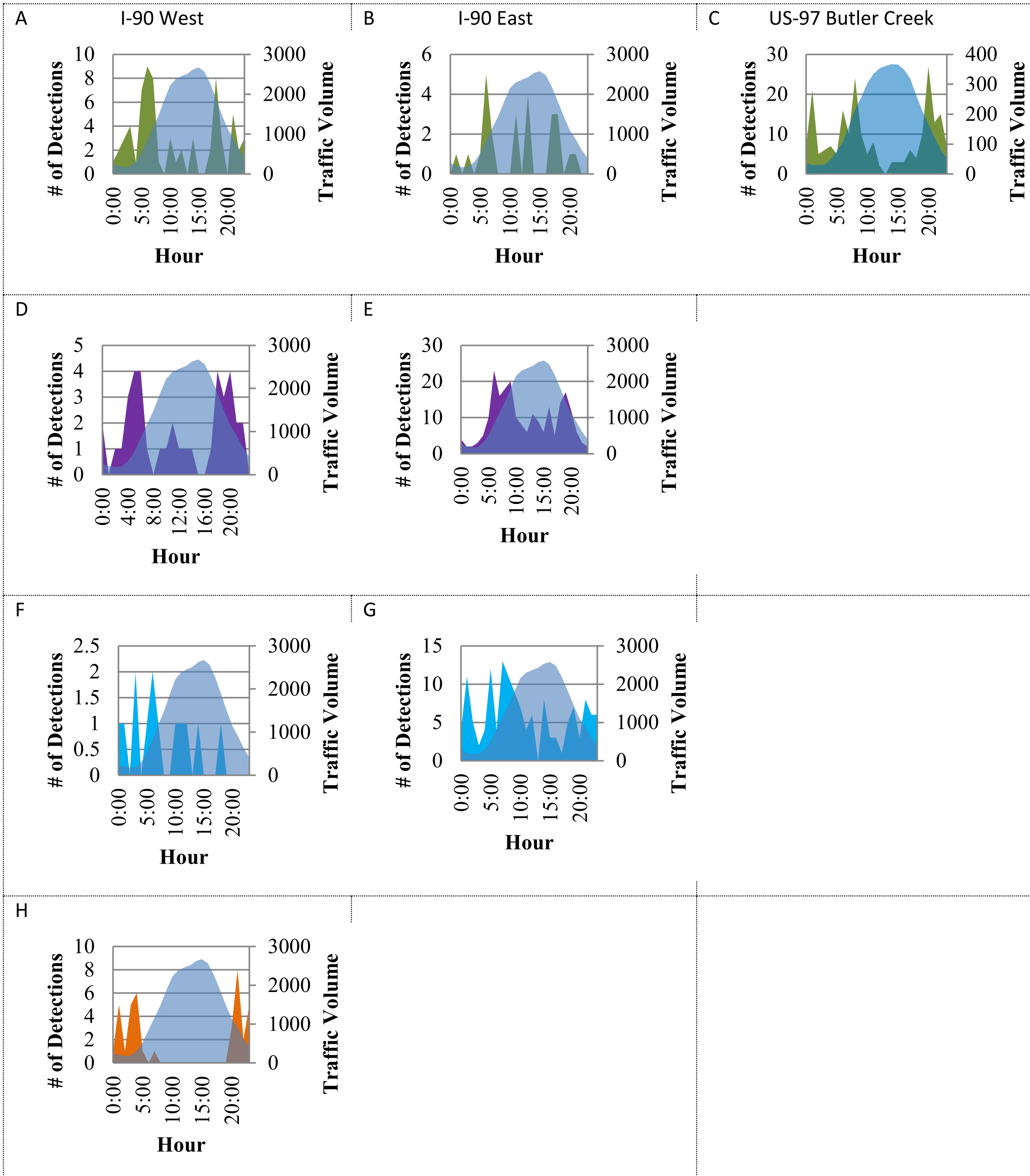


FIGURE 4 Animal abundance in relation to sunrise and sunset across all monitoring sites in Washington State.

Traffic Volume

Not all monitoring sites had traffic recorders nearby, therefore only the I-90 West, I-90 East and US-97 Butler Creek sites were used in the traffic volume analysis (Figure 5). At every site human &/or dog detections coincided with peak traffic volume between the hours of 10:00 and 16:00 hours. However, most wildlife detections displayed an inverse relationship to peak traffic volume, peaking before and after peak traffic volume. Black bear, deer and raccoon displayed the most apparent inverse relationship to traffic volume, peaking before and after peak traffic volume hours (Figure 5).Coyote detections were less abundant during peak traffic volume, but did not display as apparent of a decrease in number of detections as seen with black bear, deer and raccoon. However, there was a noticeable peak in coyote detections before peak traffic hours.


A
I-90 West
# of Detections
Traffic Volume
Hour
B
I-90 East
# of Detections
Traffic Volume
Hour
C
US-97 Butler Creek
# of Detections
Traffic Volume
Hour
D
# of Detections
Traffic Volume
Hour
E
# of Detections
Traffic Volume
Hour
F
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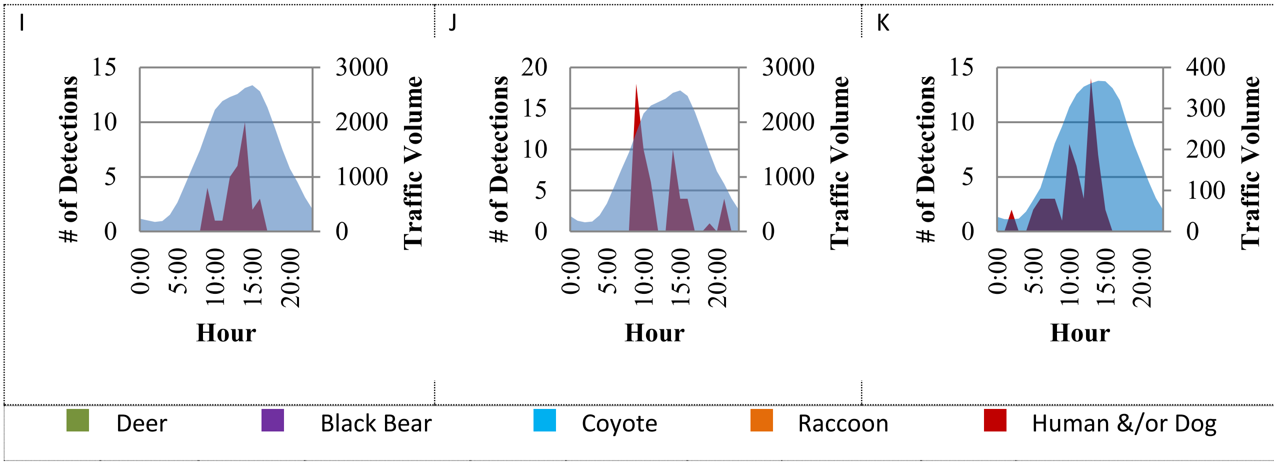

FIGURE 5 Animal abundance detections and annual average daily traffic volume (AADT) per hour at select monitoring sties in Washington State.

DISCUSSION

Species Composition

The difference in species composition among the different sites could be due to a variety of different reasons. First, surrounding habitat could influence what species are present and available to use the structure. Additionally, Julia Kintsch and Patricia Cramer found that particular structure types are favored by certain species. Elk were found to prefer bridge structures, while bears preferred culverts.[19] Scientists studying wildlife crossing as part of a long term monitoring project in Banff, Canada have also found preferential use of crossing structures by bears. Bears were found to preferentially use culvert structures verses bridges.[21] Our data supports these findings, with 39 bears detected at I-90 West, a bridge structure and 67 for year one and 158 for year two at the culvert structure at I-90 East (Table 1). Conversely, deer were found most prevalent at the I-90 West bridge structure verses the I-90 East culvert structure. It must be noted that these two structures are only two miles apart along the same highway surrounded by similar habitat and limiting confounding variables. Elk were primarily detected at a wide span bridge structure at the US-12 Cora Bridge site, supporting Kintsch and Cramer's findings of ungulate preferential use of bridge structures.[19] However, the US-2 Deadman Creek culvert detected high abundance of deer throughout the year despite the structure type. Many factors could be driving the influence of high deer detections at US-2 Deadman Creek including overall abundance of deer in this location, as well as, human habituation. [18] In addition, landscape features contribute to funneling deer to this structure as it is located in a riparian corridor amidst a highly fragmented human developed area.

Surrounding habitat and human detections varied substantially between the structures which could influence species composition and temporal activity of detections. US-2 Deadman Creek is the only structure surrounded by extensive human development which contributes to the abundance and temporal activity patterns of humans at the site. The deer at this location could be accustomed to human activity since this structure had the highest amount of human detections while still supporting some of the highest levels of deer activity. It's possible, though, that lower deer use of this structure during summer was a response to high levels of human presence during this season. I-90 West and East are located along a high traffic interstate surround by a mixture of development and habitat, while US-12 Cora Bridge and US-97 Butler Creek are surrounded by mixed agriculture and forested managed lands, low development and relatively low traffic volumes. The extent to which elk and deer may be influenced by human interactions, potentially shifting their activity patterns to avoid human activity, isn't clear based on the data presented here. However, the totality of the activity patterns observed suggests that this is a possibility. A better understanding of deer and elk activity patterns in the absence of humans would help with interpreting these results. Knowledge of the interactions between surrounding habitat, structure type, and human activity on rates of wildlife detections at crossing structures is still limited and further research is needed.

Temporal Analysis

Reoccurring trends were found within the 24 hour clock, crepuscular activity and traffic volume analyses. Wildlife abundance was greatest in morning and evening hours, usually before and after sunset. However, elk, black bear and raccoon at certain sites showed contrasting patterns. Elk and raccoon were most abundant during night time hours. The observed nocturnal activity pattern of elk at the US-12 Cora bridge site contrasts the crepuscular behavior commonly found by Ager and colleagues[20] and the diurnal pattern found by Clevenger.[21] Black bears at site I-90 East were most abundant during the day with a slight crepuscular activity pattern, peaking in abundance during the morning and evening hours. These black bear findings are similar to what is found within the literature for undisturbed black bear behavior and for black bear crossings.[22,23, 21]

The majority of wildlife detections peaked inversely to peak traffic volume hours. Normal crepuscular and nocturnal activity patterns displayed by many species detected at our monitoring sites could explain this inverse relationship. However, for black bears at I-90 East, detections could have been influenced by the traffic volume seen by decreased detections during peak traffic hours, with crepuscular peaks in activity before and after peak traffic volume hours. It has been well documented that high traffic volume hours influence the rate at which wildlife cross roads, however, further analyses on how traffic volume influences rates at which wildlife use crossing structures needs to occur.

CONCLUSION

This was the first attempt at understanding how wildlife in Washington State use existing highway structures to pass safely across highways. This research is important for understanding permeability of highways to inform management decisions. By understanding how structures and surrounding habitat characteristics affect wildlife utilization of highway underpasses, biologists, engineers and road planners will be better informed when making management decisions relevant to corridor planning, environmental retrofits and construction projects. The knowledge of what structures wildlife prefer can then be taken into account when constructing or retrofitting structures to aid wildlife movements and prevent wildlife-vehicle collisions. However, further analyses on how traffic volume and human activities influences wildlife use of crossing structures needs to be executed.

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