Assessing the permeability of large underpasses and viaducts on Interstate 5 in Southwest Washington State for local wildlife, with an emphasis on ungulates.

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Abstract

High-volume, high-speed, interstate highways negatively affect landscape connectivity, create fragmentation, and limit wildlife movement. Climate change increases many of the negative impacts of fragmentation, while creating new challenges to local wildlife. If species are to successfully adapt to climate change by migrating and dispersing, connected landscapes must be available. I-5 was the focus of this research as it is the largest and most traveled interstate on the west-coast and fragments key habitat for ungulates and other wildlife between the Washington coast and the Cascade mountains. The typical assumption is that I-5 is not permeable and represents a linear barrier to all local wildlife. However, after using the passage assessment system [PAS] on 33 structures at 20 locations in S.W. Washington and analyzing each one for a wide variety of species' needs, and behavioral traits, it can be concluded that I-5 has passable viaducts and bridges that may represent a valuable opportunity to enhance permeability with very little investment. After comparing an aggregate dataset (wildlife-vehicle conflicts) of wildlife collisions and carcass removals within the study area, it can be stated that large crossing structures receive, on average, higher rates of collisions and carcass removals than areas not associated with large structures. In addition, structures at two locations were monitored for a year to illustrate which species are currently using them to cross I-5. All 33 structures have received recommendations for enhancement. Furthermore, PAS has been used to create proxies for modeling resistance values for connectivity mapping. Lastly, locations

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Chapter 1: Introduction

Roads and road systems have numerous ecological impacts on the landscapes in which they exist. Roads with the greatest ecological impacts on their surrounding landscapes, are highways and interstates (Beckmann, Clevenger, Huijser, & Hilty, 2010; Forman & Alexander, 1998). One of the most highly traveled and under researched interstates on the west coast is Interstate 5 (I-5). The interstate runs north to south from Canada to Mexico and passes through three states–Washington, Oregon, and California. The structure boasts ~1,381 miles (~2,223 km), with ~277 (~445 km) of those miles running through the state of Washington, terminating in the north at the Canadian border and in the south at the Oregon border. Regionally, I-5 may interrupt landscape continuity and connectivity, more importantly it fragments core habitat for animals like Columbian black-tailed deer (*Odocoileus hemionus columbianus*), Columbian white-tailed deer (*Odocoileus virginianus leucurus*) [CWTD] and elk (*Cervus elaphus*) in S.W. Washington (Washington Wildlife Habitat Connectivity Working Group, WHCWG, 2010; WSDOT, 2016). Despite the scientific understanding of the effects of fragmentation and habitat loss created by highways and the need to have permeable landscapes, there is a surprising void of research related to I-5 and its permeability for native wildlife.

To date there has been no published attempt by either researchers or state/federal agencies to assess or evaluate the permeability of structures on I-5 in Washington State for large ungulates, or any other local species populations. This lack of knowledge leads one to ask a series of relevant questions. Why is permeability of I-5 important in Washington State? How can permeability be better evaluated on I-5? Where on I-5 are wildlife-vehicle conflicts greatest? Where should new research be conducted? Are current GIS maps and their associated resistance values truly representative of the structures along I-5? To what extent is I-5 permeable for local ungulates and other wildlife? Lastly, can enhancements or new applications make I-5 more permeable for ungulates and other wildlife?

Through the process of exploring these questions, this thesis will utilize a qualitative review of primary and gray literature, coupled with quantitative agency data, camera data, structure assessment data, and observations; to assess current levels of permeability for local ungulates, and to make recommendations to improve the permeability of I-5 for local ungulates in S.W. Washington State. To answer the proposed research questions, this thesis makes use of the recent convergence of 1) new research related to the effects of climate change on fragmented species; 2) new on-the-ground assessment systems; 3) relevant GIS mapping techniques/data; 4) better scientific understanding of deer and elk behaviors; 5) and robust state agency (WSDOT) data.

Why is connectivity important?

Researchers have known about the importance and repercussions of habitat fragmentation and the associated habitat loss, for at least the last 20 years (Forman & Alexander, 1998; Spellerberg, 1998). Today the knowledge is continuing to grow, researchers now understand the significant and usually negative effects roads have on ecosystems and wildlife. For example, roads increase animal avoidance, extirpation, extinction, wildlife mortality, wildlife-vehicle collisions, invasive species, and human injuries/death. In contrast, there are decreases in genetic migration, local populations, habitat, fecundity, and wildlife mobility (Alexander & Waters, 2000; Andis et al., 2017; Clevenger & Kociolek, 2006; Clevenger, 2012; Coffin, 2007; Fahrig, 2003; Forman, 2003; Forman & Alexander, 1998; Spellerberg, 1998; Wilcove, Rothstein, Dubow, Phillips, & Losos, 1998).

Highly trafficked infrastructure like highways and large interstates, first destroys habitat during construction, and permanently fragments the remaining habitat, having both direct and indirect effects on wildlife populations (Wilcove et al., 1998). Direct effects are more obvious effects; they include mortalities and population separations. Indirect effects are more subtle; for example, when a species moves away from habitat due to behavioral responses, attempting to avoid noise, human presence, open spaces, or light. Unsurprisingly, large highways and interstates with high traffic volumes generate light, noise, vehicle conflicts and chemical pollution (Beckmann et al., 2010; Coffin, 2007; Forman, 2003; Shilling et al., 2018). I-5 can alter entire ecosystems, changing species abundance, altering biodiversity, and disrupting ecological processes (Coffin, 2007).

Spellerberg (1998), summarized the effects of roads on ecosystems and wildlife (Table 1.1, 1.2, 1.3). Although most species have a negative relationship with roads; some species thrive, particularly invasive, edge associated species and human adapted species. In fact, the verges and edges created by roadways are favored by some adaptive and disturbance tolerant species. Nevertheless, for most species, roadways and the loss of habitat associated with them increase stressors and environmental pressures (Alexander & Waters, 2000; Coffin, 2007; Fahrig, 2003; Forman, 2003; Forman & Alexander, 1998; Spellerberg, 1998).

Roads are physical barriers, in road ecology the "road barrier effect" (the physical separation of species and habitat) explains phenomena associated with roads as wildlife ecological barriers. Fragmentation is one of the known outcomes of the "road barrier effect," and is compounded by variables like traffic volume, road avoidance, chemical avoidance, artificial light, and physical size and shape of the barrier (Alexander & Waters, 2000; Beckmann et al., 2010; Clevenger & Waltho, 2004; Davies, Bennie, Inger, Ibarra, & Gaston, 2013; Forman, 2003; Forman & Alexander, 1998; Shilling et al., 2018; Spellerberg, 1998).

A summary of the ecological effects of roads

Table 2.1 Effects during road construction. Spellerberg F. I. (1998). Ecological effects of roads and traffic: A literature review" Global Ecology and Biogeography Letters, vol. 7, No. 5. (Sep. 1998), p. 318.

Direct loss of habitat and biota
Effects resulting from the infrastructure and supporting activities during construction.
Impacts can occur beyond the immediate vicinity of the road: for example, changes in hydrology. Mining aggregates for the road may also take place in another area.

Table 1.2 Short term effects of roads. Spellerberg F. I. (1998). Ecological effects of roads and traffic: A literature review" Global Ecology and Biogeography Letters, vol. 7, No. 5. (Sep. 1998), p. 318.

The new linear surface crates new microclimates and a change in physical conditions can extend varying distances fromthe road's edge.
The newly created edge provides habitat to edge species.
Plant mortality increases along the edge; and such mortalities may extend varying distance from the road edge.
Plant morality has both direct and indirect secondary effects on other organisms.
Some fauna will move from the area of the road as a result of the habitat loss and physical disturbance.
Animals are killed by traffic (wildlife-vehicle conflicts)

Table 1.3 Long term effects of roads. Spellerberg F. I. (1998). Ecological effects of roads and traffic: A literature review" Global Ecology and Biogeography Letters, vol. 7, No. 5. (Sep. 1998), p. 318.

Animals/humans continue to be injured and killed. (wildlife-vehicle conflicts).
Road kills have secondary effect as carrion.
The loss of habitat and change in habitat extends beyond the road edge.
Changes in biological communities may extend for varying distances from the road edge.

There is fragmentation of habitat and this in turn has implications for habitat damage and loss, for dispersal and vagility of organisms, and for isolation of populations.
The edge habitat (ecotone) and traffic on the road may facilitate dispersal for some taxa including pest species.
The dispersal of pest species via ecotones or traffic may have secondary effects on biological communities.
Associated structures such as bridges and tunnels may provide habitat for some taxa.
Run-off from roads affect aquatic communities.
Emissions, litter, noise, and other physical disturbances may extend into the roadside vegetation for varying distances and result in changes in species composition.

Fragmentation vs. Habitat loss

Recent research has proposed a contrary paradigm to the long held idea of habitat fragmentation causing losses in biodiversity, suggesting the relationship may be based on many assumptions (Fahrig, 2003; Theobald, Reed, Fields, & Soule, 2012). In 2017, a literature review was conducted to answer two basic questions "1) Are the most significant of responses to habitat fragmentation negative or positive? and 2) Do particular attributes of species or landscapes lead to predominance of negative or positive significant responses?" (Fahrig, 2017). 118 empirical studies were evaluated with 381 significant responses, showing that 76% of studies showed a positive relationship between biodiversity and habitat fragmentation. The researcher evaluates fragmentation independent of habitat loss, separating the two concepts, suggesting that habitat loss is the main driver of the negative relationships observed and associated with "fragmentation."

Fahrig (2017), goes on to suggest that the negative effects of habitat fragmentation independent of habitat loss being bad for biodiversity may be a "zombie idea," an idea that should be dead but is not. The concept around a zombie idea suggests that some ideas or "theories" begin to become standardized, even when that idea may not necessarily be true or properly tested. These ideas continue to permeate current scientific knowledge, when they in fact should have died off, due to their irrelevance or misinterpretation. Instead of dying off, the idea goes on and on, long after it is dead. Fahrig (2003) suggested that fragmentation independent of habitat loss is not bad for biodiversity and labels the idea a zombie idea. However, labeling the concept as a zombie idea leaves little room for nuance, and implies all fragmentation independent of habitat loss is comparable to one another (Fahrig, 2017 pg.18; Fox, 2017).

Conceptually the idea that fragmentation is a net positive for biodiversity, makes some sense, as edge species do thrive where there are smaller patch edges. However, this way of perceiving fragmentation as independent of habitat loss is relatively new and unheralded, and may not be significant when long time frames are applied (Alexander & Waters, 2000; Coffin, 2007; Fahrig, 2017; Haddad et al., 2015). One aspect that confuses the concept of fragmentation as a net positive for biodiversity is the separation of fragmentation from habitat loss. Structures like I-5 fragment the landscape, also initially removing habitat during construction. The resulting barrier may fragment historical habitat or corridors, implying fragmentation creates habitat loss or vice-versa (Forman, 2003; Spellerberg, 1998; Wilcove et al., 1998). Second, the study does not address large species with wide ranges and migratory needs, instead the focus is on the biodiversity at the fragmented patch, not the species barred from accessing it (Coe et al., 2015; Coffin, 2007). Finally, the author concedes that invasive, overabundant species, and pest populations make up the biodiversity that fragmentation is positively associated with (Fahrig, 2017). There is no consideration for historical species, extirpations, historical abundance, or need to move for climatic changes, it simply focuses on higher concentrations of biodiversity and the positive relationship associated with fragmented patches (Forman & Alexander, 1998; Krosby, Tewksbury, Haddad, & Hoekstra, 2010; Sgrò, Lowe, & Hoffmann, 2011).

Ultimately, biodiversity alone may not be indicative of a healthy patch of habitat, it appears to be necessary but not sufficient for describing the relationship between fragmentation and habitat loss. However, if this new paradigm is supported with strong scientific evidence, the scientific community will have to reevaluate how landscape connectivity is prioritized and described. One important implication of viewing small patches of habitat as important pieces of a connected landscape, is that resources could be redirected to help conserve and protect smaller and more urban patches of habitat. Utilizing small or even suboptimal habitat could facilitate changes in ranges or migratory needs of species under a changing climate (Doerr, Barrett, & Doerr, 2011; Fahrig, 2017; Hannah, 2011).

Roadways, highways and large interstates like I-5, are unique barriers that can restrict access to suitable habitat, destroy habitat, and fragment landscapes. In the case of large roads with high traffic volumes, fragmentation and habitat loss may be tied together to one landscape feature, and may in fact be inseparable (Beckmann et al., 2010; E. S. Long, Diefenbach, Wallingford, & Rosenberry, 2010; WSDOT, 2016). Not only has there been research suggesting that fragmentation reduces biodiversity anywhere between 13 % and 75 %, which directly conflicts with the Fahrig (2003) conclusions; but there is also strong evidence showing that the longer the habitat is fragmented, the more degraded it becomes (Fahrig, 2003; Haddad et al., 2015). In addition, the same study agreed that there may be initial explosions of certain species abandoned, and in some cases, this could cause an increases in biodiversity, but that any gains were slowly lost over time (Haddad et al., 2015). This can be interpreted to suggest that fragmented landscapes may have short term benefits, but that connected landscapes insure long-term ecological benefits.

Regardless of which definition of fragmentation or habitat loss is used, there are currently ways to mitigate the negative effects of both fragmentation and/or habitat loss. Connectivity can alleviate the negative effects of roads associated with fragmentation and/or habitat loss. A connected landscape facilitates access to daily and seasonal habitats, can reestablish genetic flows, increase local populations, enable movement for migratory species, and maintain genetic and evolutionary resilience (Forman, 2003; Sgrò et al., 2011; Wade, McKelvey, & Schwartz, 2015).

Wildlife-Vehicle Conflicts WVCs

Wildlife-vehicle conflict (WVC) is a term used in this thesis that includes events like collisions, collisions created by near misses, carcass removals, and near misses. In the United States a vertebrate is killed in a vehicle collision every 11.5 seconds, culminating in 1 million mortalities every single day. Over the course of an entire year, roughly 365 million vertebrates are killed on roads (Federal Highway Administration [FHWA], 2008). One way to put these numbers into perspective, is to compare them to the estimate of 100 million animal deaths a year due to hunting; which are probably inflated as it is from an animal rights activist group (DA4A, 2010). Regardless, it appears likely that wildlife-vehicle collisions kill more vertebrates every year than hunting within the United States (Forman & Alexander, 1998). It has been estimated that between 720,000 and 1.5 million deer are hit in vehicle collisions every year in the United States, resulting in 29,000 human injuries annually (FHWA, 2008; Gonsor, Jensen, & Wolf, 2009). Unfortunately, some of these collisions are fatal, resulting in roughly 200 human fatalities every year (Forman et al., 2003; FHWA, 2008). Washington State Department of Transportation [WSDOT] (2018) reports that in Washington State, roughly 1500 wildlife-vehicle collisions are reported by the Washington State Patrol [WSP] every year. Notably, these numbers could be much higher, because according to WSDOT not all collisions get reported. In fact, WSDOT removes approximately 4873 deer carcasses and 223 elk carcasses every year from state roadways, showing a large gap in reported collisions vs. carcass removals (Romin & Bissonette, 1996; WSDOT, 2018). In addition, Washington

State sees an average of one fatality a year with around 167 injuries to humans (WSDOT, 2018a). Furthermore, these incidents result in an average of over a thousand dollars per citizen in property damage annually (WSDOT, 2018b).

To build a better database of collisions, WSDOT is currently monitoring and recording reported wildlife-vehicle collisions with the help of the Washington State Patrol [WSP]. To facilitate a better visualization of these collisions, WSDOT creates GIS maps of collision data[1] reported by the WSP (Fig. 1.1). Clearly, this type of data has many limitations, as not all incidents are reported. In fact, Romin & Bissonette (1996) suggested that in the late1990s up to 50% of incidents went unreported, and currently WSDOT and FHWA agree that there is significant data that goes unreported (FHWA, 2008; Romin & Bissonette, 1996; WSDOT, 2018a). Another important limitation is that the data only shows the few collisions, not the successful crossings, road avoidances, or whether an area is even accessible to wildlife. One final limitation of WSDOT-specific WVC data is the fact it is not comparable to different locations throughout the state, all that is shown is the number of collisions or removals. WSDOT does not currently evaluate the data per traffic volume, meaning the data says nothing about the probability of hitting an animal. This could be remedied by differentiating between areas with high vs. low annual average daily traffic (AADT). Regardless of the obvious limitations of current WVC datasets, understanding and utilizing wildlife-vehicle collision data in combination with carcass removal data can be an

[1] Data is raw and does not consider the probability of hitting an animal. For example, in order to make comparison of locations, counts of collisions and carcasses should be evaluated alongside a measure of vehicle traffic (e.g. counts per 100,000 AADT).

important tool when evaluating whether an area is in need of further research or monitoring.

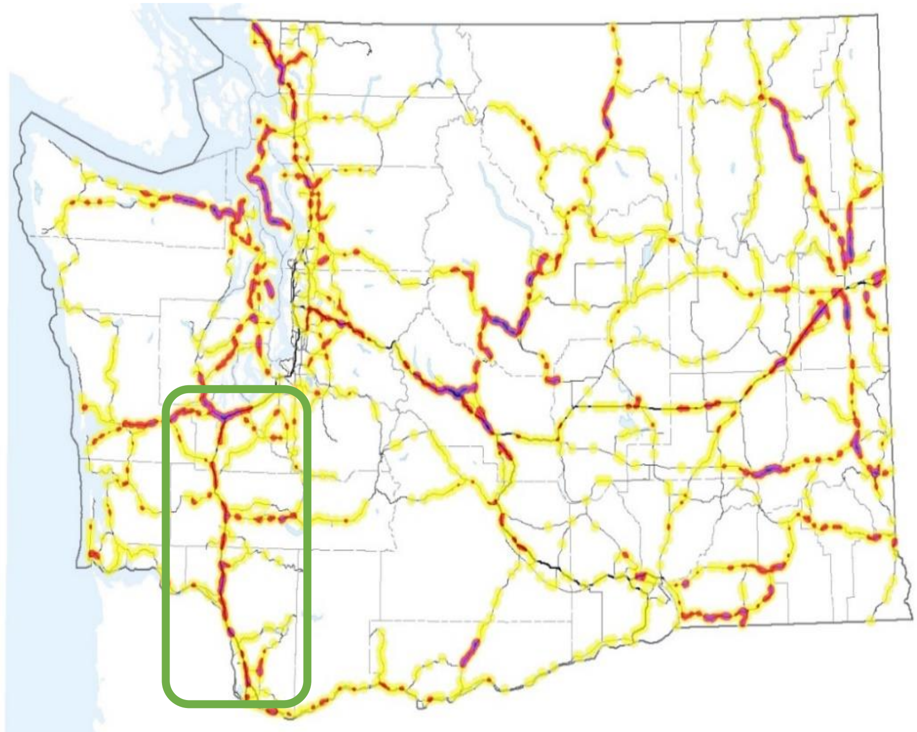

Figure 2.1 Unpublished kernel density map for Washington State deer-vehicle collisions. . Purple densest, red medium density, yellow low-density. Green box I-5 S.W. WA. Washington State Department of Transportation (WSDOT) (2018) [Map].

Large animals with wide ranges like deer and elk are extremely susceptible to wildlife-vehicle collisions, and accidents involving ungulates typically result in damage or injury (Bissonette & Cramer, 2006; Huijser, Camel-Means, et al., 2016). Seasonal migratory routes for deer are one predictor of where wildlife-vehicle collisions will take place (Coe et al., 2015). Also, where large populations of deer and elk exist, roads in that area show higher rates of collisions (Yinhai Wang, Yunteng Lao, Yao-Jan Wu, & Joanathan Corey, 2010). If ungulates exist near, or migrate across roadways, there will be at least some level of WVC.

Factors associated with high collisions rates have been well documented. Speeds over 50 MPH, rural areas, time between dusk and dawn, wide shoulders, the months of October and November, AADT over 4,000 and Mondays are all associated with higher rates of wildlife-vehicle collisions (Forman & Alexander, 1998; Neumann et al., 2012; Yinhai Wang et al., 2010). Fortunately, knowledge of how to mitigate collisions is also becoming more robust. Two of the main mitigation options are wildlife fencing and crossing structures, which can reduce collisions by 91% and 63 % respectively (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). In addition, two categories of mitigation have been developed, one focuses on human behaviors (i.e. observing speed limits, signs, education, and vigilance). The other focuses on animal behavior (i.e. movements, attractions, avoidance, bridges and fences). When planning to mitigate for WVCs, both human behavior and animal behavior should be considered, this will create safer roadways and should lessen WVCs in general (Glista, DeVault, & DeWoody, 2009).

Summary

The negative effects of a fragmented landscape and the threat of wildlife-vehicle conflicts make thorough research of structure permeability necessary for insuring safety and ecological resilience of landscapes. Although I-5 has less collision density than in other locations in Washington State, it is important to note that I-5 is very difficult for wildlife to access; therefore, the low density is still significant considering the ease of which other interstates and roadways can be accessed by wildlife. The lack of collisions on I-5 may be potentially due to the fact that I-5 is a formidable linear barrier of sound, light, steel and concrete, but more research is needed to know with any certainty (Bissonette & Cramer, 2006; Donaldson, 2005; Stankowich, 2008). Limiting the financial costs of vehicle damage, and human/wildlife safety, are compelling reasons to prioritize permeability research on the I-5 Corridor. Just as compelling are the needs of ecological systems and wildlife to have access to connected landscapes, which is well documented. Thus, this thesis seeks to better evaluate the current permeability of I-5 and its associated structures for ungulates and other wildlife in S.W. Washington State.

Chapter 2: Climate Change

Climate change greatly increases the need for permeability of the landscape and increases the negative effects associated with fragmentation and/or habitat loss (Doerr et al., 2011). Historical changes in climate forced many species including humans to migrate, or shift ranges (Lawler, Ruesch, Olden, & McRae, 2013; McLeman & Smit, 2006). Unfortunately, human infrastructure now has the potential to limit or prohibit movement across the landscape, making migration, range shifts and adaptation far more difficult than in the past, if not impossible (Vos et al., 2008; Washington Wildlife Habitat Connectivity Working Group, WHCWG, 2011). Another complication is the fact that planners and practitioners are forced to keep pace with a climate that appears to be changing more rapidly than previously predicted (Heller & Zavaleta, 2009; IPCC, 2013; Krosby et al., 2010; Snover, Mauger, Whitely Binder, Krosby, & Tohver, 2013).

Climate projections vary greatly depending on future production of greenhouse-gases (GHGs). It is predicted that if GHGs are greatly reduced warming could increase by as little as +1.8 °F (which seems unlikely). However, if GHG production remains unchanged, what is known as the "business as usual" scenario, and then it is predicted that temperatures could rise as much as +6.7 °F (range +4.7 °F to +8.6 °F) (IPCC, 2013; Snover et al., 2013). This change is already occurring, for example in the Pacific Northwest [PNW] the region has already warmed +1.3 °F between the years 1895-2011. Another PNW trend is that all seasons except for spring have been shown to have statistically significant warming compared to previous year's seasons (Snover et al., 2013). It has become clear that the climate is changing currently specifically by warming, regardless of the range of predictions. It is therefore time to implement mitigation and adaptation strategies.

Extinction, Fragmentation, and Climate Change

One way to attempt to quantify the relationship between habitat loss and fragmentation and possible extinction rates due to climate change, is to use a power-law relationship model. A power-law relationship describes the relationship between two quantitative variables, where one variable changes at a rate to a certain power of another. For example, the species-area relationship is described as $S = CA^z$, where S= #of species, A=area, and C and z are constants (Rosenzweig, 1995). This relationship has been used to quantify extinction rates when the area accessible to species is reduced by habitat fragmentation, by assigning a power-law relationship to area and number of species (Thomas et al., 2014). Research conducted in 2014 used the power-law relationship for 1,103 different species in 8 different locations (biomes) covering 20% of the Earth's surface, varying quantitative methodologies were used to avoid many of the assumptions and generalizations to which the power-law relationship on its own gives rise (Thomas et al., 2014). Also, by giving corresponding extinction rates for different climate range predictions specific to each research location, the researchers were able to calculate averages of all locations and species within the study. The study used predictions from older climate change studies, showing climate range predictions, for maximum climate range predictions extinction rates are predicted to be (~35%), for medium range climate predictions (~24%), and for minimum predictions (~18%). This thesis recommends using current climate predictions to update these predicted extinction rates (IPCC 2013; Thomas et al., 2004). The study concludes that if a species has limited dispersal and its habitat is fragmented the extinction rate could be anywhere between 38-52%, and for species with free dispersal and connected habitats the rate could be between 21-37%. Although this research uses many equations and models to avoid bias or data gaps, it is still based on assumptions. However, this research still has some merit, it does show that there is a relationship between extinction rates for some wildlife due to their inability to disperse, and quickly adapt to a changing climate.

Connectivity and Climate Change

There has recently been a surge in research related to the need for connectivity to maintain biodiversity through a changing climate and ways to mitigate existing fragmentation of the landscape (Clevenger, 2012; Hannah, 2011; Heller & Zavaleta, 2009; Krosby et al., 2010; Lawler et al., 2013; McCollister & van Manen, 2010; B. H. McRae et al., 2016; Theobald et al., 2012; Thomas et al., 2004). Heller & Zavaleta (2009) conducted an exhaustive review of the literature, making recommendations as to what practitioners and planners should do to help mitigate climate change for wildlife (Heller & Zavaleta, 2009). They reviewed 22 years of science consisting of 524 recommendations from 113 peer-reviewed articles. From that analysis, five reoccurring recommendations are discovered. The five are ordered from most frequent to least; 1) increase connectivity/corridors and remove barriers; 2) integrate climate change into planning exercises; 3) mitigate threats (e.g., invasive species, fragmentation, pollution); 4) study species responses to climate change; 5) increase reserves. The most frequent recommendation is to increase connectivity and remove barriers and a piece of the third recommendation is to decrease fragmentation. The recommendations support the idea that a permeable landscape is necessary to mitigate fragmentation, and that barriers created by roads will exacerbate the negative effects of climate change, possibly leading to higher extinction or extirpation rates (Coffin, 2007; Doerr et al., 2011; Heller & Zavaleta, 2009; Sgrò et al., 2011; Spellerberg, 1998; Thomas et al., 2004).

Evolution and Climate Change

Creating or enhancing permeability of structures will be an important mitigation technique to ensure robust wildlife populations through a changing climate. There are different recommendations on to how to best mitigate the effects of fragmentation in a changing climate, and planners and practitioners must make better and more robust decisions to help facilitate adaptive responses (Malcolm, Markham, Neilson, & Garaci, 2002; Sgrò et al., 2011; Vos et al., 2008). One shift in thinking that may help planners better prepare for climate change is considering evolutionary processes more critically when planning for mitigation or assisting in adaptation (Sgrò et al., 2011). Historically, species have been able to disperse to track climate change, if species that adapt through movement are to persist going forward, they will need to have spatial opportunity to move (Araujo, Thuiller, & Pearson, 2006; Lawler et al., 2013; Thomas et al., 2004). In the past the landscape allowed for selection and genetic variation through movement, allowing species to respond to indirect and direct effects of a changing climate. Genetic plasticity and gene flow can help to build population and genetic resilience when facing quickly changing environmental pressures like climate change (Sgrò et al., 2011). Evolutionary responses to climate change can vary, dispersal, long distance and short distance migrations, and even rapid evolution are possible reactions to a quickly changing climate (Bradshaw & Holzapfel, 2008; McGuire, Lawler, McRae, Nuñez, & Theobald, 2016; Sgrò et al., 2011). Although many evolutionary responses happen over long time frames, some genetic changes can happen in the tens of years, but only if the landscape lends to free movement of genes and species dispersal, which is currently limited by human infrastructure (Bradshaw & Holzapfel, 2008; Sgrò et al., 2011).

A paradigm shift may be needed to think in evolutionary terms. First, policies must be crafted that take into account the fact that local climate will not be the same in the future, and that local wildlife are not always the best wildlife for building ecological resilience to a changing climate (Sgrò et al., 2011) Two recommendations are offered to help planners consider evolutionary processes, "1) Identify and protect evolutionary refugia for multiple populations in a landscape; 2) increases connectedness and gene flow across climate gradients" (Sgrò et al., 2011). By combining evolutionary processes with classic connectivity conservation, and by creating corridors both long and short, a robust and resilient landscape can be created that allows for specie's adaptations (Hannah, 2011; McGuire et al., 2016; Sgrò et al., 2011; Washington Wildlife Habitat Connectivity Working Group, WHCWG, 2011).

Velocity of Change

Lastly, climate change is moving much faster globally and locally than earlier predictions have foretold, and it is being driven by novel and anthropogenic phenomena unprecedented in the history of the Earth (Krosby et al., 2010; IPCC 2013; Snover et al., 2013). Relevant research has been conducted using a qualitative literature review to investigate historical migrations of species during climate changes (Krosby et al., 2010). The article suggests that historical migrations covered vast distances, distances that are simply not available currently due to a fragmented landscape. They also suggest that increasing reserves or local habitat is simply ineffective in connecting the great distances wildlife will need to escape regions in which they now find themselves no longer adapted to persist in. Furthermore, the article suggests north-south movement is critical, as well as altitude increases (i.e., lowland species moving higher into mountain ranges) for species to persist through a changing climate (Krosby et al., 2010). In fact, Krosby et al. (2010) say "thus, increasing connectivity may increase probability of persistence of many organisms as climate changes", illustrating the importance of structure permeability (p. 1687). It is interesting to note that Theobald et al. (2011) have suggested that the enhancement of biodiversity through landscape connectivity is simply an assumption. If this is true, then it would seem reasonable to infer that there may be many assumptions about the effects of increased habitat connectivity, this would include assertions related to the effectiveness of mitigating the effects of fragmentation complicated by climate change (Krosby et al., 2010; Theobald et al., 2011). In addition, past climate gradient research shows that north-south movement may be less important in the PNW and S.W. Washington than previous research has suggested research (Krosby et al., 2010; Washington Wildlife Habitat Connectivity Working Group, WHCWG, 2011). It is apparent that more detailed and thorough research must be conducted to better establish a body of knowledge related to the effects of connectivity related to climate change. Anthropogenic climate change is occurring far faster than any historical climatic changes, meaning there is no precedent for the coming change and therefore it is almost impossible to predict with any certainty exactly what will take place. We do know that due to the current speed of climate change, combined with a fragmented landscape, that some species will not be able to move fast enough to escape extinctions, and extirpations (Heller & Zavaleta, 2009; IPCC, 2013; Krosby et al., 2010; Snover et al., 2013; Thomas et al., 2004).

Summary

Permeability is extremely important in reducing the negative effects of fragmentation, improving highway safety, decreasing wildlife-vehicle collisions, and mitigating and adapting to the effects of a changing climate. In addition, planners and practitioners could do a better job of thinking in evolutionary terms to help build resilient populations and landscapes. Thus, with the changes in climate already experienced in the PNW it is imperative more attention be given to the permeability of structures like I-5 in Washington State. If one assumes the data and research are correct, it then becomes clear if permeability is not addressed or done too slowly, it may greatly increase the extinction and extirpation rates of some local species. This thesis aims to help planners and practitioners better understand the current weaknesses and strengths of I-5 as it relates to landscape connectivity, in order to better plan for a changing climate.

Chapter 3: Connectivity Mapping

There are generally three scales at which landscape permeability may be evaluated: continental (broad-scale, not species specific), regional (spans broad to finer-scale), and local on the ground assessments (fine-scale) (Kintsch & Cramer, 2011; Singleton & Lehmkuhl, 1999; Theobald et al., 2012; Washington Wildlife Habitat Connectivity Working Group (WHCWG), 2010). On the ground assessments are typically performed by visiting a location or structure with observations occurring in a 10m x 10m area or smaller. However, before one can utilize and employ such fine-scale assessments, one must locate areas in need of detailed evaluations.

The most basic mapping technique is creating a least-cost path (LCP), which maps the path of least resistance between habitat cores. LCPs do not locate areas wildlife are using, instead they provide a hypothetical map showing possible or likely corridors (Epps, Wehausen, & Bleich, 2007). Furthermore, LCPs rely heavily on the subjectivity of the person or persons creating the parameters for mapping. Nevertheless, LCPs are still useful for locating areas where further research should be conducted. Natural landscape flows (NLF) and least-cost corridors (LCC, derived from least-cost paths LCPs) are utilized to generate maps of potential connectivity through a landscape, and can be generalized, or species specific in scope. NLFs and LCCs can be used to help locate areas in need of detailed fine-scale assessments (Beier, Spencer, Baldwin, & McRAE, 2011; Singleton & Lehmkuhl, 1999, 2001; Theobald et al., 2012; WHCWG, 2010; WSDOT, 2016).

Relevant landscape connectivity data exists to help predict where permeability research should be done, and it is imperative it is utilized. One cost effective way to make reasonable predictions are regional connectivity maps driven by Geographical Information Systems [GIS] technology. Such maps are a powerful visual aid for planners and practitioners and are becoming more accurate and advanced, by including more variables relevant to connectivity (Beier et al., 2011; Wade et al., 2015; WHCWG, 2010). Typically, linkages or corridors are identified by developing some type of cost or resistance layer (described further below). Depending on the purpose of the map and its intended audience, there are a variety of models and software packages that can be utilized to create these maps (Wade et al., 2015).

It has been nearly two decades since the first papers showing significant maps of broad-scale non-species specific connectivity for Washington State were created (Singleton & Lehmkuhl, 1999, 2001). The study utilized different techniques to analyze wildlife habitat and habitat linkages along I-90 in the Snoqualmie Pass area. Wildlife monitoring (i.e. camera monitoring, snow track transects, structure monitoring) and GIS mapping were used to produce a robust analysis of the landscape connectivity. One mapping technique used by Singleton & Lehmkuhl (1999), was least-cost paths which are built by assigning each cell on a GIS raster a cost or resistance for a species to move across, and as the distance from the source is increased, the cost of movement accumulates. Their technique evolved into a cost-weighted distance and least-cost corridor methods in later models developed by the same researchers (Singleton & Lehmkuhl, 1999, 2001)

Cost-weighted distance & Least-cost corridors

Singleton & Lehmkuhl (2001) employed cost-weighted distance and least-cost corridors (LCC) to map habitat linkages for large carnivores in Washington State. Least-cost corridors are the calculated cost of moving between two sources and passing through a given cell, while cost-weighted distance is the accumulated cost of moving through a landscape based on resistance values. The study concluded that Southwest [S.W.] Washington presented a significant barrier to focal species in the study. The barrier in S.W. Washington is attributed to distance, human development, and state highway density (Singleton & Lehmkuhl, 2001). The study admits that field surveys should still be done for more accuracy, and it is possible that by not investigating structures on the interstates, the cost attributed to those roads systems was in fact too high (Singleton & Lehmkuhl, 2000; WHCWG, 2010). It may be that CWD and LCC mapping techniques are necessary, but not sufficient for robust connectivity mapping. For example, Theobald et al., (2011) argued that least-cost corridor (LCC) does not incorporate enough values into its data set for comprehensive regional to local-scale mapping purposes. Although the study was focused on non-carnivores, and found S.W. Washington as the greatest barrier, the researchers suggest black bear (*Ursus americanus*) and elk (*Cervus elaphus*) should have maps made to show their connectivity through S.W. Washington. Singleton & Lehmkuhl (2001) suggested that S.W. Washington would be a place that would be worthy of deeper and continued research related to connectivity for elk populations. This study points to the need for more research into the permeability of I-5 for elk, which is one goal of this thesis.

Resistance value

The concept of landscape resistance (i.e. more or less resistance to movements through some land covers or structures compared to others) is employed by assigning numerical values to landscape features (e.g. housing density, roads, recreation) with each having a different resistance or cost associated with moving through that point on the map. A map is typically produced, showing linkages that represent the 'easiest' (least resistance) possible paths across a landscape (Wade et al., 2015; WHCWG, 2011). For example, a landscape feature that is optimal for a species (i.e. allowing for unimpeded movement), would be assigned a value of one, the least possible resistance or cost for moving. Inversely, a feature that is impermeable and cannot be moved through, would be assigned the highest possible value (e.g. 10,000). Each focal species could potentially have different resistance values, depending on how that species behaves in or around the specific landscape feature being accounted for (Adriaensen et al., 2003; Spear, Balkenhol, Fortin, Mcrae, & Scribner, 2010; WHCWG, 2010; WSDOT, 2016; Zeller, McGarigal, & Whiteley, 2012).

Resistance is typically derived from expert opinions. One comprehensive review of the literature found that 80% of resistance models were in fact derived from expert opinion (Zeller et al., 2012). Studies comparing empirically driven resistance values to expert opinion resistance values found that empirically driven values were more accurate than opinion driven models (Cleveneger, Wierzchowski, Chruszcz, & Gunson, 2002). However, due to its convenience, cost-effectiveness and simplicity of implementation, expert opinions will most likely continue to facilitate resistance values, at least in the near future. Creating a resistance layer for GIS is a daunting task and doing so with expert opinion has been openly criticized for its lack of empirically-driven decision making. Complicating the usage and reliability of resistance layers, is the fact that there is no single value, or consistent way to assign values, that fits all situations, meaning each map, for each species, in different locations will require different approaches to implement resistance values (Adriaensen et al., 2003; Cleveneger, Wierzchowski, et al., 2002; Spear et al., 2010; Zeller et al., 2012). However, resistance layers sometimes driven by opinion, sometimes by empirical evidence, and sometimes from both, showing landscape features as they hinder or facilitate a specie’s movement through the landscape, is the standard for the time being (Zeller et al., 2012).

Once a resistance layer is chosen and developed one of two algorithm types are applied, to show possible linkages. Circuit-scape theory (i.e. omnidirectional connectivity, which considers movement as analogous to electrical resistance) and linkage-mapping (i.e. least-cost paths, least-cost corridors) are used, which have both been shown to have strengths and weaknesses (Adriaensen et al., 2003; B. H. McRae & Beier, 2007; B. H. McRae et al., 2016). For the purposes of this thesis, least-cost models have been utilized, in part because the models that exist locally use the least-cost models, and in part because it has been suggested to be the more robust of the models and has been used more often, and recommended more frequently (Singleton & Lehmkuhl, 2001; Theobald et al., 2012; Washington Wildlife Habitat Connectivity Working Group WHCWG, 2010; WSDOT, 2016; Zeller et al., 2018, 2012) .

Landscape flow maps

One way to map for connectivity is to map connections and landscape flows at a continentally broad-scale. Theobald et al., (2012) is critical of past mapping techniques and suggests least-cost distance (LCD) is the most robust, offering a "full service of values" and then goes on to suggest more variables should be used to create broad-scale maps that can make generalizations, not limited to a particular species (p. 128). Created with overlapping resistance layers, the LCD path represents the least amount of resistance (or cost of movement), an animal would encounter moving through a landscape to a specific location, typically a node or habitat core (Adriaensen et al., 2003; Wade et al., 2015; WSDOT, 2016; Zeller et al., 2012). In order to build a better model for large-scale mapping, three additions to current least-cost distance (LCD) variables are offered: "1) Develop "natural" area models that take into account the degree of human modification, and the future possible limits to connectivity; 2) consider connectivity as a function of a continue gradient of permeability; 3) quantify a metric of centrality networks to understand significance of each specific cell" (Theobald et al., 2012). As an example, Theobald et al. (2012) published a nationwide map of landscape flow, revealing medium to high landscape centrality (connections that exist within areas of high 'naturalness'), flows entering Washington State and crossing over the I-5 structure (Fig. 3.1, Theobald et al., 2012).

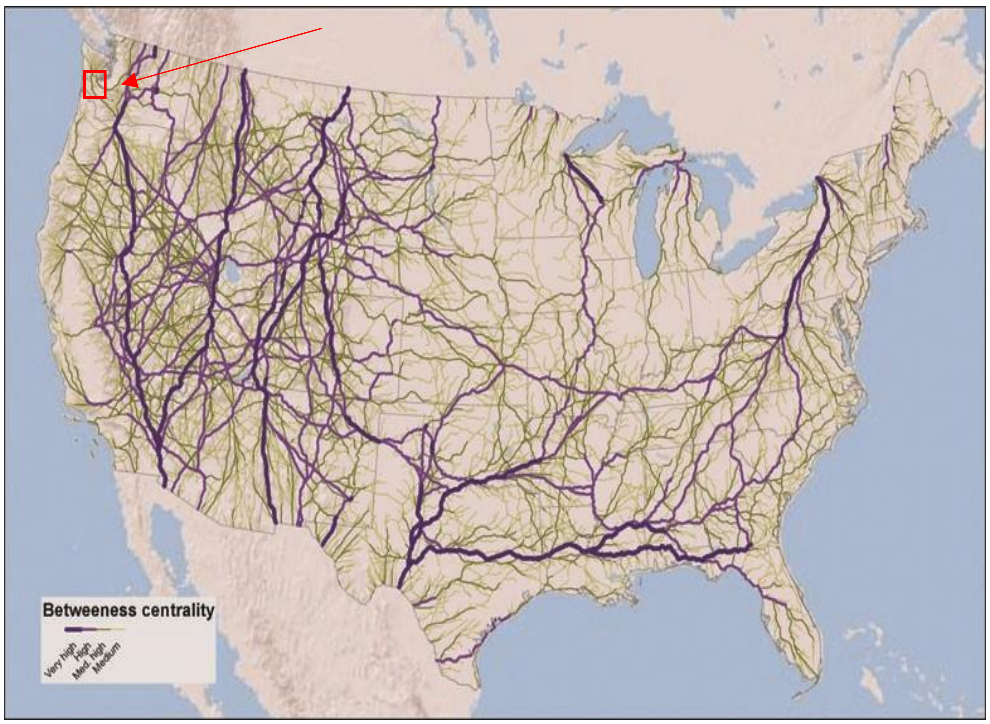

Figure 3.1, Nation-wide connectivity and landscape flow. High flows are purple and med-high are gold. Red box highlights this thesis study. Note: Fig 3 Theobald M. D., Reed E. S., Fields K., & Soulé M. (2011). "Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States". Conservation Letters vol. 5 (2012) p.128.

A rescaled version can be used to better evaluate local conditions in S.W. Washington; the map better illustrates flows of medium to high values crossing over I-5 (Fig. 3.2, Theobald et al., 2012). In Washington the highest priority areas cross over I-90 in Eastern Washington. Regardless, the I-5 corridor in S.W.

Washington encompasses routes with med to high centrality, illustrating the importance of these areas in connecting the Cascades to the Coast in Western Washington. In addition, these routes also have the potential to connect natural areas in the Olympic Mountains to the Cascades.

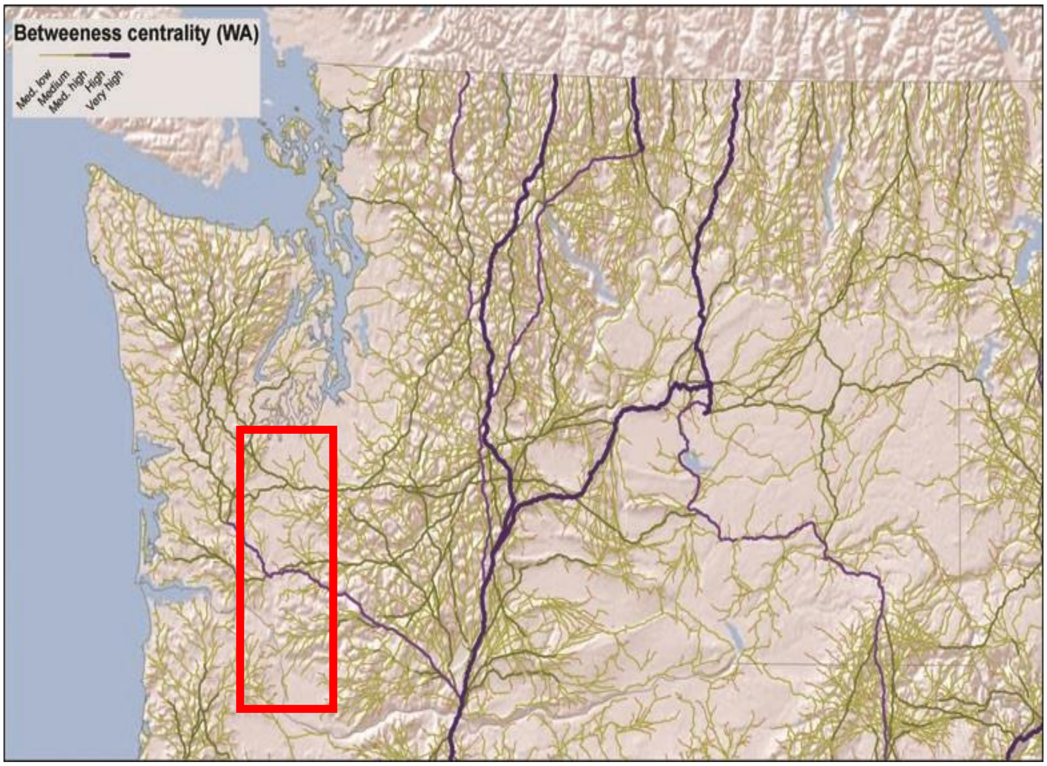

Figure 3.2 Washington State connectivity and landscape flow. Purple high flows and gold med-high flow. Red box highlights this thesis study area. Note: Fig 6 Theobald M. D., Reed E. S., Fields K., & Soulé M. (2011). "Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States". Conservation Letters vol. 5 (2012) p.131.

The Washington State Department of Transportation (WSDOT) and the Washington State Department of Fish and Wildlife (WSDFW) created the Washington Wildlife Habitat Connectivity Working Group (WHCWG, 2010). To implement their mission, the group initiated the Washington connected landscapes project. The project has 5 main goals/objectives: "1) scientific analysis of habitat connectivity at varying spatial scales, while considering current and future landscape conditions; 2) to create tools and methods to support any analysis; 3) building transboundary relationships in order to maintain connectivity inside and outside of Washington's borders 4) continuing research and using adaptive management to continue to build and make better models; 5) public outreach and education about connectivity to a wide array of interested parties, individuals" (WHCWG, 2010).

One product of this project was the first statewide analysis evaluating connectivity through the state of Washington (WHCWG, 2010). The statewide analysis helps to better calculate the overall connectivity and patterns related to landscape resistance to wildlife movement, it incorporates variables many maps lack, giving a robust map set that has already influenced further research (Beier et al., 2011; Kintsch & Cramer, 2011; WHCWG, 2010). However, one obvious assumption that could use intensified reevaluation are the resistance values assigned to major interstates like I-5. The study assigns a single value to the linear feature of I-5 for each species, one permanent value that does not vary along the I-5 corridor. We know that in fact I-5 has many viaducts, culverts and other underpasses that no doubt changes the permeability of I-5 in specific areas. Ideally I-5 would be represented by a mosaic of resistance values, not a homogenous linear barrier (WHCWG, 2010; WSDOT, 2016).

The product of the statewide analysis was a series of maps showing; 1) overall resistance to movement across the landscape; 2) important habitat (habitat concentration areas [HCAs]); 3) cost-weighted distance (cost that accumulates while moving away from HCAs); 4) modeled linkages (LCPs between HCAs, for 16 different focal species (including elk and mule/black-tailed deer). A general takeaway is that broad-scale landscape patterns appear to have high potential for restoring habitat connectivity along I-5 south of Olympia (Theobald et al., 2012; WHCWG, 2010).

Mule deer (including black-tailed deer) maps

Mule deer (*Odocoileus hemionus*)/black-tailed deer (*Odocoileus hemionus columbianus*) is one of the 16 species focused on in the statewide analysis. The first map for mule/black-tailed deer shows habitat concentration areas (HCAs) (Fig. 3.3).

Figure 3.3 Mule/Black-tailed Deer Habitat Concentration Areas (HCAs). (in green) and Gap predicted distribution (in gray), and it is important to note that I-5 is entirely covered in the gray area. Study area is highlighted by red box Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010 Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p.78.).

The second map shows resistance values and the third cost-weighted distance (CWD) (Fig. 3.4 & 3.5). I-5 is shown to be surrounded by HCAs that are not linked together. (WHCWG, 2010, McRae, Shirk, & Platt, 2013; Shirk & McRae, 2013; WHCWG, 2010).

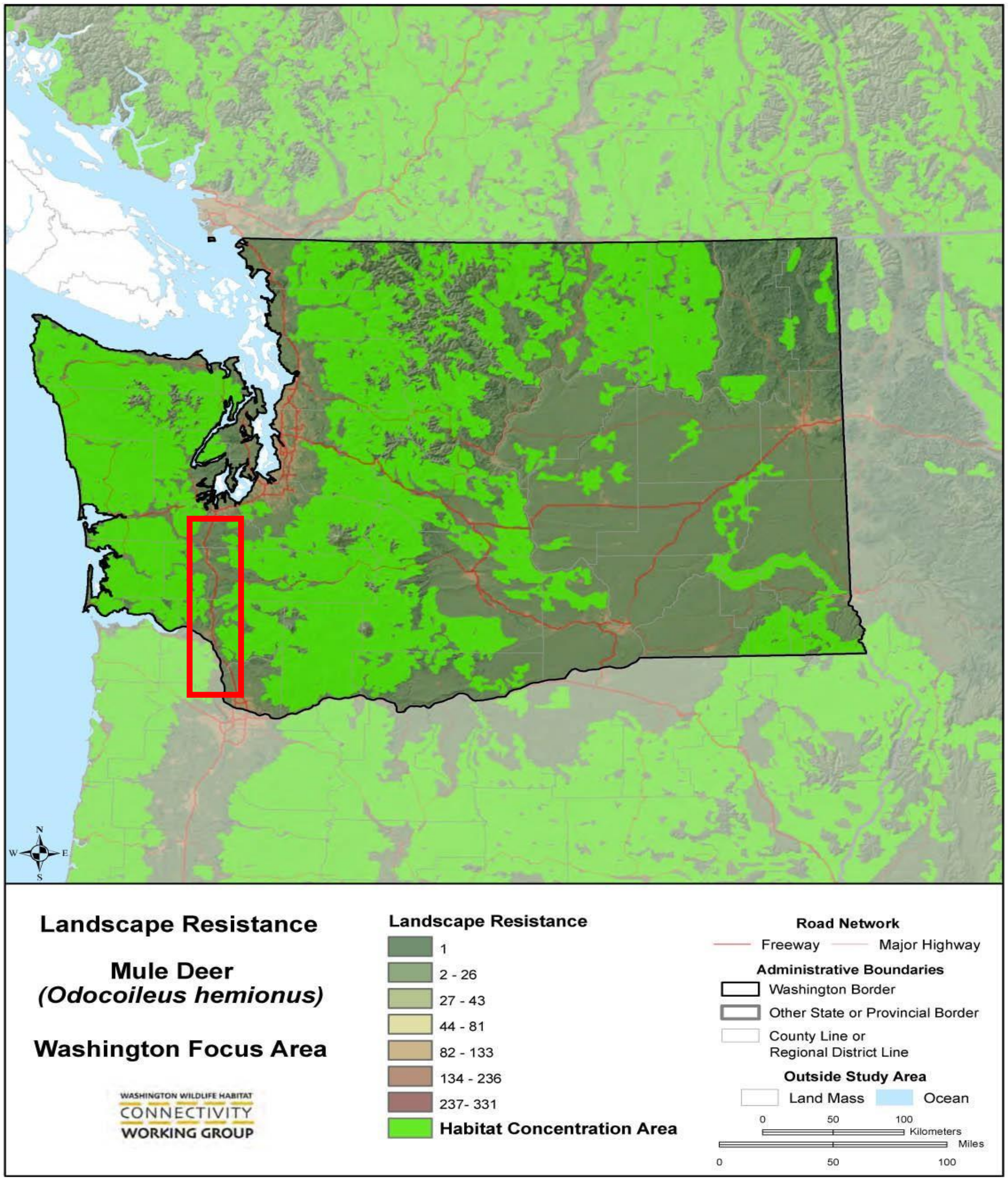

Figure 3.4 Mule/Black-tailed Deer HCA and landscape resistance map. The green area represents HCAs and the darker the gray area the more resistance is present. The red box identifies the study area Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010). "Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p. 80

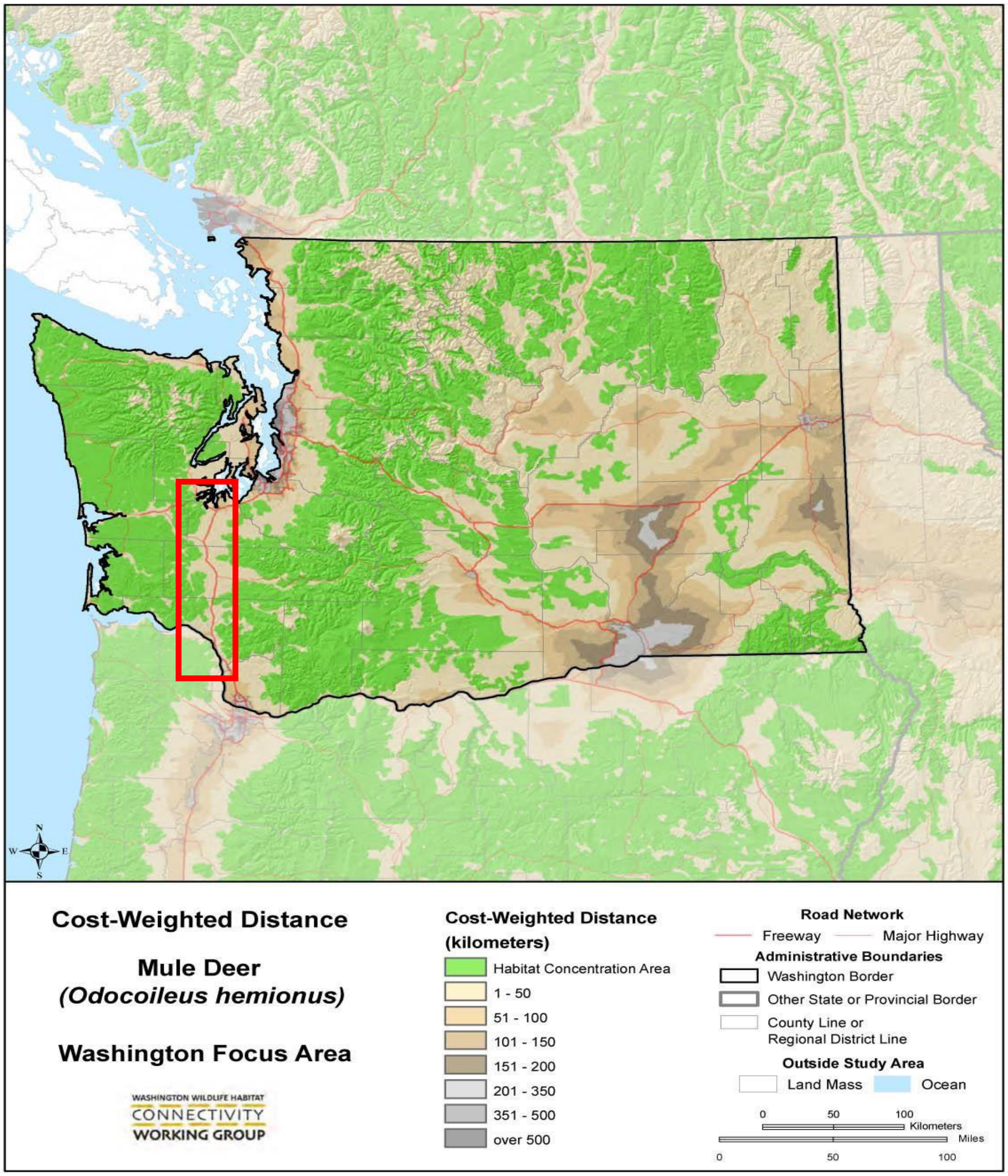

Figure 3.5 Mule/Black-tailed Deer Cost-weighted distance map. Green represents the HCAs and the darker colors represent the accumulated cost weighted distance. The red box identifies the study area or this thesis. Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010). "Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p. 81.

Lastly, a map of normalized least-cost corridor (NLCC) linkages based on the difference between least-cost corridors (LCCs) and least-cost distances (LCDs), showing where movement may be encouraged or impeded (Fig. 3.6)

(Wade et al., 2015, WHCWG, 2010). Least resistance corridors for deer were shown to cross over I-5. Therefore, important linkages may exist on I-5 in S.W. Washington. Consequently, the I-5 structures in this area should be deeply assessed for permeability using an on the ground assessment, specifically the Passage Assessment System or PAS (Kintsch & Cramer, 2011; WHCWG, 2010).

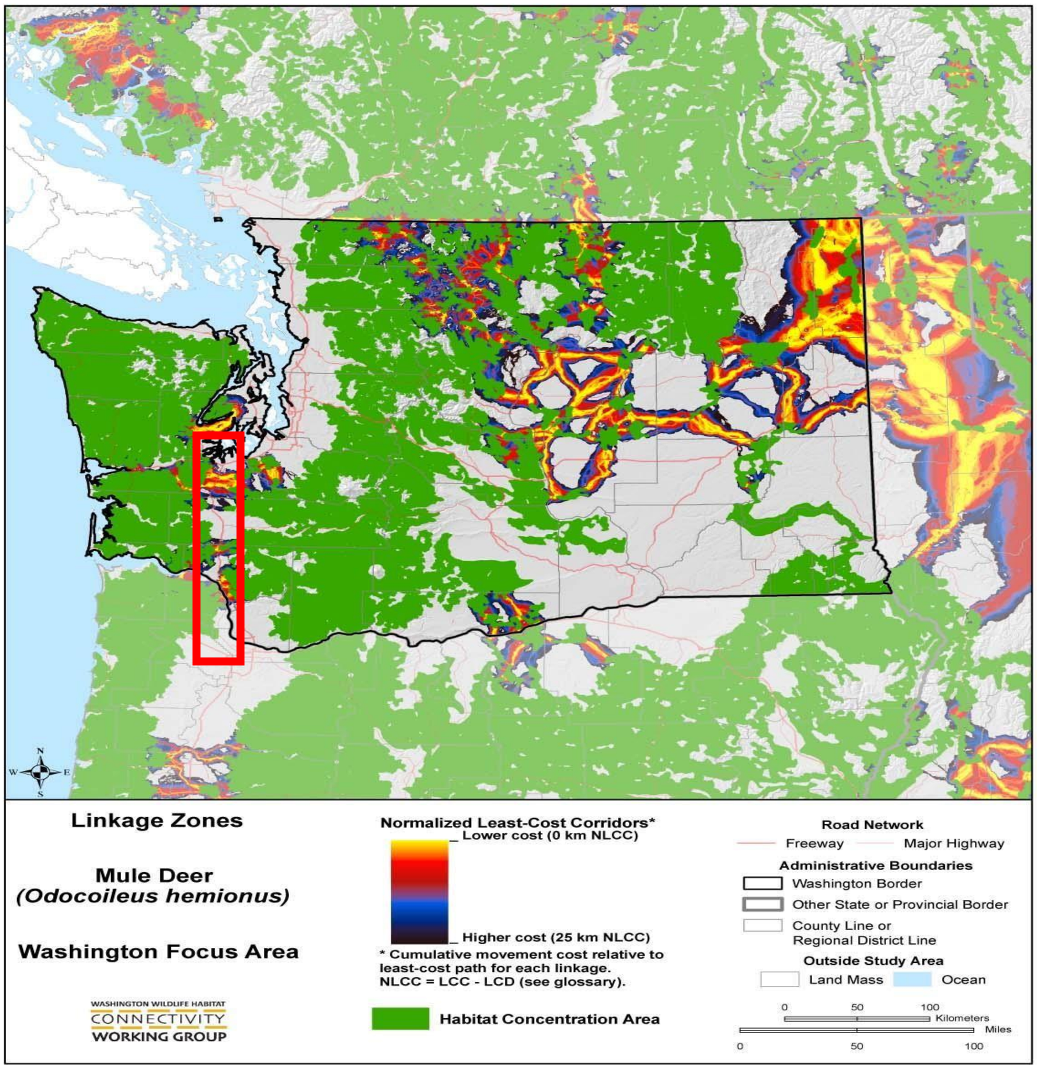

Figure 3.6 Mule/Black-tailed Deer Linkage Zone map. The HCAs are connected by gradient valued least-cost corridors. The yellow represents the least resistance and the dark blue the most. Red box highlights study area for this thesis Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010). "Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p.78.

Elk maps

Elk (*Cervus elaphus*) is another one of the focal species represented in the statewide analysis and because it has been identified as an important species to study in S.W. Washington, the species has been included in the research for this thesis. (Kintsch & Cramer, 2011; Singleton & Lehmkuhl, 2001; WHCWG, 2010). The same values that were applied for mule/black-tailed deer mapping were also applied to elk, and a similar set of maps were generated (Fig. 3.7).

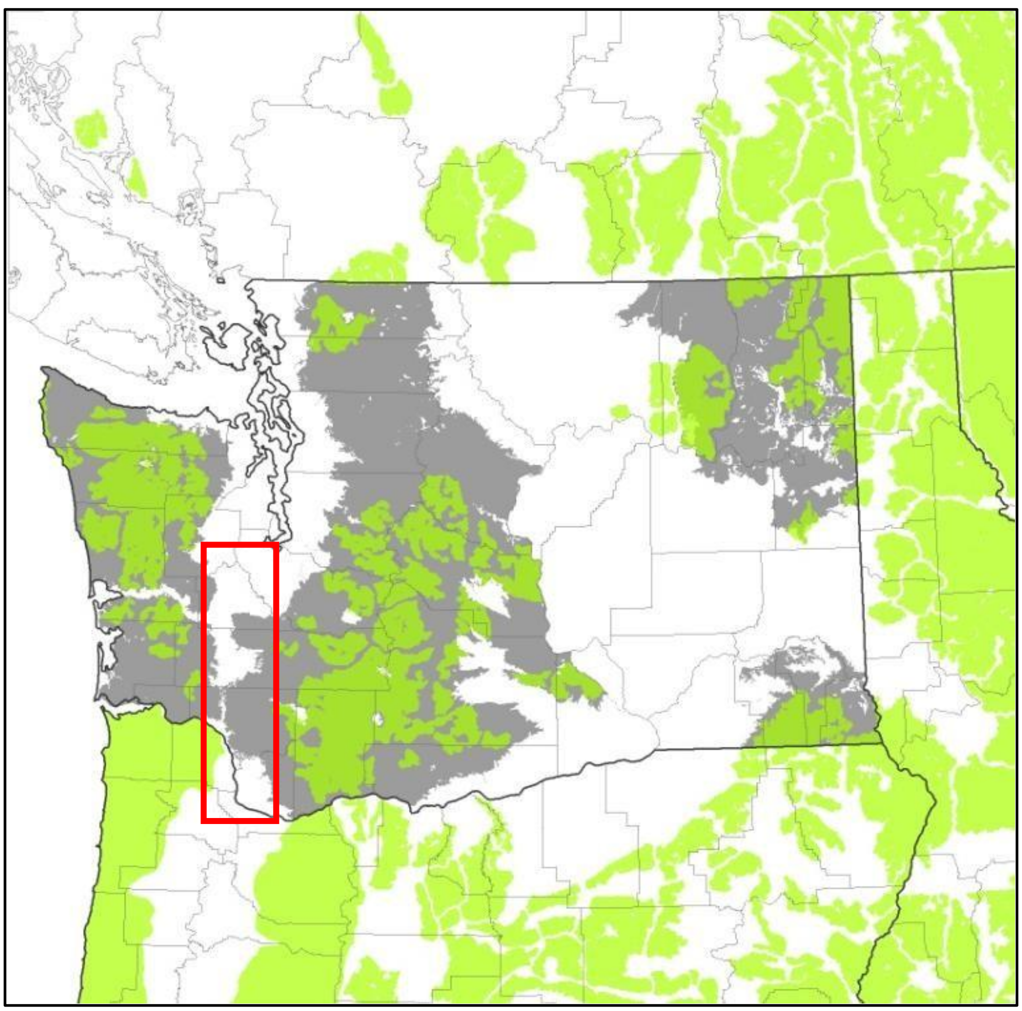

Figure 3.7 Elk habitat concentration areas map. HCAs shown in green, thesis study area highlighted in red box. Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010). "Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p.101.

The maps show far less habitat for elk, than for mule/black-tailed deer; however, S.W. Washington still shows significant patches of core habitat. The next two maps we see are landscape resistance (Fig. 3.8) and cost-weighted distance layers (Fig. 3.9). Although there appears to be significantly more resistance in general than with mule/black-tailed deer, there still seems to be some areas along the I-5 corridor that show possible paths of least resistance (WHCWG, 2010).

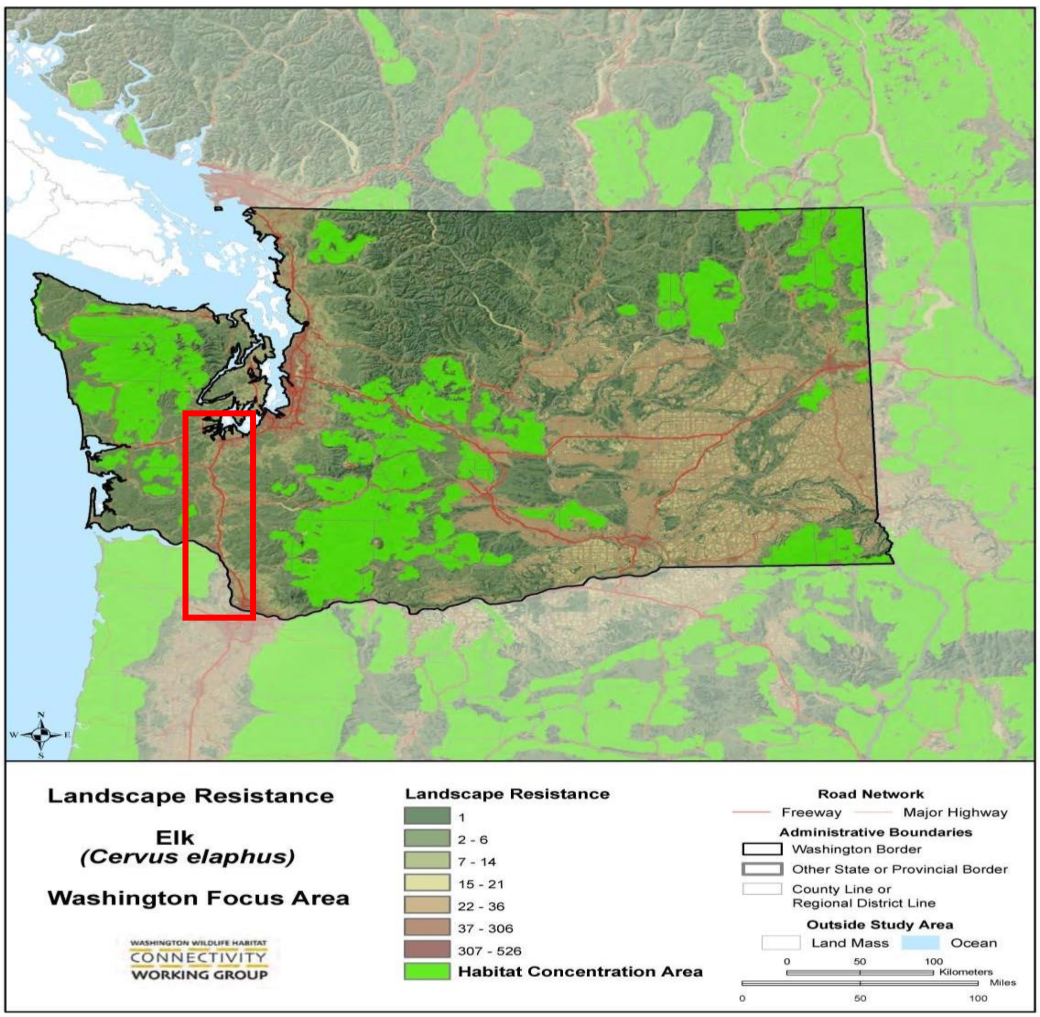

Figure 3.8 Elk landscape resistance map. HCAs are in green, while resistance is shown in a gradient, the highest resistance is represented by the darkest colors. Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010). "Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p.103.

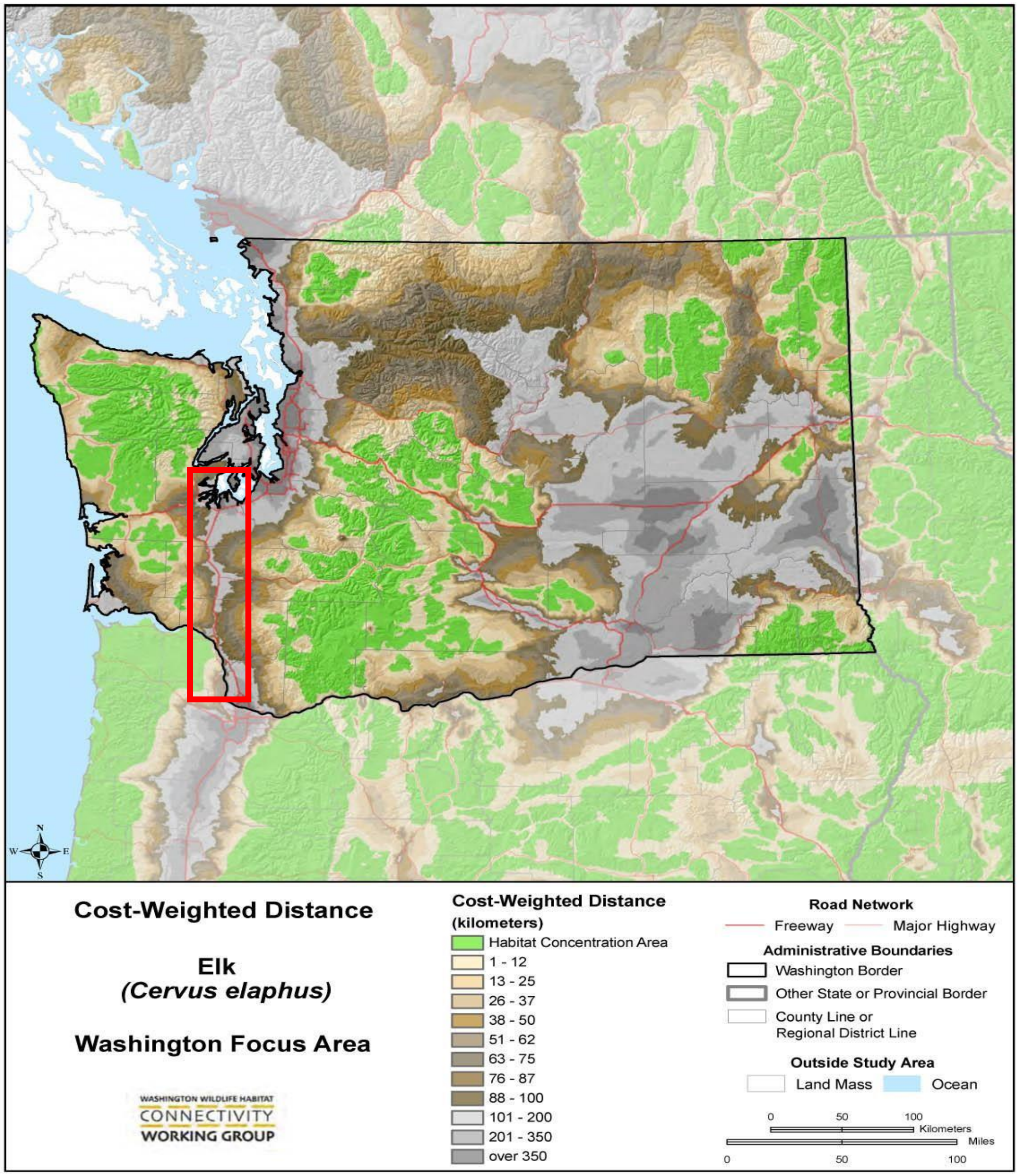

Figure 3.9 Elk cost-weighted distance map. HCAs are shown in green, while coats weighted distance is shown in darken shades with different values. Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010). "Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p. 104.

Lastly, a map of normalized least-cost corridor (NLCC) linkages (Fig. 3.10), showing lines crossing the I-5 corridor in three different locations in S.W. Washington. Overall, there appear to be significant connections along I-5 around the city of Chehalis, thus I-5 in S.W. Washington needs to be researched for permeability for elk populations (Singleton & Lehmkuhl, 2001; WHCWG, 2010).

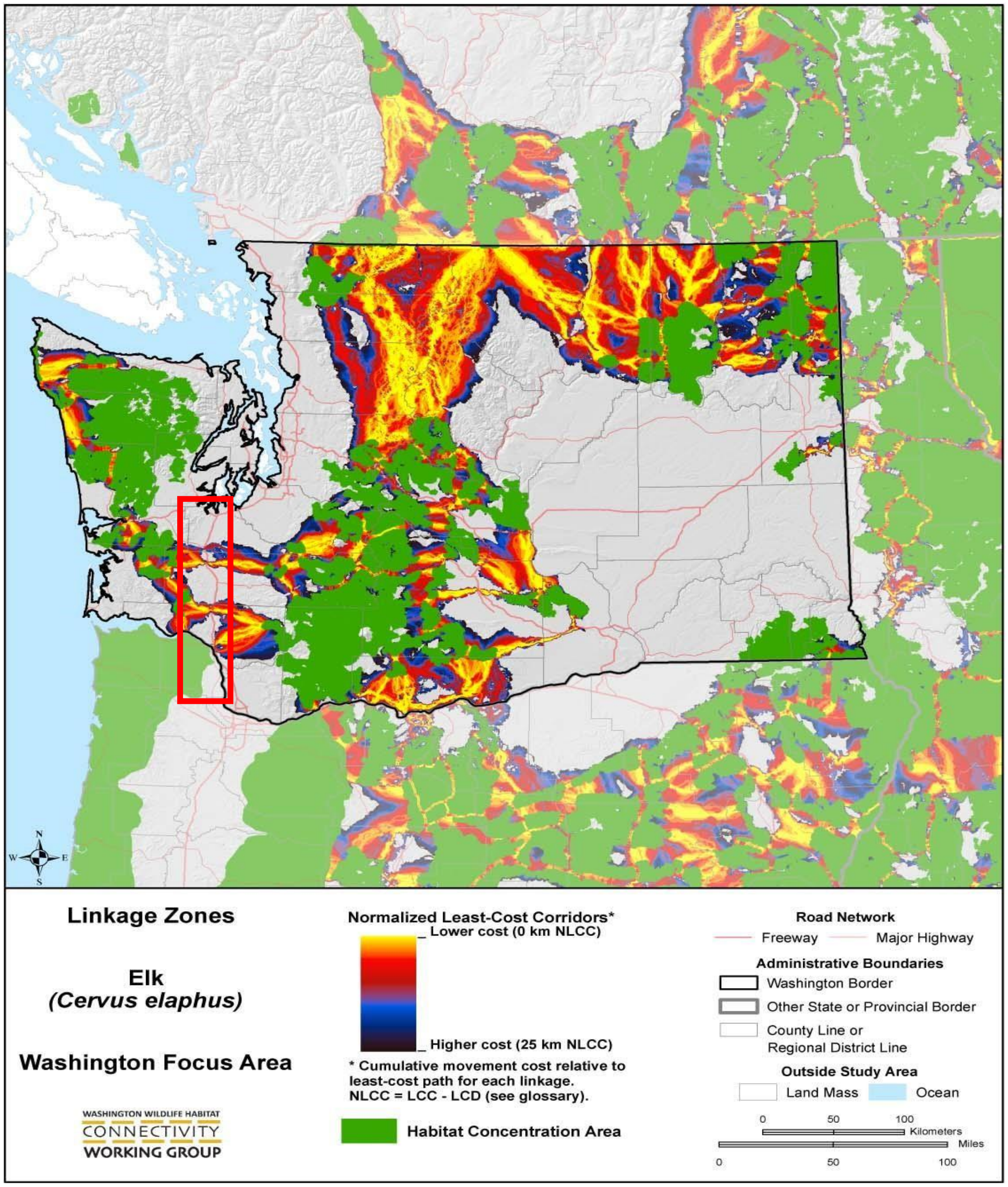

Figure 3.10 Elk linkage zones map. HCAs shown in green, least-cost corridors shown in colored lines, yellow represents the least resistance while dark blue shows the highest resistance along the corridor. Red box highlights the study area for this thesis Note: From Washington Wildlife Habitat Connectivity Working Group (WHCWG) (2010). "Washington connected landscape project: Statewide analysis". Washington State Department of Fish and Wildlife and Transportation, Olympia Washington. p. 105.

Columbian white-tailed deer maps

In 2016, mapping was also done focusing on a specific population of Columbia white-tailed deer (*Odocoileus virginianus leucurus)* [CWTD], around the Columbia River area in S.W. Washington (WSDOT, 2016). The study had the following objectives;

“1) Develop a habitat connectivity model using GIS technology; 2) Focus on the range of the distinct population associated with the Columbia river; 3) Incorporate available GIS data, including but limited to road and railroad data; 4) Make the final model public, via the Lower Columbia Estuary Partnership” (WSDOT, 2016). Techniques utilized in this study to map for LCPs, cores, nodes, and resistance values are roughly the same as the 2010 WHCWG statewide analysis developed for deer and elk, in fact it also applies “Linkage Mapper” to produce outputs of connectivity for CWTD (McRae et al., 2013; Skirk & McRae, 2013;WHCWG 2010; WSDOT, 2016).

The most informative map is done with the same values and outputs as the statewide analysis for deer and elk, showing normalized least-cost paths (LCPs) derived from cost-weighted distance, by assigning landscape features a resistance value (Washington Wildlife Habitat Connectivity Working Group WHCWG, 2010; WSDOT, 2016) (Fig 3.11). Importantly, I-5 separates many of the identified cores and nodes.

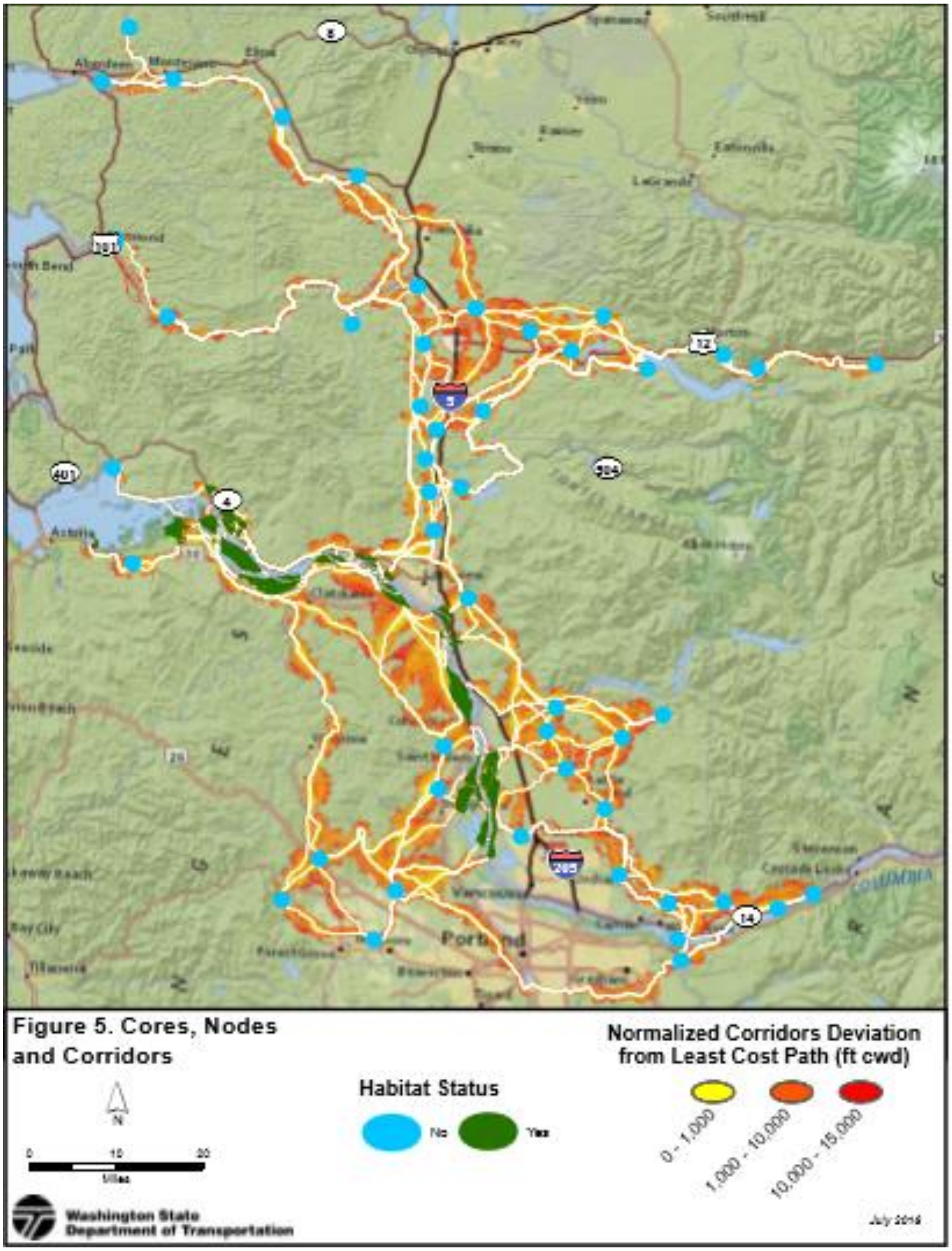

Figure 3.11 Columbian white-tailed deer cores, nodes and corridors. CWTD SW Washington maps, the map shows occupied habitat in green, suitable but unoccupied habitat in blue, and LCPs in yellow to red, yellow being the path of least resistance. Note: From (WSDOT, 2018b pg24) WSDOT (2018) "Columbian White-tail deer (Odocoileus virginianus leucurus) habitat connectivity analysis"

Interestingly, the CWTD study experimented with changing resistance values at certain crossing structures. Unlike other studies that assign highways a single homogenous resistance value, this study utilized Google Earth to locate possible structures that might be attractive to CWTD. Lowered resistance values were assigned to specific structures on I-5, creating a more realistic model of the permeability of the landscape. Although, the values were based on cursory visualizations, lacking an on the ground assessment, this varying of values at open structures is currently the most realistic attempt to understand the type of barrier I-5 creates, or does not create for wildlife, specifically CWTD (WSDOT, 2016).

Four of the experimental locations in the CWTD study are located on the I-5 corridor, and within the study area of this thesis. Locations include: Owl Creek[2], Lewis River, East Fork Lewis River, and the Kalama River. Of these bridges, 3 of 4 of them showed deviation from assigned LCPs after resistance was lowered (WSDOT, 2016). To illustrate the changes in pathways, maps were generated comparing the before (linear continuous resistance values) and the after (lowered resistance values assigned to large underpasses) (Fig. 3.12, 3.13, 3.14) (WSDOT, 2016).

[2] Owl Creek is one of two locations within the study area of this thesis that was monitored by cameras.

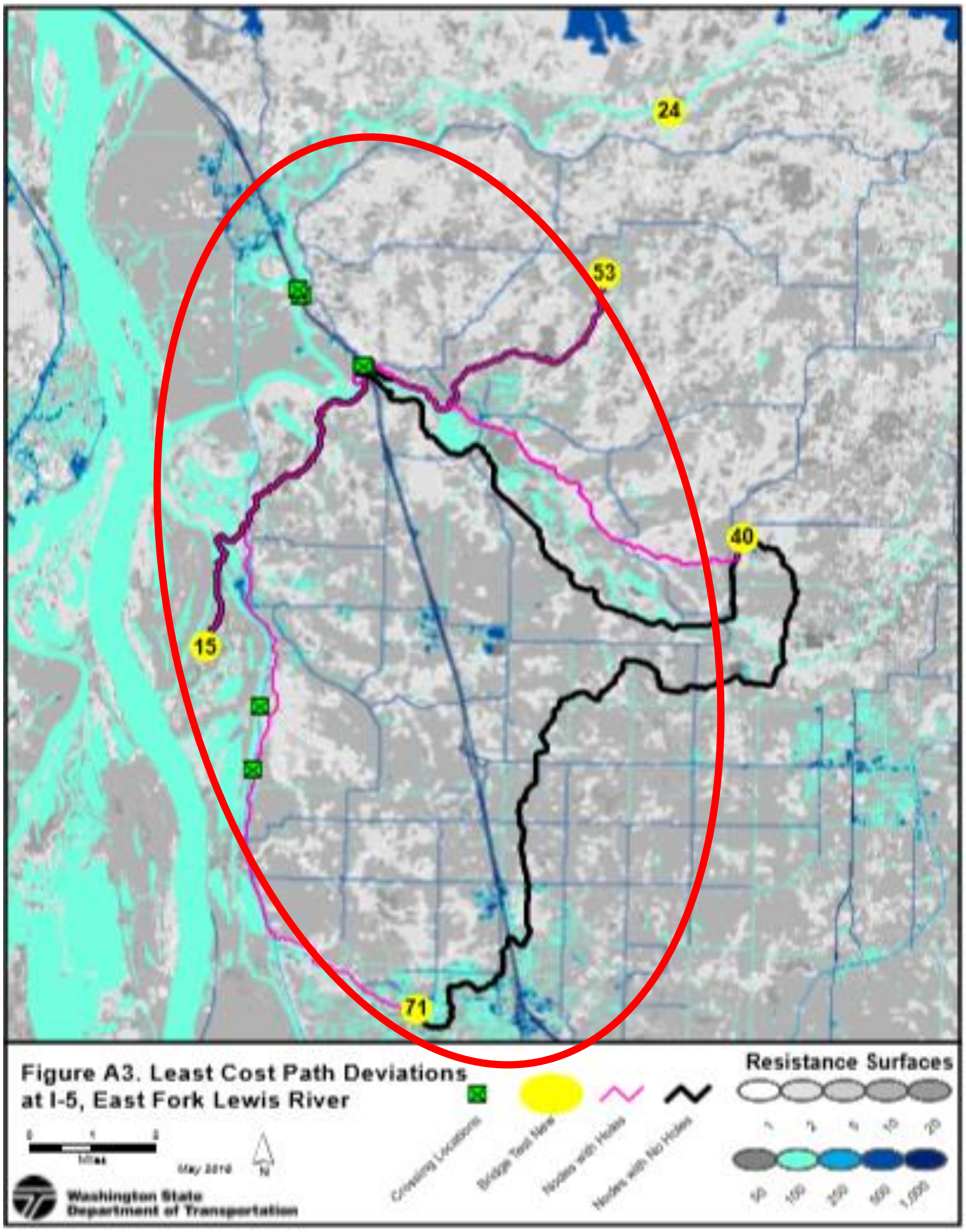

Figure 3.12 Columbian White-tailed Deer least cost paths at East Fork Lewis River. The map shows deviations is the East Fork Lewis River crossing on I-5, the yellow dots represents nodes and the lines represent LCPs for CWTD. The black line is the original, map with solid resistance values for all I-5. In contrast, the red lines represent the corrections in the LCP, when considering the gap, the structure makes. The study area for thesis is highlighted in red Note: from WSDOT (2016) "Columbian White-tail deer (Odocoileus virginianus leucurus) habitat connectivity analysis" pg.31 Least paths and deviations.

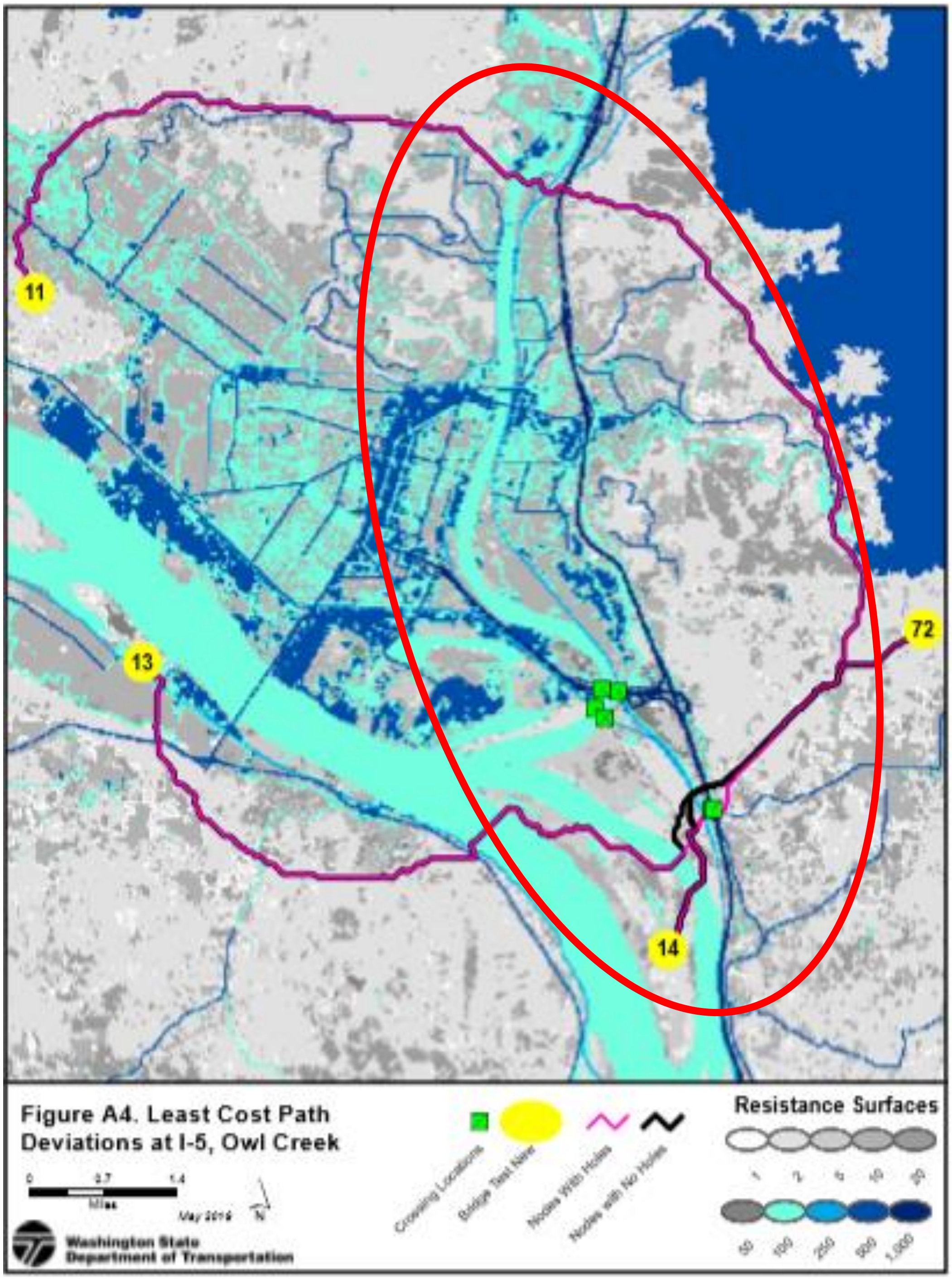

Figure 3.13 Columbian White-tailed Deer least cost paths at Owl Creek. The yellow dots represent nodes being connected, the black lines are the original solid resistance values, and the redlines are the new pathways created by adding gaps, this time at Owl Creek, I-5/thesis study area is circled in Red. Note: From WSDOT (2016)"Columbian White-tail deer (Odocoileus virginianus leucurus) Habitat connectivity analysis" pg.32 Owl Creek Least cost paths and deviations .

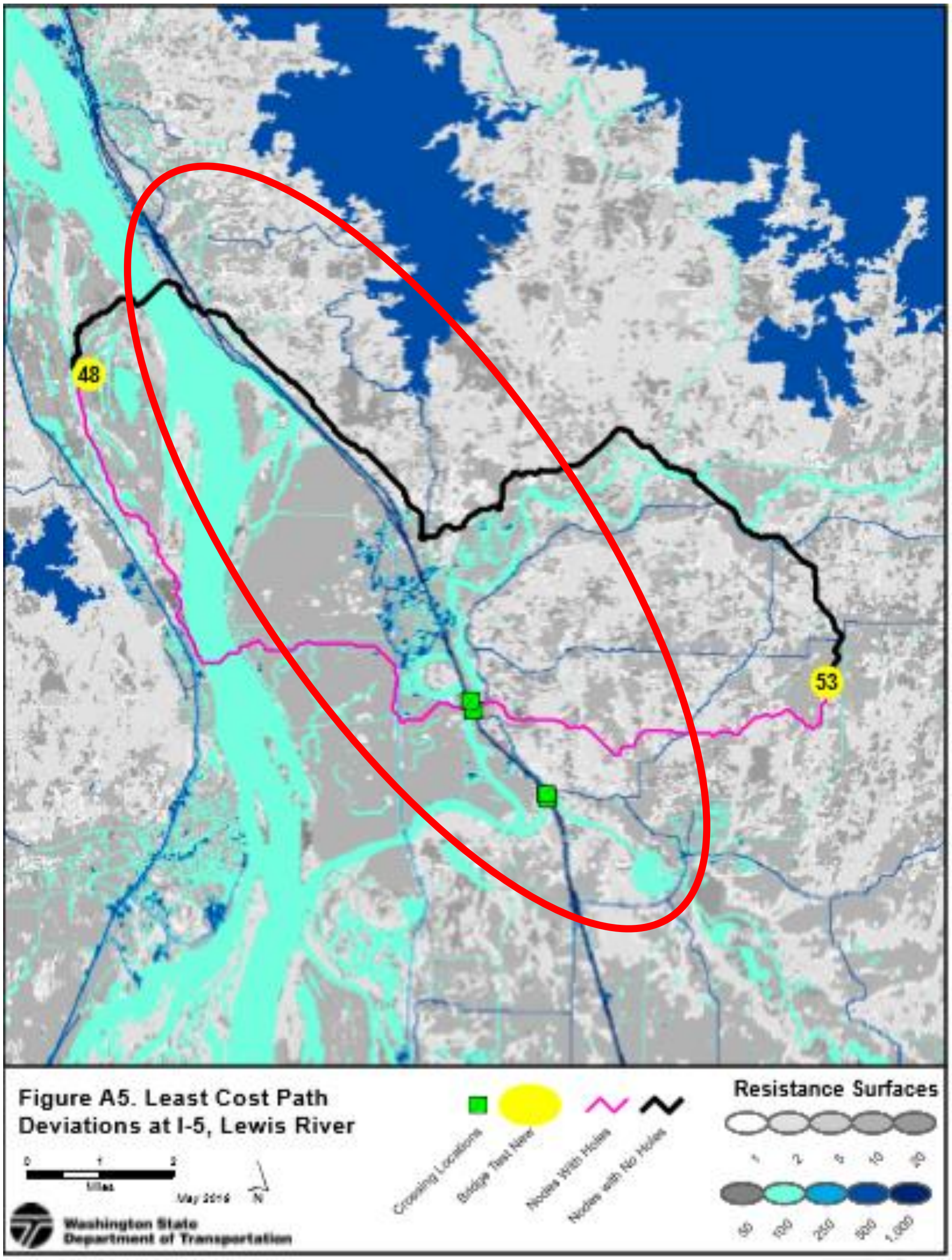

Figure 3.14 Columbian White-tailed Deer least cost paths at Lewis River. The yellow dots represent nodes being connected, the black lines are the original solid resistance values, and the redlines are the new pathways created by adding gaps, this time at Owl Creek, I-5/thesis study area is circled in red. Note: From. WSDOT (2016) "Columbian White-tail deer (Odocoileus virginianus leucurus) Habitat connectivity analysis" pg.33. Lewis River least coast paths and deviations.

Overall, the attempt to bring more realism to mapping products by incorporating more realistic resistance values, was cursory, lacking deep knowledge of specific locations and their unique attributes. However, the potential to better inform mapping resistance layers is clear. This thesis will propose that for large linear features that present intense resistance to wildlife, like I-5, the Passage Assessment System (PAS, Chapter 4) may be utilized to give more accurate and realistic values to better model an individual structure's permeability (Kintsch & Cramer, 2011; WSDOT, 2016).

Ultimately, assigning resistance values to features like I-5 would ideally incorporate the variability in its resistance to wildlife movement. Unlike other roads, I-5 has a unique set of circumstances, as it is very difficult to cross for most species, and the traffic volume is consistently high. There are barriers of fencing, guardrails, and medians that make I-5 seemingly impermeable. However, where large viaducts, bridges and underpasses exist, may represent the only choice for successful movement across I-5. Assigning realistic resistance values must be employed in order to truly understand what type of barrier I-5 is creating. One way to do that is to use the rating system from PAS to inform resistance layers that incorporate I-5 as a landscape feature.

Summary

There are already in existence numerous GIS maps that suggest locations for further investigation and study of connectivity in Washington State on the I-5 corridor. Much of the literature researched for this thesis suggests that more should be done to evaluate S.W. Washington's mule/black-tailed deer, CWTD, and elk population's ability to move across the landscape. When the maps are used in conjunction with wildlife-vehicle collision data, a picture begins to develop of where one might focus assessing the permeability of I-5. By combining some of the available mapping data this thesis argues that I-5 between the Oregon border and Olympia should be further assessed for the permeability of structures on I-5 for mule/black-tailed deer, CWTD and elk populations in Washington State. Therefore, the research for this thesis was conducted between milepost 0 and 100 to evaluate the permeability of I-5 for elk and deer populations in S.W. Washington State.

Chapter 4: The Passage Assessment System [PAS]

Money is an important limiting factor when considering any new infrastructure project, cost is a barrier to implementing conservation projects in general, and connectivity projects are no different. It is undeniable that the construction of new wildlife bridges, culverts and the accompanying fencing and mitigation structures associated with landscape connectivity enhancement are extremely expensive and can take long time frames to complete; regardless, wildlife structures, culverts, and fencing have been shown to be affective when employed. Retrofitting, or enhancing existing structures (e.g., bridges, culverts) can cost a fraction of new development and can happen on much shorter timescales (Glista et al., 2009; Huijser, Camel-Means, et al., 2016; Huijser, Fairbank, Camel-Means, Graham, Watson, et al., 2016; Kintsch & Cramer, 2011, 2011; Kintsch, Jacobsen, & Cramer, 2015; Romin & Bissonette, 1996). Evaluation of existing structures can only occur with on the ground assessments of the structures themselves to help identify permeability, being site specific helps to focus strained resources where they will be most useful.

Large-scale assessment

There are two assessment systems relevant for this thesis. First, there is the regional large-scale system that incorporate local-scale considerations that indicate where in-depth evaluations should occur. Second, there is the on the ground assessment system that evaluates individual structures and their ability to allow movement through them for individual species (Clevenger 2012, Kintsch & Cramer 2011). The first type of assessment model was used to address the conflicts between wildlife and Hwy 3 in S.W Alberta and S.E. B.C. in Canada, where research was conducted that "synthesized existing biological data, analysis, reports regarding key landscape, habitat linkages, and wildlife mortality for large mammals" (Clevenger, 2012, p.304). By using local connectivity models and data on wildlife-vehicle collisions, 31 locations were identified for analysis. To evaluate the research sites located, a 5-criteria assessment model was utilized. The 5 criteria are as follows:"1) local conservation value: connectivity for daily activity and needs, and considerations for seasonal migrations; 2) regional conservation: considerations for large animal populations with relatively low densities; 3) transportation mitigation opportunity: considers whether mitigation strategies will be easy or difficult to implement, looking at variables like size, cost, and age; 4) highway mortality: rate of wildlife mortality 5) land security: evaluate condition, ownership, and development possibility" (Clevenger, 2012). Each of the criterion are given a value from 1 (low) to 5 (high) and then evaluated by an expert to quantify the importance of each location (Clevenger, 2012). This type of model could be effective for locating areas with contiguous tracts of habitat that would promote connectivity, and reduce collisions (Alexander & Waters, 2000; Romin & Bissonette, 1996).

Although the practical utility, novelty and significant implications of the 5-criteria tool are apparent (e.g., its ability to evaluate into the future, and to locate local areas in need of deeper assessment); it still lacks the many micro variables needed to evaluate on a local-scale to location specific criteria. In addition, this approach could be interpreted as too broad in nature to use at a site-specific level, it lacks the multitudes of scales and variables one must consider while evaluating the specific needs of unique locations for specific species (Beier et al., 2011; Kintsch & Cramer, 2011; Theobald et al., 2012; Wade et al., 2015) . The 5-criteria model would be more effective when coupled with a location specific assessment system. However, the 5-criteria tool should be utilized and employed before and/or after PAS has been used. By combining the five-criteria tool with fine-scale assessments one can provide guidance for where short and long-term investments in connectivity can be assessed and prioritized for maximum benefit.

Fine-scale assessment PAS

The second assessment model is applied on the ground, and is site- and species- specific, and is known as the Passage Assessment System [PAS] (Kintsch & Cramer, 2011). On the ground the assessments can help planners, practitioners and state agencies make realistic and cost-effective recommendations for enhancements of retrofitting existing structures to increase permeability for local wildlife. WSDOT has ecological priority maps that are typically based on optimal habitat patches, wildlife-vehicle collisions, and traffic volume to help locate high investment priority locations. In addition, the models do not include climate gradients or small patch habitats that promote biodiversity. By assessing each known structure with PAS, state agencies will have an inventory of each structure's potential for crossing species. In addition PAS can be used to complement the ecological priority models. Thus, whenever building, repairs, or upgrades are made within any location where structures exist, the agency can immediately know where to focus their attention, and resources. Moreover, PAS can help locate where monitoring and further research should take place (Kintsch & Cramer, 2011; Kintsch et al., 2015; Shilling, Cramer, Farrell, Reining, & Trans, 2012). The purpose of this thesis focuses strictly on the I-5 corridor in S.W. Washington, but the procedure and system could be utilized anywhere structures exist within a roadway and there is potential for wildlife conflict.

The PAS survey is the most suitable model for the scope and purpose of an evaluation of the permeability of I-5. PAS was developed in 2010 for WSDOT to assess permeability for existing culverts, underpasses, or bridges (e.g., retrofitting, landscape enhancement, fencing, human behavior modification), to mitigate fragmentation, while limiting costs by making practical enhancement suggestions (Clevenger, 2012; Glista et al., 2009; Huijser et al., 2016; Kintsch & Cramer 2011; McCollister & van Manen, 2010).

PAS was developed by incorporating a multitude of considerations from the biological (e.g., food, water, breeding, migration) to the environmental (e.g., traffic volume landscape, vegetation, structure shape, structure size), typical variables suggested for use in connectivity assessments (Alexander & Waters, 2000; Clevenger, 2012; Neumann et al., 2012; Theobald et al., 2012) . To deeply evaluate structures for specific species and in specific locations, researchers found it necessary to create two main classifications, one for wildlife “species movement guilds”, and one for infrastructure “structure functional classes”

(Kintsch & Cramer, 2011). Species movement guilds help to categorize, and group species based on mode of locomotion, road related behavior, predator-prey relationships, and crossing preferences (Kintsch & Cramer 2011).

The ”species movement guilds” have had extensive changes to definitions and have included more species as PAS has been in a constant state of refinement, and the guilds have become ever more inclusive of a more diverse range of species (Kintsch & Cramer, 2011; Kintsch et al., 2015; Shilling et al., 2012). Species that share similar traits, needs, and behaviors are grouped together into guilds. However, some species fit into numerous guilds as the guild membership can be flexible depending on specific scenarios (Kintsch and Cramer, 2011). Kintsch (2015) suggests the guilds are utilized as an operational framework for informing the functionality of crossing structure designs and assessing functionality of existing structures. The eight classes are informed by five specific factors; 1) primarily anti-risk behavior and adaptations; 2) need for specialized habitat conditions; 3) movement capacity and mode of locomotion; 4) need for cover or openness; 5) body size (Kintsch et al., 2015 pg. 3). Using the five factors, species are assembled together in guilds that best reflect the wide array of variances between species, while acknowledging the shared behavioral and biological functions and needs (Table 4.1).

Species Movement Guilds

Table 4.1 Species movement guilds used in PAS. Species in bold are the focal species for this thesis (Kintsch & Cramer 2011; Kintsch et al., 2015).

Guild Name	Guild Members	Crossing structure attributes
Cover Obligates	American Pika (*Ochotona princeps*), Jumping Mouse (*Zapus trinotatus*), etc…	Small structures; suitable cover with natural pathways inside structure; natural habitat cover within structure.
Openness Obligates	**Elk (*Cervus elaphus*),** Pronghorn (*Antilocapra americana*), etc….	Clear line of sight; natural substrates; available escape routes; large structures, overpasses, viaducts.
Semi-Aquatic Obligates	River otter (*Lontra canadensis*), American Mink (*Neovison vison*) etc…	Riparian habitat through structure; cover inside and without structure; predator-prey relationship driven. Possible use of artificial floors.
Medium structure generalists	Bobcat (*Lynx rufus),* Black bears (*Ursus americanus*) etc…	Able to use large and medium structures; dry pathway, nearby habitat; natural substrate preferred; known to use artificial substrates.
Large structure generalists	**Deer (*Odocoileus spp.*),** Mountain lion (*Puma concolor*) etc…	Uses many sizes of structures; highly adaptable; semi-clear lines of sight natural or artificial substrates; body size influenced.

Specialists conditional	Northern leopard frog (*Lithobates pipiens*), Christmas island red land crabs (*Gecarcoidea natallis*) etc….	Species specific considerations must be made; typically require specialized structures.
Specialist arboreal	Flying Squirrels (*Glaucomys sabrinus* and *G. volans*) etc…	Large viaducts with canopy; specialized arboreal bridges/ladders
Specialist aerial	Bats (*Order Chiroptera*), Royal terns (*Sterna maxima)* etc…	Viaducts that allow forsuccessful gliding.

The research for this thesis focuses on large structure generalists (deer), and openness obligates (elk) due to the frequency of collisions on I-5 and around the state, and availability of habitat, and local ranges (Kintsch & Cramer, 2011; WHCWG, 2010; WSDOT, 2018a). Also, by focusing on larger species it creates an opportunity to enhance and recommend changes that could positively affect many smaller species, as well as large ungulates.

Focal Species

In the context of PAS, mule/black-tailed deer (*Odocoileus heminous* and *Odocoileus heminous columbianus*) and Columbian white-tailed deer (*Odocoileus virginianus leucurus*) (CWTD) are adaptive ungulates and belong to the large structure generalist species guild, although they have traits that could also put them in the openness obligate guild (Kintsch & Cramer, 2011; Kintsch et al., 2015; WSDOT, 2016). PAS assigns documented species behavior to each guild, in the case of deer, things like preferring high visibility and ground cover are considered. Species in this guild are typically highly adaptable, and are known to utilize structures (e.g., culverts, bridges) without known preferred attributes (e.g. smaller, darker) when necessary (Gordon & Anderson, 2003; Kintsch et al., 2015; McCollister & van Manen, 2010; Reed, Woodard, & Pojar, 1975). Members of this guild also prefer openings proportional to their body size (as wide as they are tall) to be more favorable when deciding to enter or use a structure. In addition, guild members prefer clear lines of sight from one side of the crossing to the other; and openings less than 100 ft. long. In general, this guild prefers medium to large underpasses, culverts, bridges, viaducts and wildlife overpasses (Kintsch & Cramer, 2011).

Black-tailed deer are a sub species of Mule deer but are considered to be the same species, in fact intraspecific hybrids can exist where ranges overlap (WDFW, 2004). Mule/black-tailed deer and CWTD are herbivores that require a mosaic of habitat patches and networks for their daily needs (e.g. foraging) and seasonal migrations (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; Long et al., 2010; WHCWG, 2010). Migration rates have been shown to be influenced or altered by roadways with 8,000 or higher annual average daily traffic (AADT) (Coe et al., 2015). These high traffic rates create even greater barriers; specifically for ungulate populations (Gagnon, Dodd, Ogren, & Schweinsburg, 2011). Fear in general, and specifically fear of human hunted populations and predator prey relationships also drive deer behavior when approaching structures and roads. In fact, human presence can drive deer to avoid crossing structures altogether, depending on the level of human presence, in general deer are typically dissuaded by human presence (Gaines, Singleton, & Ross, 2003; Laundre, Hernandez, & Ripple, 2010; Stankowich, 2008).

There is an abundance of research on mule/black-tailed deer behavior around roads and their adaptability; the data highlights a possible opportunity for the species, as they can adapt to many diverse types of structures (Gordon & Anderson 2003; Gordon, Haschke, Plumr & Anderson, 2003; Kintsch & Cramer 2011; Reed et al., 1975; Singer, Huyett, Kintsch, & Huijser et al., 2011). The adaptive nature of mule/black-tailed deer could mean that planners could find cost effective ways to help mule/black-tail deer adapt to unconventional passages. It is also quite possible that they are crossing at places where they are not expected to.

Deer are expected to use structures from between 20 ft wide by 12 feet tall to 23 ft wide and 8 ft tall, and while this is functionally true, it does not give a value of the third dimension, the overall length of the structure. However, for size considerations in three dimensions there has been in practice for many decades the concept of the "openness ratio" derived from simple formula (Width x Height)/ (Length), in meters, the result is the openness ratio or index (Forman, 2003; Kintsch et al., 2015; Reed & Ward, 1985; Reed et al., 1975). For deer recommendations range from 0.6 to 2.0 openness (Gordon & Anderson, 2003; Kintsch et al., 2015; Reed et al., 1975; WSDOT, n.d.-a). WSDOT recommends a 0.6 openness ratio and is the baseline for the research for this thesis (Reed, Beck, & Woodard, 1979; Reed et al., 1975; Reed & Ward, 1985).

Notably, PAS was developed without the inclusion of the openness index/ratio due to its inability to take into account structure attributes, wildlife habituation of structures, and varying thresholds for different species (Clevenger, Chruszcz, & Gunson, 2002; Jacobson & Jacobson, 2007; Kintsch & Cramer, 2011; Reed et al., 1975). Regardless, for large animals like elk and deer, the index still has some value for assessing the functionality and appeal of structures. For the purpose of this thesis, openness was included in the final analysis, in part because ungulates are the focal species, and in part because agencies like WSDOT s use openness ratio for secondary consideration when making recommendations and guidelines when evaluating size of structures for species like elk and deer. Although the openness ratio is not a factor considered when rating a structure with PAS, it still has some merit and value for ungulates as a rough size guideline and for WSDOT as a tool for making structure planning recommendations and in advising region biologists and engineers on general size requirements for certain species. For those reasons, this thesis includes openness values for each structure, but those specific values were not used to make judgments on a structure's guild ranking, However, the types of attributes that contribute to an openness value are surveyed and accounted for in PAS. For the purpose of PAS attributes that a white-tailed deer might find attractive or unwelcoming like, light (as ungulates tend to prefer clear lines of sight through structures), distance to safe areas, and structure design were used to stand in for openness. Interestingly, the methods used in PAS for determining "openness" is still relativity new, and has not been used as widely or as frequently as the original openness ratio (Cleveneger, Chruszcz, et al., 2002; S.L. Jacobson & Jacobson, 2007; Kintsch & Cramer, 2011; Reed et al., 1979)

Although there is far less research for Columbian white-tailed deer compared to black-tailed and mule deer, many papers focus on other subspecies of white-tails, that can be inferred from to inform one about the behavior of the local population (E. S. Long et al., 2010). Many of the traits that mule/black-tailed deer have are shared with the CWTD, but there are difference both behaviorally and politically between the species (WDFW, 2004). Politically, the CWTD were put onto Oregon and Washington's endangered species list in 1967 due to population declines. Another tactic used to help rebound populations was assisted migrations, moving deer up against the west side of I-5 in S.W. Washington (WDFW, 2004; WSDOT, 2016).

Behaviorally, CWTD tend to be more timid around people and roads than other deer, although much of the same needs drive them to move across the landscape (E. S. Long et al., 2010). Populations of white-tailed deer (*Odocoileus virginianus*) (WTD) in Pennsylvania were radio collared to investigate dispersal behavior through a landscape with roads of a semi-permeable nature. The 3-year study showed some interesting results that help to illuminate the interaction of roads. 77% percent of the 363 animals dispersed, after adult ranges were established 57-65% of the animals avoided crossing roads all together. Interestingly, the animals did not avoid the verge and edges of the roads, much of their quality food source can be found in these locations, the animals simply did not attempt to cross the roads. Suggesting landscape features may more strongly influence WTD deer than other deer, who attempt to cross roads and structures more frequently (Coe et al., 2015; E. S. Long et al., 2010). Therefore, it is important to note that although these species of deer fit into the same species guild for the purpose of PAS, that behaviors will not necessarily be the same and specific considerations may need to be made when considering crossing structure enhancement or rating (Kintsch & Cramer, 2011)

Elk (*Cervus elaphus*) are very high openness fauna and have been categorized by PAS as belonging to the openness obligates guild (Kintsch & Cramer, 2011; Kintsch et al., 2015). This guild is characterized by PAS as having an instinctual paranoia of predation, and areas that appear to be predator ambush locations, requiring very open entries with excellent lines of sight (Kintsch & Cramer, 2011). Ground cover is another preferred attribute; however, the ground cover must be positioned so the visibility of the animal is not hindered (Gagnon et al., 2011; Kintsch & Cramer, 2011). Openness obligate guild members require specific dimension considerations for optimal passage size, typically preferred structures are wildlife overpasses, viaducts and occasionally large bridge underpasses (Gagnon et al., 2011; Gagnon, Theimer, Dodd, Manzo, & Schweinsburg, 2007; Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; Kintsch & Cramer, 2011; Kintsch et al., 2015). WSDOT suggests a minimum openness ratio of 5.14 for elk based on camera evidence. However, many other variables go into final size recommendations made by WSDOT, as openness is never used as a standalone variable.

Elk have cultural significance both for the indigenous peoples of Washington State and current non-indigenous local populations as a staple big game species (WHCWG, 2010; WDFW, 2005). Locally, two subspecies of elk exist, west of I-5 Roosevelt elk (*Cervus elaphus roosevelti*) are found, on the east Cascade crest rocky mountain elk (*Cervus elaphus nelsoni*) are found, and intraspecific hybrids have been found within the Cascades (WDFW, 2005). Elk are also important members of the ecosystem as herbivores and large prey, and they are adapted to a wide variety of habitats. Certain populations of elk need wide tracts of land, because of their need to seasonally migrate, which put elk into conflicts with roadways (Gagnon, Dodd, Ogren, & Schweinsburg, Kintsch & Cramer, 2011; WHCWG, 2010).

Elk are one of the most cautious species when it comes to roadway crossings. For elk roads typically have 1) physiological/energetic effects; 2) effects on distribution and habitat use; 3) effects from vulnerability to mortality and potentially on population dynamics (McCorquodale, 2013). High traffic volumes increase the negative effects on elk, these effects can be present up to 500 m from where the traffic exists, suggesting many elk may avoid highly used roads altogether (Gaines et al., 2003). Although some research has shown the noise from more intermittently traveled roads having sporadic bursts of noise in a quiet area may cause even more flight from roadways (Gagnon, Theimer, et al., 2007). Once disturbed, elk tend to move immediately, and sometimes great distances in a prey flight response (Laundre et al., 2010; Naylor, Wisdom, & Anthony, 2009).

Unlike deer, elk have a much greater fear of human presence and activity. As previously mentioned traffic noise can affect elk distribution/dispersal up to 500m, single motors 250m, and non-motor vehicles 200m from the source (Gaines et al., 2003; Naylor et al., 2009). In fact, even hiking trails and recreational areas create avoidance behavior in elk, it could then be inferred that even minimal human presence will keep elk from using structures that otherwise could be optimal crossings (Gaines et al., 2003). Light is also a variable that can dictate elk usage of structures, if a passage is not lit well enough for clear lines of sight an elk may avoid that location (Clevenger & Waltho, 2004; Kintsch & Cramer, 2011).

Overall, although elk and deer are both ungulates, elk lack the ability to adapt as deer do, specifically to human presence and infrastructure. Deer can learn new behaviors on individual levels and adapt quickly. In contrast, elk may not use structures simply because the lead bull or cow won't use it. The difference in species characteristics, requires evaluating structures with species specific crossing structure needs in mind. (Gagnon, Schweinsburg, & Dodd, 2007; Kintsch & Cramer, 2011; Kintsch et al., 2015).

Structure functional classes

"Structure functional classes" are categorized by dimensions and size, the difference in size profiles is mostly driven by structural needs and wildlife crossing preference considerations for specific species, or avoidance by specific species (Bissonette & Cramer, 2006, 2008; Clevenger & Waltho, 2004; Kintsch & Cramer, 2011). Kintsch & Cramer (2011) suggest that functional classes give practitioners like engineers and biologists a common framework from which to communicate and plan. There are five categories for structure functional classes: 1) small underpass structures; 2) medium underpass structures; 3) large underpass structures; 4) viaducts; 5) wildlife overpasses (Kintsch & Cramer, 2011; Kintsch et al., 2015). Due to the size requirements for local ungulate populations this thesis investigated mostly large underpass structures (≥ 3.1 m (10') span by ≥ 3.1 m (10'); high or lower and wider ≥6.1 m (20') span by 2.4 m (8') high) and viaducts (≥6.1 m (20') high over multiple spans, total span of ≥ 120') (Kintsch et al., 2015 pg. 5).

Structure size is just one variable that needs to be considered when evaluating structures for ungulates. In general, ungulates require specific openness, low noise levels, width, and short distances to cover for a structure to be attractive (Clevenger & Waltho, 2000). Fencing when used in combination with crossing structures are shown be effective in reducing collisions and increasing animal crossings, this has been studied for both elk and deer (Clevenger & Waltho, 2000; Huijser, Camel-Means, et al., 2016; Huijser, Fairbank, Camel-Means, Graham, Watson, et al., 2016; McCollister & van

Manen, 2010). Overall, combing optimal structural attributes with species needs and behavioral responses allows users of PAS to make high quality fine-scale evaluations, and relevant cost-effective recommendations (Kintsch & Cramer, 2011).

Using PAS

Originally, PAS was implemented via personnel recording structure attributes and additional notes, by hand on paper. This is cumbersome in the field and makes data storage and retrieval unnecessarily difficult (Kintsch & Cramer, 2011). Currently, WSDOT has made the process and data storage far more streamlined and up to date. Survey 123 for ArcGIS (ESRI) has been utilized to collect data remotely on an I-pad. Not only does it make field work easier and data storage more comprehensive, it also means the camera necessary for PAS is built into the data recording device. WSDOT's approach to data collection makes PAS even more cost effective and simple to use.

PAS has some limitations, for instance, some of the information entered requires subjective evaluations (i.e. habitat percentage, noise level and landcover), resulting in many inputs being derived from qualitative measures. In addition, PAS is still in its infancy as a truly robust and tried tool for practitioners. Kintsch & Cramer (2011) suggest that PAS as a document is always in need of constant refinement, to craft the system into a true evaluation tool for local transportation departments. Despite these limitations, PAS utilizes a dense variable set including structure dimensions, passageway substrate, vegetation cover, landscape attributes, biological needs and drivers, animal behavior, and human use to create a comprehensive survey with an accessible user interface. Simplicity and utility are the systems strengths, one simply answers a series of general assessment questions and a divided or undivided highway query, the only tools required to answer the questions are a clipboard/I-pad, a GPS unit, a camera, and a 200 ft. measuring device/range finder (Kintsch & Cramer, 2011). For a full set of PAS questions please refer to appendix A. The goal of PAS is to determine whether the structure is 1) permeable to specific species; 2) can be made to be permeable for specific species; 3) and if it can be enhanced, how?

PAS gives ratings for each structure specific to the different species guild, an A, C, or F. A represents an optimal pathway with minimal enhancements needed, possibly suggesting this guild is currently using the structure if habitat is close by. C represents a crossing that is passable or could be passable with enhancements to the structure. Lastly, F is a structure that without being rebuilt will not pass that specific species. For example, if a structure is too small for an elk to enter it will get an automatic F (Kintsch & Cramer, 2011). These ratings could potentially be used in resistance mapping of large interstates with high volumes of traffic. Structures could be evaluated and then a number assigned to each letter, this would create a more realistic map of resistance when evaluating permeability of landscapes. The coastal connectivity working group (Washington Habitat Connectivity Working Group & Northwest landscape Conservation Design) is currently attempting to implement PAS as a proxy for resistance values in a current connectivity mapping effort in western Washington on advisement from this author.

PAS requires some local specificity to be added when used, adjusting the system for different locations, ecosystems, and species. This makes the system applicable to multiple structure types in numerous regions around the globe. Vermont is one example, it has utilized this system with some success, making minor adjustments to species guilds as it relates to local species (Shilling F. et al., 2012, Kintsch & Cramer 2011). The guilds themselves are in a constant state of redesign with exclusions and inclusions of new species from diverse geographical locations, building a robust applicability to the system (Kintsch et al., 2015).

Summary

Building new infrastructure for wildlife permeability is expensive. However, using newly developed techniques and assessment systems (i.e., 5-criterion, PAS) give state agencies the ability to mitigate costs, by locating and utilizing existing structures and pathways. These structures can be retrofitted or enhanced, for less than new structures can be built. In order to identify permeable structures for elk and deer in Washington State, PAS has been employed on 33 structures at 20 locations on the I-5 corridor. This thesis used PAS to evaluate structures on I-5 for wildlife, with an emphasis on ungulates (i.e. deer, elk), giving ratings of A ,C and F. Lastly, it may be possible to use PAS guild ratings to inform resistance layers when mapping for connectivity along the I-5 corridor.

Chapter 5: Methods

Study Area

Mileposts 0-100 were identified as the main study area (Fig 5.1) by utilizing local connectivity maps to prioritize sections of I-5 that should be further analyzed for permeability (Theobald et al., 2012; Washington Wildlife Habitat Connectivity Working Group, WHCWG, 2010; WSDOT, 2016, 2018a).

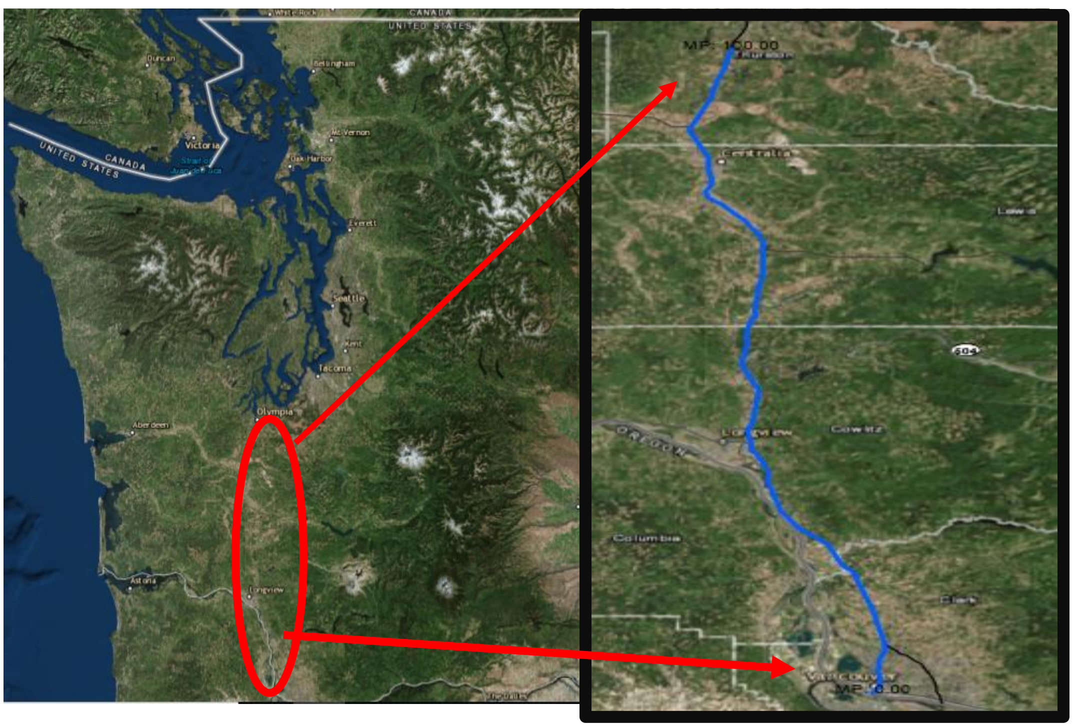

Figure 5.1 Map of Washington State and the I-5 Corridor in SW Washington between Milepost 0-100. The blue line represents the study area in its entirety.

Once the area was identified and the limits defined, a working list of potential crossing structures within the study area was constructed. In order to obtain a list of structures, two WSDOT databases were queried. For bridges and other large structures, WSDOT's BEISt (Bridge Engineering Information System) was queried. For culvert identification, a different WSDOT database called HATS (Highway Activity Tracking System) was queried. The combined lists were then scrutinized for proper location and size (excluding any structure < 8 ft in diameter), which resulted in 95 total structures. The principle behind the size limitation was to make sure minimum size baselines for the structures were roughly large enough to pass deer (*Odocoileus heminous spp*.).

Due to the limited time frame associated with this thesis, a hierarchical ordering system was employed to expedite assessment of the most ecologically valuable locations. Five priority classes were created based on two criteria to sort structures; 1) does the structure have a minimum of ~25% "natural" area within or around the structure; 2) size (largest were prioritized). The largest structures with ~25% naturalness, were sorted as priority one locations, which were assessed for this thesis.

Ultimately, 37 priority one structures were identified for immediate analysis. Priority two structures consisted of 5 structures; priority three consisted of 21 structures; priority four consisted of 6 structures; and priority five consisted of 26 structures; adding up to a total of 95 structures. However, two priority one structures were removed after closer analysis, the first location was a cattle culvert at milepost 23.3, as it was found to only pass through the southbound side. Additionally, the location was very difficult to access due to wetland denseness and lack of on the ground foot access. The second omitted location was a railroad crossing at milepost 77.2, this location had limited access due to high speed rail (both passenger and freight), for safety reasons the railroad agency would not permit access to this location for this study. Other omissions included three structures that were built so close together that they simply could not be assessed as two separate structures and were therefore combined into one structure. This left 33 priority one structures located within 20 separate locations, all of which were assessed for this thesis. Lastly, a map of the priority 2-5 structures was assembled to help inform areas for future research (Fig. 5.2).

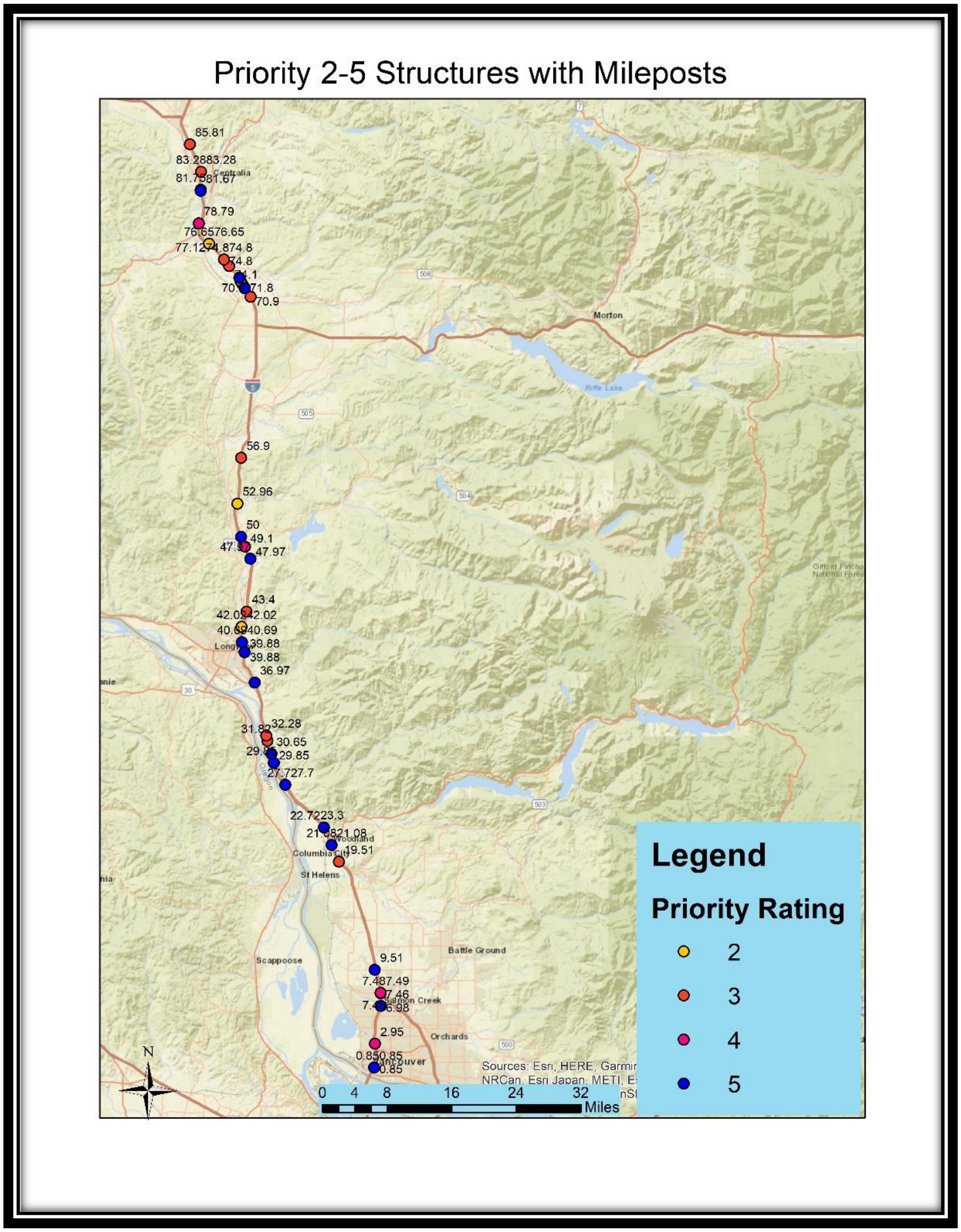

Figure 5.2 Study area's 2-5 priority locations. Yellow are priority 2, orange priority 3, pink priority 4, and blue represents priority 5 locations.

Employing PAS

Originally, paper survey sheets were used to record PAS survey results. However, WSDOT has streamlined the process by creating a survey 123 ArcGIS (ESRI) mobile survey application that can be easily used with any mobile digital device (Kintsch & Cramer, 2011). For the purpose of this thesis an iPad was employed to capture both photographs and data. The iPad automatically collected the coordinates, but all other attributes of a structure were entered by hand into the device.

A Weaver 8x 1000yd Buck Commander laser rangefinder was utilized to make long measurements without assistance. However, the rangefinder was limited to only displaying whole numbers, so measurements have been digitally rounded to the nearest foot. In addition, due to topography and location access points, many measurements are approximations, not exact measurements. For small measurements a 100’ tape measure was employed. Many photos were taken at each location and were captured using the same iPad that was being used to collect data for Survey 123 ArcGIS (ESRI).

Notably, PAS was developed without the inclusion of the openness index/ratio due to its inability to take into account structure attributes, wildlife habituation of structures, and varying attractiveness thresholds for different species (Clevenger, Chruszcz, et al., 2002; Jacobson & Jacobson, 2007; Kintsch & Cramer, 2011; Reed et al., 1975). Regardless, for large animals like elk (*Cervus* *elaphus*) and deer (*Odocoileus spp.*), the index still has some value for making agency recommendations about size minimums.

For the purpose of PAS, attributes that a Columbian white-tailed deer (*Odocoileus virginianus leucurus*) might find attractive or unwelcoming, like too much of, or lack of light (as ungulates tend to prefer clear lines of sight through structures), distance to safe areas, and structure designs were used to generate a more robust analysis of individual structures than openness ratio may be able to offer. (Cleveneger, Chruszcz, et al., 2002; S.L. Jacobson & Jacobson, 2007; Kintsch & Cramer, 2011; Reed et al., 1979).

PAS Local Species Considerations

Because deer and elk were the focal species for this thesis their needs were the most focused on when applying PAS. However, in order to make the analysis more robust and useful, numerous local species were used as proxy candidates for their individual guilds. Furthermore, all guilds were ranked at each structure, the species within those guilds that were taken into consideration were all local and known to have ranges within the study area. Importantly, rankings are exclusive to the region in which they are assigned (SW Washington) and have been tailored for specific species, while still accounting for other local members of those guilds (Table 5.1).

Focal Species

Table 5.1 Species that were considered as proxies for their guilds during the PAS analysis. Species in bold are the focal species for this research (Kintsch & Cramer, 2011).

GUILD	Generally Considered Species for Assessment
Cover Obligates	American Pika (*Ochotona princeps*) Rabbits: Eastern Cottontail (*Sylvilagus floridanus*) Snowshoe Hare (*Lepus americanus*)
Semi-aquatic	Northern River Otter (*Lontra canadensis*) Beaver (*Castor canadensis*)
Medium structure generalists	Black bear (*Ursus americanus*) Bobcat (*Lynx rufus*) Red fox (*Vulpes vulpes*)
Large structure generalists	**Mule deer (*Odocoileus hemionus hemionus*)** **Black-tailed deer (*O. hemionus columbianus*)** **Columbian white-tail deer (*O. virginianus leucurus*)** Mountain lion/cougar (*Puma concolor*)
Openness obligates	**Elk (*Cervus elaphus roosevelti*)**
Arboreal	Northern flying squirrel (*Glaucomys sabrinus*) Humboldt’s flying squirrel (*Glaucomys oregonensis*)

PAS & Resistance Layers

Originally, the letter rankings assigned for PAS (A, C, and F) were qualitative ratings for the possibility of structure enhancement. For example, A meant it was optimal or could use a little retrofitting. C meant that it needs retrofitting, and F meant retrofitting was not possible. However, in order to make PAS rankings relevant and applicable to resistance surfaces, the definitions of the rankings were in some cases slightly adjusted. Consequently, this meant that each rating had two considerations, enhancement and current permeability, this led to ratings that do not necessarily reflect the enhancement protocol, but rather considered whether a species could use that structure currently. This meant that structures with an F for a given guild may also have possible enhancements that could change that rating. In addition, in order to use PAS as a proxy for resistance values, rankings took into account the extent of the structure's current permeability, not just what could be (although only a few structure rankings were adjusted in this way). With that in mind the enhancement notes for each structure spells out clearly which retrofitting techniques or technology could be implemented to enhance even an F rated structure. If a structure had a strong conflict of definitions, they were given two ratings and identified as such within the analysis. Lastly, this way of using PAS is only possible because none of the visited structures had fatal flaws, meaning none were automatic Fs for all guilds, leaving room to mark something as an F with the potential for possible enhancement (Kintsch & Cramer, 2011).

The Northwest Coast Landscape Conservation Design Project partnership with the Washington Habitat Connectivity Working Group are currently creating a new landscape connectivity mapping model for S.W. Washington. This model is still in the planning prototype stages and a finished product is not yet available. In order to create a more informed mapping product, the group is using the research from this thesis in their preliminary landscape resistance layers. This was done by incorporating the guild rankings as proxies for structure permeability produced by using the PAS, something not done in previous analyses conducted by the Washington Habitat Connectivity Working Group (Kintsch & Cramer, 2011; WHCWG, 2010, 2011). Ultimately, the guild PAS rankings were averaged at each evaluated structure location. The average was then made into a multiplier in order to create a value for each structure within the resistance layer. Resistance values of non-passable areas on I-5 given a value of 1000, the minimum value allotted to passable areas had a range of 300 to 999 depending on PAS average rankings. Finally, the crossing structure raster was combined with landscape resistance, in order to reduce resistance values at evaluated structures.

Camera Monitoring

Two locations were monitored for wildlife usage for a year, Lacamas Creek from March 1st 2018- February 28th 2019, and Owl Creek from August 1st 2017- July 31st 2018, which is shorter than the minimum of two years WSDOT typically employs; but necessary for the timeframe and scope of this thesis. Camera data typically is very limited in capturing the species in the area as they do not collect samples of animals crossing roads; however, I-5 is a nearly impassable barrier so camera data may in this specific instance show which animals are crossing at a given structure (Clevenger, Long, & Ament, 2008). Furthermore, camera data may be necessary to better understand wildlife abundance in a given area, but is not sufficient on its own (R. A. Long, Mackay, Zielinski, Ray, & Editors, 2008). However, for the purpose of this thesis camera data has been used to reflect the usage of a particular structure, to determine which species is using it, and how often it is used, no other conclusions have been derived from the data.

Both Owl and Lacamas Creeks were outfitted with wildlife infrared triggered cameras by WSDOT prior to this research. At Owl Creek there were two Reconyx Hyper fire PC900s on both the northwestern side of the southbound structure, and the southeastern side of the northbound structure. In addition, there was a Bushnell Trophy Cam HD Aggressor setup next to the Reconyx on the southeast side of the northbound structure, the Bushnell was aimed down to capture smaller animals. The camera on the northwest side of the structure faces primarily at the dirt road that runs east to west through the structure (that was mostly used by semi-trucks). The camera is mounted to Telespar (square steel tubing) and cemented into the ground about 7 ft 6 inches from the road on an angled abutment. The top of the Telespar is roughly the height of the lens so it was used as the measuring point of height for each camera, for this camera the Telespar is roughly 1 ft 7 inches tall. The southeastern cameras are under the northbound side of the freeway, the Bushnell was the eastern most of the two cameras, no more than a foot apart. It sat about 1 foot and 5 inches tall, with a strong 45-degree angle to capture smaller animals, such as reptiles and amphibians. The Reconyx next to it faced directly ahead to capture the larger species using the structure, and it sat about 1 foot 6 inches high (Fig 5.2). Notably, Owl Creek is unique, in that it is the only location that sits within close proximity to elk, black-tailed deer, and Columbian white-tailed deer converging LCPs.

Owl Creek Camera setup

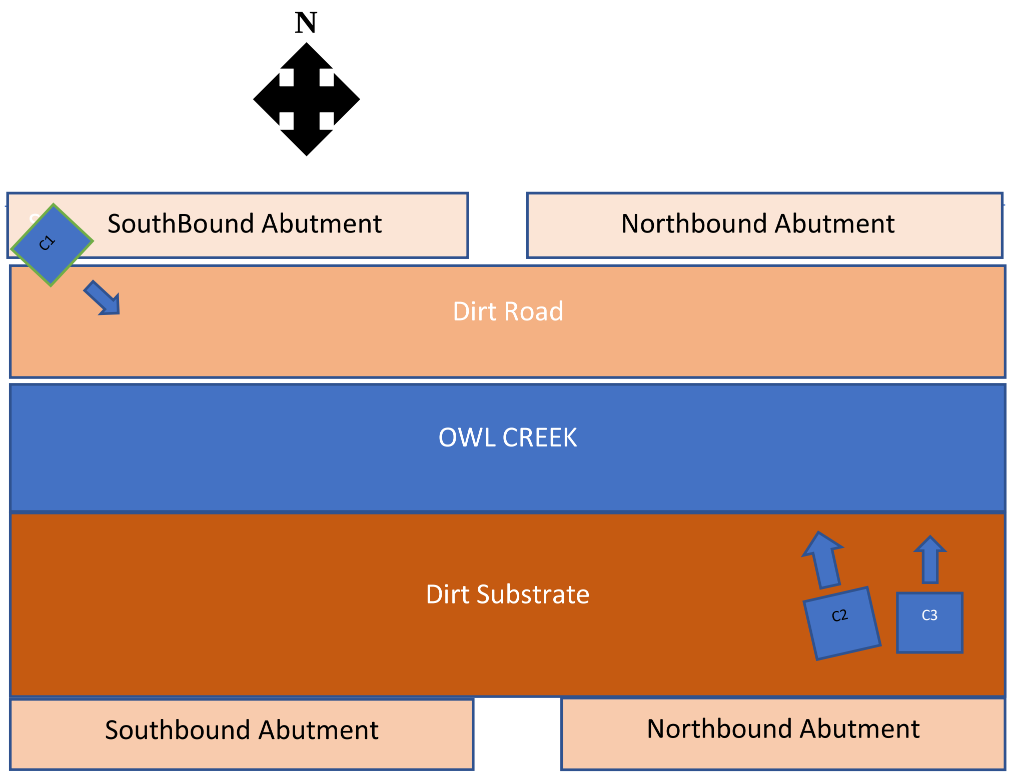

Figure 5.3. Camera trap setup at Owl Creek. (not to scale). A simple diagram of the camera placement at Owl Creek. C1 Reconyx aimed at road, C2 Reconyx aimed at creek, C3 Bushnell aimed down at a 45-degree angle to capture smaller animals.

The second location that was outfitted with cameras was Lacamas Creek, it also had a total of 3 cameras, all three at this location were Reconyx Hyper fire PC900s. One was positioned on the northeastern side of the structure overlooking the road, it sat about 14 ft from the road on a steep slope, and was 1 foot 7 inches from the top of the Telespar. Another camera was situated on the southeastern side of the creek in the middle of the “natural” substrate at the eastside of the structure, it stood roughly 3 feet 7 inches tall. Lastly, a third camera was mounted high on the southwest side of the southernmost section of a sloped dirt abutment, it stood 3 feet 2 inches tall to the top of Telespar (Fig. 5.3).

Lacamas Creek Camera Setup

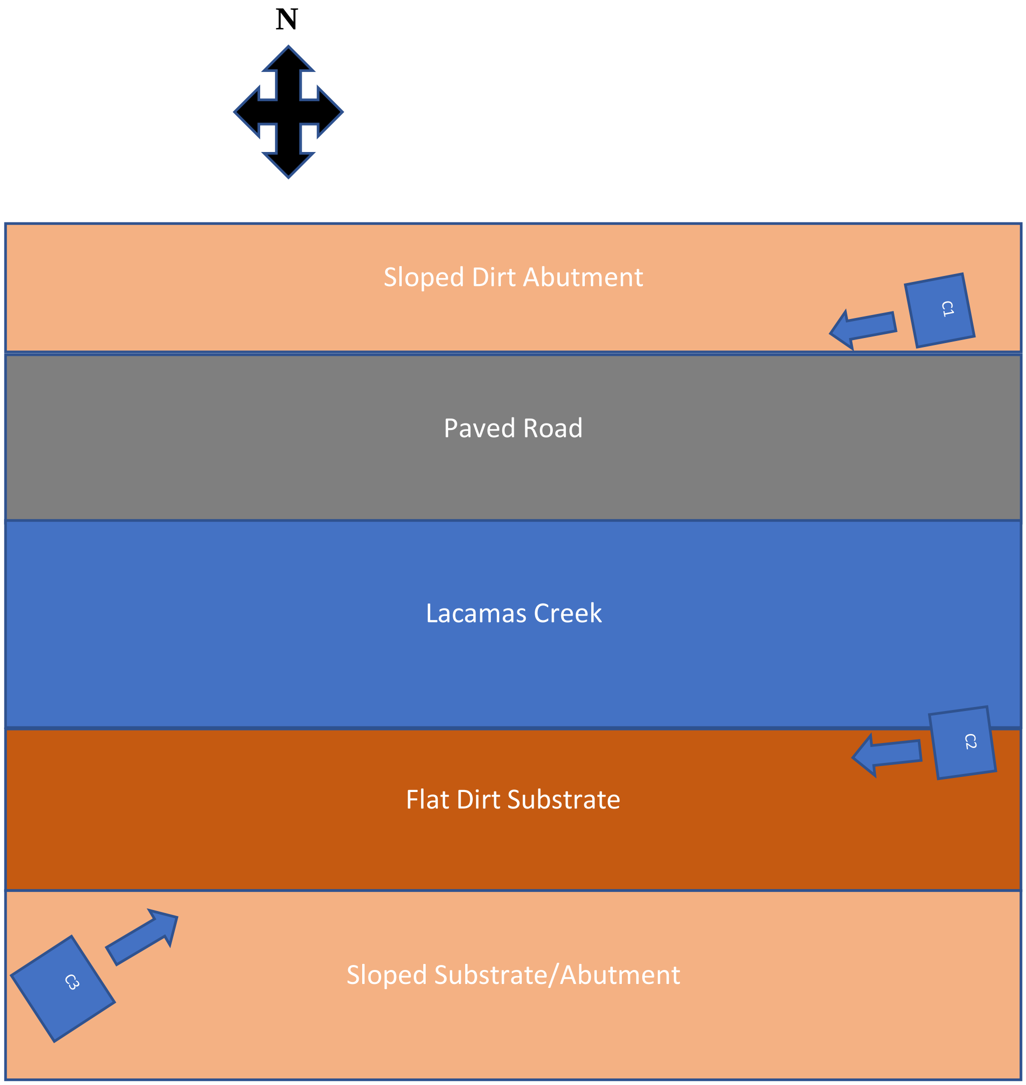

Figure 5.4. Camera trap setup at Lacamas Creek. (not to scale). Simple diagram of camera locations at Lacamas Creek. C1 is a Reconyx facing west/southwest, C2 is a Reconyx on the southeast side of the creek facing west, C3 is a Reconyx facing easterly from a southwest position.

The camera trap methods and data methodology employed in this thesis are directly derived from the WSDOT protocol for camera trapping. In 2011, WSDOT began its camera trapping program as a part of the research project that designed the Passage Assessment System (PAS), after the research finished WSDOT continued to monitor and collect data on many different structures on state roads throughout Washington State (Kintsch & Cramer, 2011; McAllister & Carey, 2016). Roughly once a month (when possible), the data cards were collected from the cameras and the batteries were replaced. The data was then taken and uploaded to the WSDOT database and organized chronologically for manageability. Each photo was then viewed, and the species type and action type were noted in an excel spread sheet. Variables recorded included, date, time, temperature, species, sex, approximate age, and whether it passed through the structure or not. The detections were broken into 30-minute segments and included one or more animals. Any animal still present after the 30-minutes was then placed into the next 30-minute block and the detection continued. Results are typically reported as expanded detections, which reflects the total number of individuals, not the total number of detections (McAllister & Carey, 2016). In order to remove bias of repeated animal detections at different ends of the structures, detections of the same species type, at the same time, were removed and the data combined to create an aggregate dataset, that did not repeat detections (McAllister & Carey, 2016).

Data Sources and Statistical Analysis

In this thesis wildlife-vehicle conflicts (WVCs) are defined as wildlife-vehicle collisions, near wildlife misses resulting in collisions, and carcass removals. In order to compile the aggregated WVC data, two separate WSDOT databases had to be queried and combined (Carcass Removal and Collisions). WSDOT keeps extensive records on carcass removals reported by maintenance staff, or carcass salvages reported by citizens. The result is the carcass removal database. In the past, the database was limited, and the collection methods were cumbersome, consequently reports had many inaccuracies. In the last five years WSDOT has digitized much of the process and has allocated more time and care in ensuring its accuracy, resulting in a more accurate dataset. However, duplicates, false locations, and incorrect species identification reporting still happen. The collisions database is composed of records submitted by the Washington State Patrol (WSP) and analyzed by WSDOT. Typically using roadkill data to make assumptions about wildlife crossings on a given road is limited due the varying reasons an animal might cross the road and be hit by a car and does not represent the wildlife that successfully cross the road (Clevenger, Chruszcz, et al., 2002; Malo, Suarez, & Diez, 2004). Because this thesis focuses on I-5 where successful crossings may in fact be impossible for most species, collisions and carcass data for this thesis have been used to inform where wildlife is attempting to cross and where structures or enhancements are most needed.

Average Annual Daily Traffic (AADT) represents the yearly average traffic at a given location, it does not include variables that can have impacts on traffic volume, like peak seasons and times of day. WSDOT has traffic monitoring locations throughout the study area, notably not every single mile section is monitored, there are specific locations that are physically monitored, and that average is attributed to the entire section of roadway. Conveniently, WSDOT has both public and internal GIS maps that show these values, for this thesis internal GIS maps were queried for data.

In order to summarize traffic volumes at all 20 locations, and at each mile within the study area, AADT was assigned to each location and incorporated into the analysis. One reason of using AADT was to better reflect the probability of a motorist experiencing a WVC. Another consideration for incorporating AADT into the analysis was the fact that traffic volume may affect both WVCs and animal approaches to roadways. It has been shown that animal-vehicle conflict (AVC) or WVCs tend to decline when AADT exceeds 25,000, and that there is very little difference between AVCs (WVCs) 35,000 - > 55,000 AADT, possibly making them suitable for direct comparison (Yinhai Wang et al., 2010). However, proximity of suitable habitat and variables like speed, number of lanes and frequency of trucks have been shown to be just a few possible factors associated with whether a given animal may attempt to cross a roadway or not (FHWA, 2008; Romin & Bissonette, 1996; Yinhai Wang et al., 2010). All WVCs were recorded per 100,000 AADT (slightly lower than the highest AADT value within the study area), in order to standardize the WVC data by traffic volumes in the area (Appendix D).

For the purpose of this thesis the WVC data was assigned to three datasets for statistical analysis and comparison. The first was the structure location data (SLD) for each of the 33 structures' 20 locations, WVC per 100,000 AADT were then assigned to those locations if they happened within ± 0.5 mile on either side of the structure. For example, if the middle of a structure was milepost 21.5 then 0.5 would be added to either side to give a mile range from milepost 21-22. Two structures were removed because of mile overlap with other structures, any residual data point was assigned to the MNSD dataset.

The second data set known as the gap non-structure data (GNSD) represented every section without an associated structure on the interstate between milepost 0-100, and every event that occurred within that gap was attributed to it. In order to make the data usable in a statistical analysis the data was then subset by road mile, so the sums were WVCs per 100,000 AADT per 1-mile section. The third dataset represented mile by mile non-structure data (MNSD) of WVCs per 100,000 AADT, excluding structure associated mileposts and WVCs.

Initially, two-tailed t-tests were employed with JMP to compare the different datasets to determine if there was any difference in the means of WVC per 100,000 AADT mile sections associated with known large structures and WVC per 100,000 AADT mile sections not associated with known large structures. Two comparisons were made to test the hypothesis that there was in fact a difference in the means of GNSD per 100,000 AADT and SLD per 100,000 AADT, or MNSD per 100,000 AADT and SLD per 100,000 AADT.

Prioritizing Structures for Enhancements

In order to make recommendations as to which structures should be prioritized for resources and new research, two separate considerations were made; 1) which structures were located within known least-cost paths, and may provide the best opportunity for a connected landscape; 2) which structures had the highest number of associated WVCs per 100,000 AADT, providing the best opportunity for increasing driver and wildlife safety (WHCWG, 2010; WSDOT, 2016). Consequently, two different lists were generated, one to prioritize safety, the other to prioritize ecological connectivity for a given species.

Locating Areas in Need of Further Research for New Wildlife Crossing Structures

The criteria for locating and prioritizing locations for new structures was identical to the process for locating structures for enhancements. For the least-cost paths comparisons, any area that fell within a known pathway was prioritized. Furthermore, any area that had quality least-cost paths but had inadequate existing structures was added to the priority list. In order to create ArcGIS (ESRI) maps that informed these locations, public data was used in combination with the data assembled for this thesis. For mileposts and state road layers public WSDOT GIS layers were used. For LCPs the WHCWG's statewide analysis was utilized and the open sourced layers used. Lastly, for any public land maps Washington DNRs public layers were utilized (DNR, n.d.; WHCWG, 2010; WSDOT, n.d.-b).

For the WVC per 100,000 AADT data, the gap data (GNSD) was scrutinized in order to make suggestions as to where new structures might be most beneficial for the safety of both motorists and wildlife. Sections of Interstate that did not have a large associated structure within its boundaries were considered to be gaps. For example, if a structure exists at milepost 31 and its northern milepost range falls on milepost 31.5, and the next milepost exists at milepost 42, and its southern range falls on milepost 41.5, then the difference between the two would represent one gap. The gap in the previous example would be 10 miles long and would include all WVCs within its milepost range. The data was then made comparable to each other by first analyzing WVC per 100,000 AADT, and then by WVC per 100,000 AADT per mile. In total, 5 sections of I-5 were identified as exceeding the mean of 13.23 WVC per 100,000 AADT per mile and were included in the results.

Chapter 6: Results

PAS Study Area Results & Discussion

In all, 20 locations representative of 33 structures were mapped along with their overall PAS letter rankings for each guild (Appendix C). For large structure generalist (Deer), 12 were rated A (decent crossing structure, could use minor enhancements/retrofits) and 8 are rated C (passable or can be made passable, in need of enhancing/retrofits) (Fig. 6.5). Elk, in part due to their behavioral traits, and in part due to poor structure design, received a total of four F (non-permeable, unable to enhance/retrofit) ranked locations; however, Elk still received 17 locations that rank as Cs (Fig. 6.6). Importantly, Columbian white-tailed deer may actually fall into both Guilds, but for the purpose of this thesis they are classified as large structure generalists.

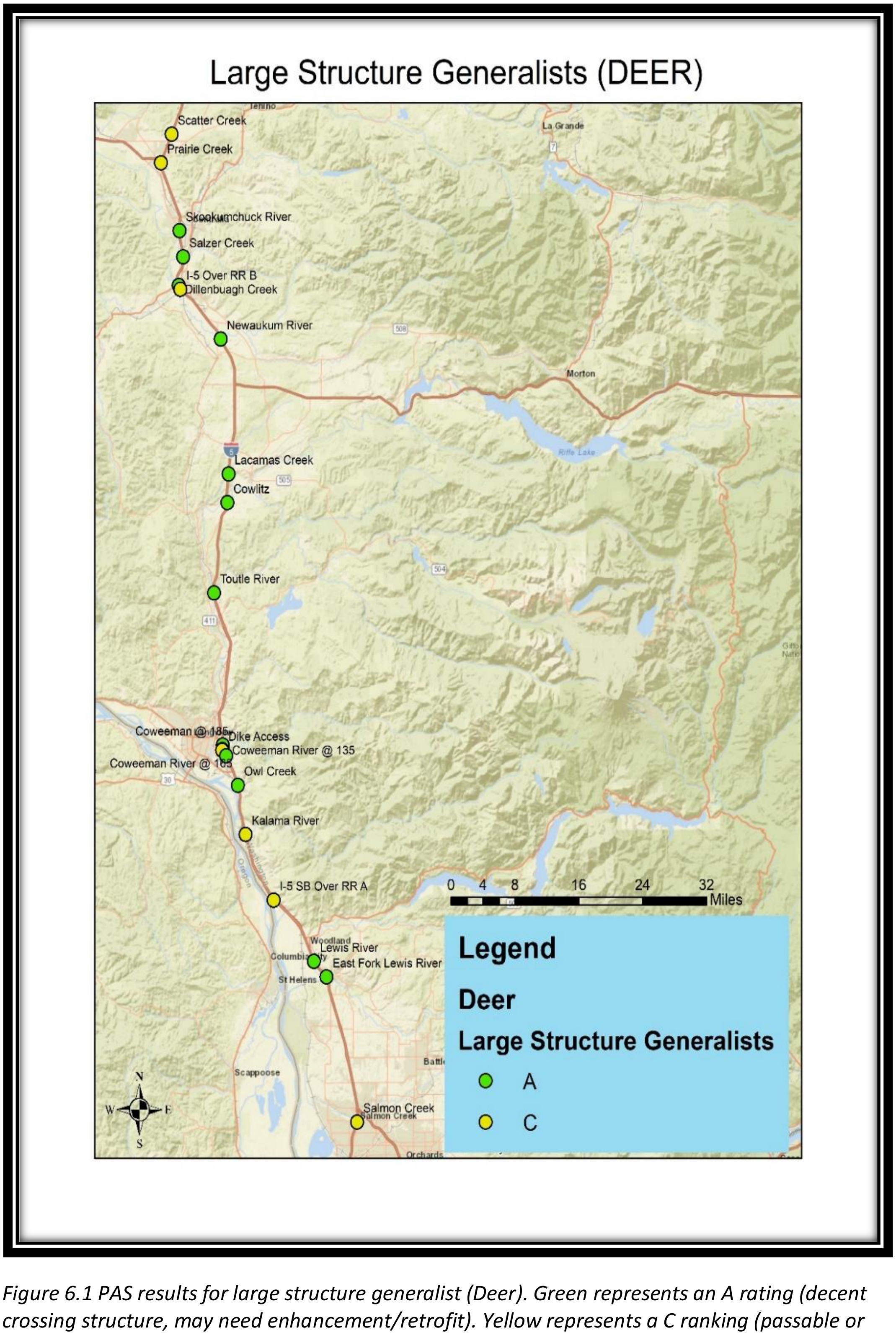

Figure 6.1 PAS results for large structure generalist (Deer). Green represents an A rating (decent crossing structure, may need enhancement/retrofit). Yellow represents a C ranking (passable or can be made passable, in need of enhancements). Red represents a F ranking (not passable cannot be made passable with enhancements/retrofitting) (ESRI et al., n.d.; Kintsch & Cramer, 2011).

Figure 6.2 PAS results for openness obligates (Elk). Green represents an A rating (decent crossing structure, may need enhancement/retrofit). Yellow represents a C ranking (passable or can be made passable, in need of enhancements). Red represents a F ranking (not passable cannot be made passable with enhancements/retrofitting) (ESRI et al., n.d.; Kintsch & Cramer, 2011).

Priority Locations Associated with Known Ungulate Least-Cost Paths (Results and Discussion)

By combining; 1) habitat concentration areas and least-cost paths (LCPS) form the WHCWG’s (2010) state-wide analysis for elk and black-tailed deer with; 2) habitat cores, nodes and LCPs for CWTD from WSDOT’s (2016) analysis with; 3) ungulate PAS data for large structures within the study area, maps were generated illustrating the relationships between PAS rankings, and possible ungulate LCPS (Fig. 6.3,6.4,6.5) (WHCWG, 2010; WSDOT, 2016). LCPs represent locations where corridors and accessible habitat may be most abundant. The assumptions of resistance based on expert opinion that the LCPs used (i.e. assigning I-5 a single resistance value), may have forced some of these paths into areas where there is strong urban development, suggesting they do not truly represent a realistic path of least resistance for some species (WHCWG, 2010). Prioritization of location importance were determined by analyzing visual proximity of PAS ranked structures to known ungulate LCPs. Utilizing the PAS ranking maps and the elk and deer connectivity models, has highlighted areas in need of further research. Locations of interest presented in this thesis are listed in no particular order of importance.

1. Scatter Creek (Deer LCP) (Fig. 6.3) (PAS results appendix B.1)

- One associated structure
- MP: 90.37
- 2014 through 2017 WVCs per 100,000 AADT associated with the location: 12.31

Scatter Creek is a small bridge that has strong seasonal variability in water height and flow. During the dry months it is a small gravel crossing that may be utilized by animals like deer. However, during the winter months there is water flow that may inhibit or prevent usage for some animals. Furthermore, the location is most likely too small for elk to use. Two LCPs cross I-5 north of Scatter creek (Fig. 6.3) and suggest this location may be within paths deer may use (WHCWG, 2010). In addition, the area is connected to a WSDOT mitigation area that is "natural" on the east side but flows into more developed areas further to the west. This location would be an excellent place for further monitoring and for wildlife infrastructure enhancements. Furthermore, Prairie Creek (PAS results appendix B.2) just to the south, may be a better option for enhancement and retrofitting due to its larger size (Fig. 6.3). Lastly, a section of I-5 south of both Scatter and Prairie Creek has been identified in this thesis as possible area for further research into the applicability and possibility of a wildlife only crossing structure.

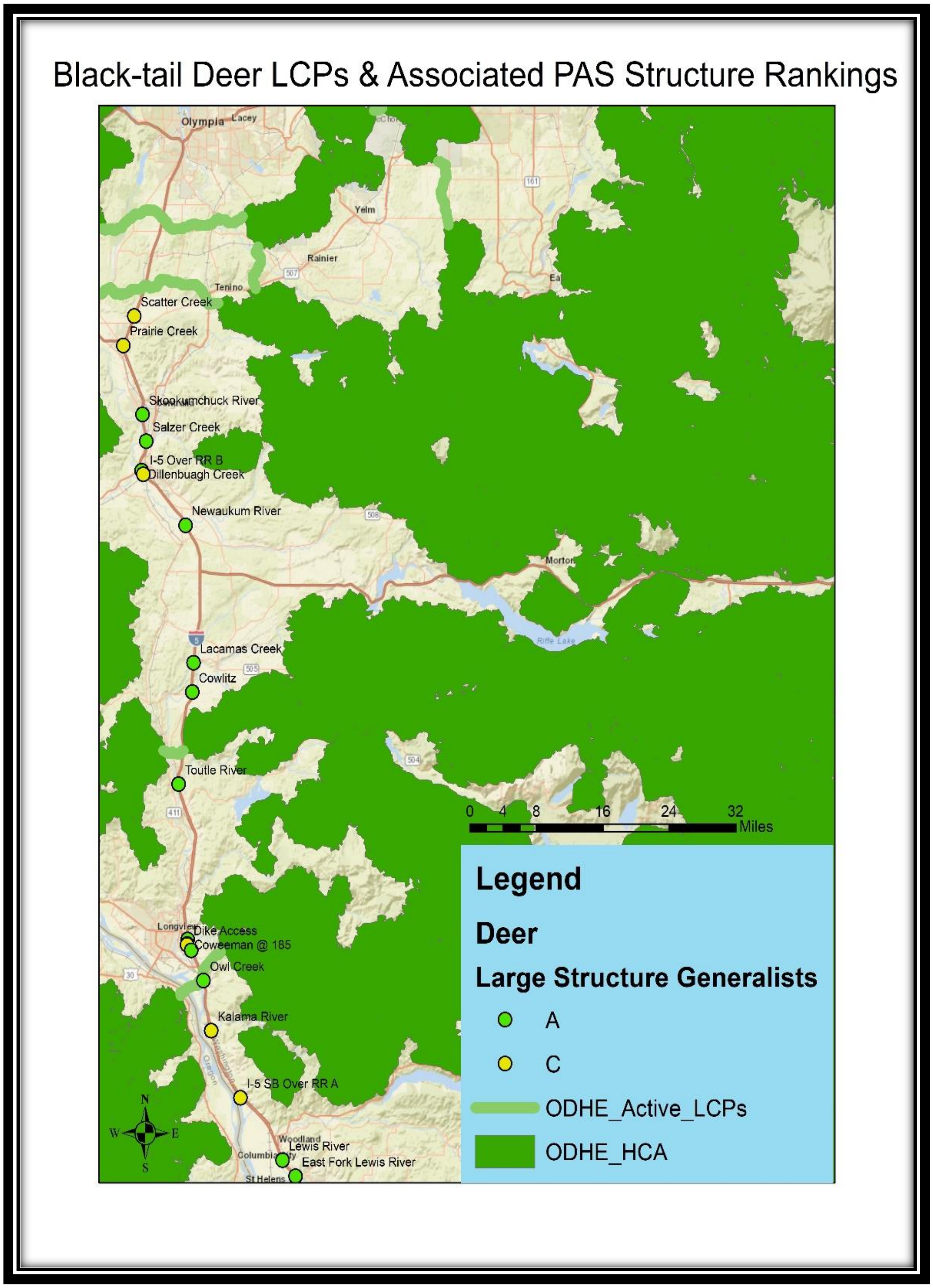

Figure 6.3 Mule/Black-tailed Deer linkages and ranked highway structures. Map shows deer LCPs and their relationship to corresponding locations with PAS rankings. Green dots represent locations with a PAS ranking of A. Yellow dots Represent locations with a PAS ranking of C. The green areas are habitat concentration areas for black-tail deer (ODHE_ HCA) and the light green lines connecting them are the LCPs (ODHE_Active_LCPS) (ESRI et al., n.d; Kintsch & Cramer, 2011; WHCWG 2010).

2. **Salzer Creek (Elk LCP) (Fig. 6.4) (PAS results appendix B.4)**

    - One associated structure
    - MP: 80.21
    - 2014 through 2017 WVCs per 100,000 AADT associated with the location: 13.33

    Salzer Creek is a large structure and has potential to aid wildlife crossings, if it was not for its proximity to development and use by private agricultural landowners. The Salzer Creek structure is located just north of the city of Chehalis, and south of the city of Centralia. There is also encroaching development to the west of this structure and an active frontage road. If landowners on either side of this structure worked with state agencies and conservation groups, it may be enhanced for passage of some wildlife. However, it is unlikely this location will become less developed or become more natural in the future. This location may represent the best known LCP for elk, but even with enhancement it would be unlikely elk would use this location (Kintsch & Cramer, 2011; WHCWG, 2010). More monitoring and research could be utilized at this location.

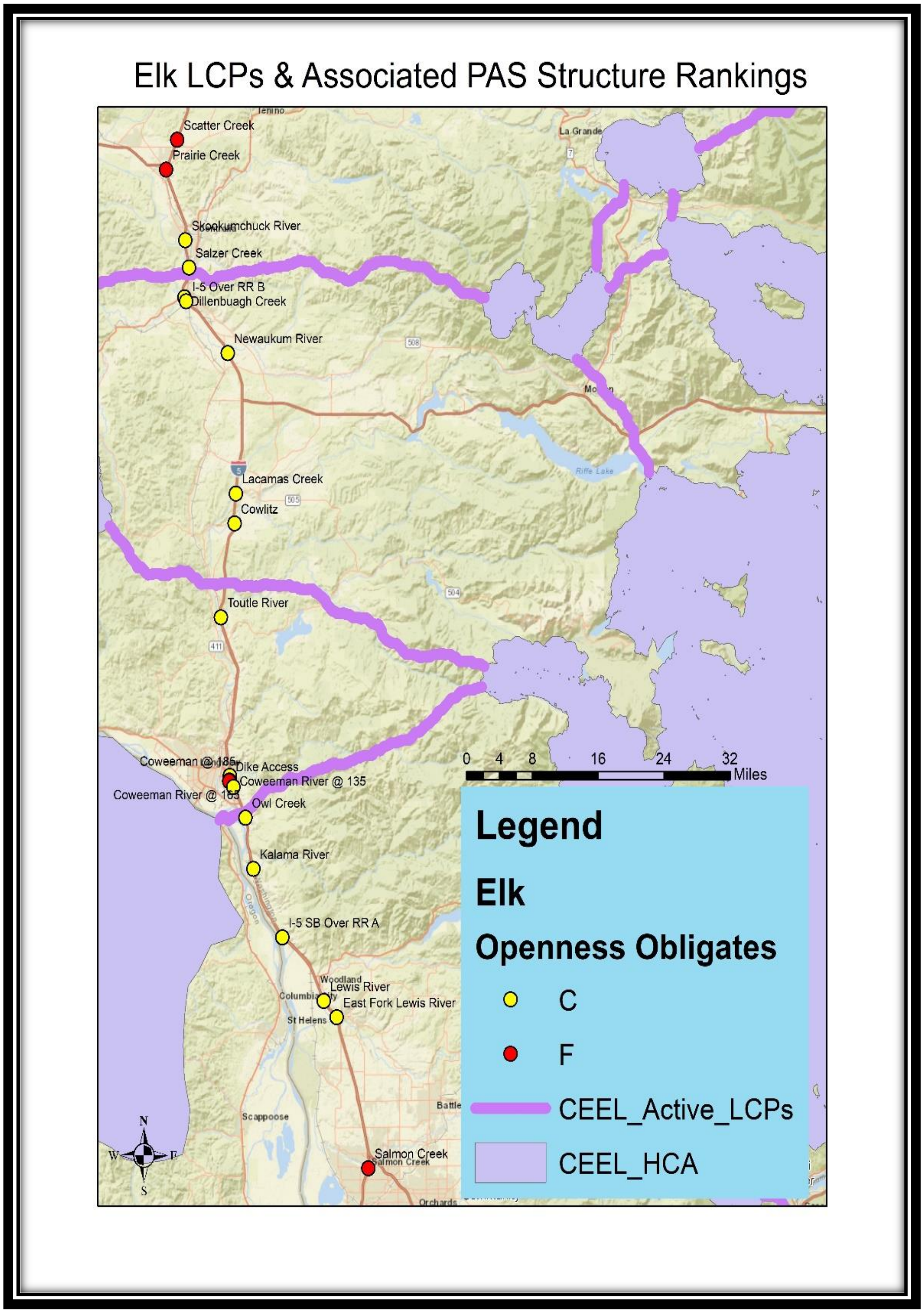

Figure 6.4 Elk linkages and ranked highway structures. Map shows elk LCPs and their relationship to corresponding locations with PAS rankings. Yellow dots Represent locations with a PAS ranking of C. Red dots represent locations with a PAS ranking of F. The solid lavender areas are habitat concentration areas for elk (CEEL_HCA) and the purple lines connected them are the LCPs (CEEL_Active_LCPS) (ESRI et al., n.d; Kintsch & Cramer, 2011; WHCWG 2010).

3. **Newaukum River, Lacamas Creek, Cowlitz River, East Fork Lewis River, Lewis River, Salmon Creek, I-5 South Bound only RR B. (CWTD LCP) (Fig. 6.5, 6.6)**

   Due to the difference in modeling approaches CWTD have the most identified LCPs, when compared to elk and black-tailed deer (WHCWG, 2010; WSDOT, 2016). Development and human presence may limit species movement at some of the identified locations. Nevertheless, this thesis recommends these locations of interest for possible monitoring efforts and future research.

   A. **Newaukum River (PAS results appendix B.7)**

      Two associated structures. Milepost 72.24

      2014 through 2017 WVC per 100,000 AADT: 37.93

   B. **Lacamas Creek (PAS results appendix B.8)**

      One associated structure. Milepost 61.31

      2014 through 2017 WVC per 100,000 AADT: 16.28

   C. **Cowlitz River (PAS results appendix B.9)**

      One associated structure. Milepost 59

      2014 through 2017 WVC per 100,000 AADT: 24.44

   D. **East fork Lewis River (PAS results appendix B.19)**

      Two associated structures. Milepost 18.21

2014 through 2017 WVC per 100,000 AADT: 7.60

E. Lewis River (PAS results appendix B.18)

Two associated structures. Milepost 19.83

2014 through 2017 WVC per 100,000 AADT: 12.65

F. Kalama River (PAS results appendix B.11)

Two associated structures. Milepost 31.82

2014 through 2017 WVC per 100,000 AADT: 22.54

G. I-5 southbound only RR B (PAS results appendix B.17)

One associated structure. Milepost 26.01

2014 through 2017 WVC per 100,000 AADT: 21.74

H. Salmon Creek (PAS results appendix B.20)

One associated structure. Milepost 6.32

2014 through 2017 WVC per 100,000 AADT: 9.33

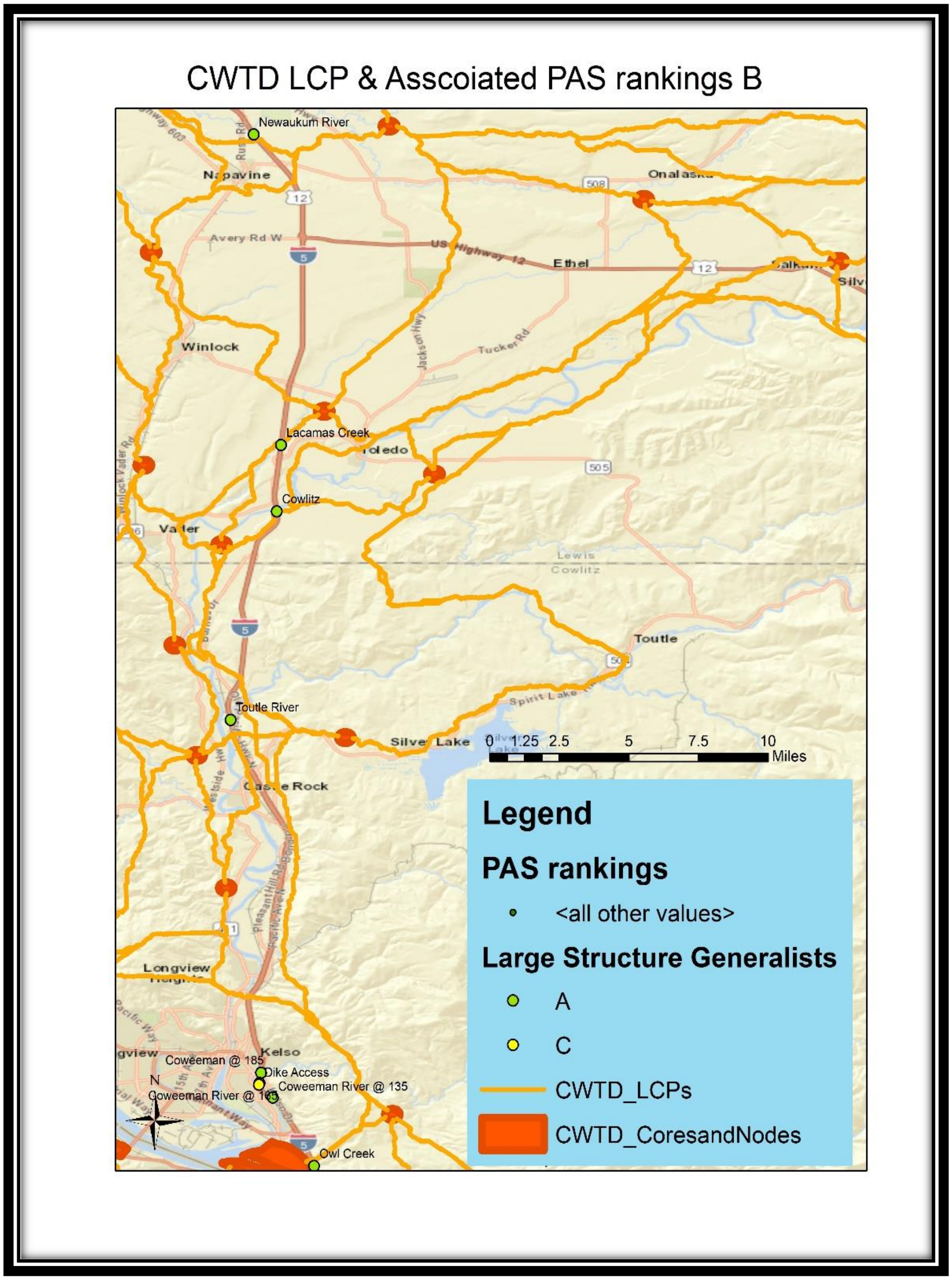

Figure 6.5 Columbian White-tailed Deer corridors and ranked highway structures, section B. Columbian white-tail deer (CWTD) Section B Newaukum-Owl Creek LCPs associated with PAS crossing I-5 section B. Orange lines represent the LCPs (CWTD_LCPS), while solid orange areas represent cores and node (CWTD Cores and nodes). Green dots represent locations with a PAS ranking of A. Yellow dots Represent locations with a PAS ranking of C. (ESRI et al., n.d.; Kintsch & Cramer, 2011; Washington Wildlife Habitat Connectivity Working Group (WHCWG, 2010); WSDOT, 2016).

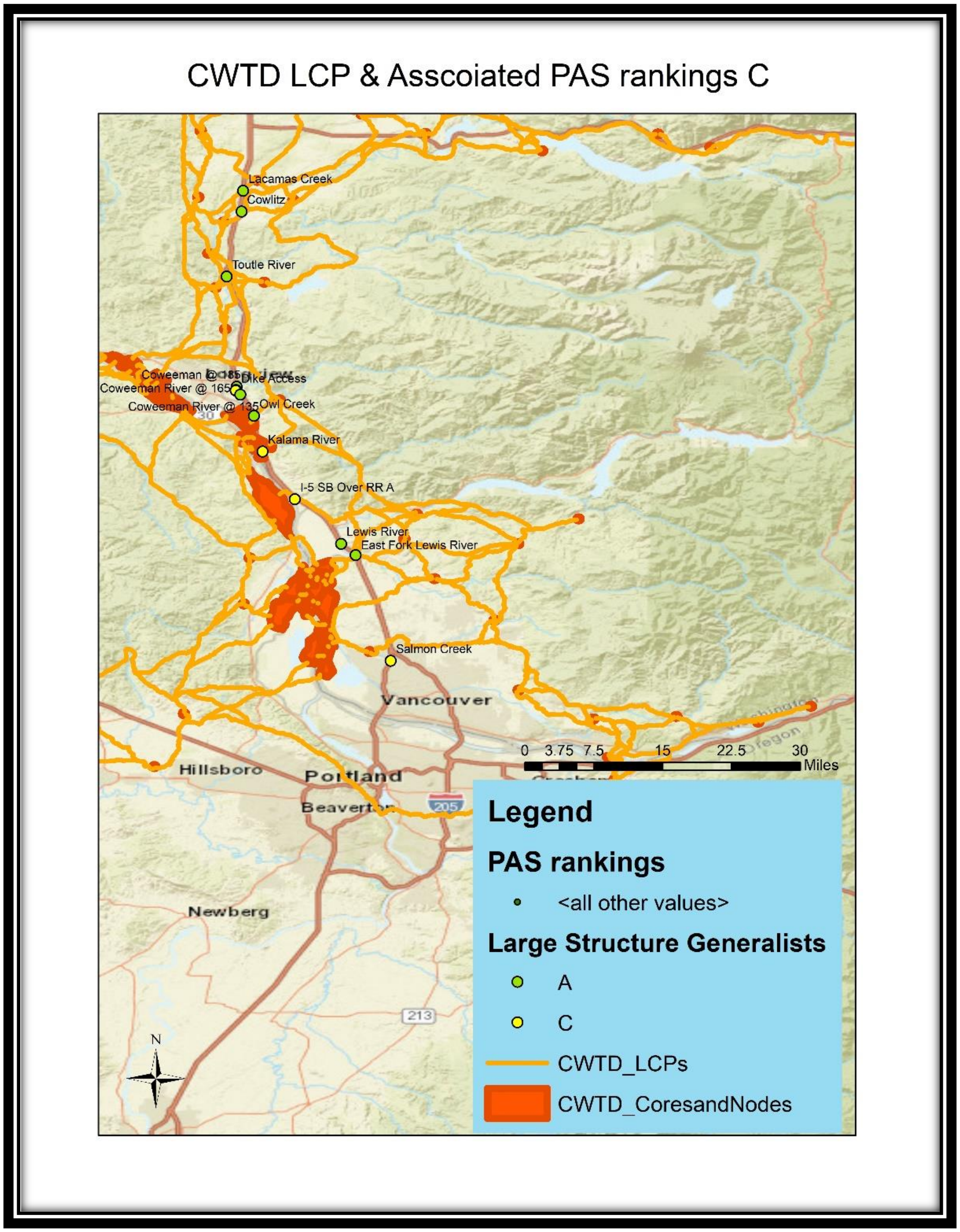

Figure 6.6 Columbian White-tailed Deer corridors and ranked highway structures, section C. Columbian white-tail deer (CWTD) Section C Lacamas Creek to Salmon Creek LCPs associated with PAS crossing I-5 section B. Orange lines represent the LCPs (CWTD_LCPS), while solid orange areas represent cores and node (CWTD Cores and nodes). Green dots represent locations with a PAS ranking of A. Yellow dots Represent locations with a PAS ranking of C. (ESRI et al., n.d.; Kintsch & Cramer, 2011; WHCWG, 2010; WSDOT, 2016).

4. **North of the Toutle River MP 51-59 (LCP convergence) (Fig. 6.7) (Most likely location for a wildlife only structure) (PAS results appendix B.10).**
    - 2014 through 2017 WVCs associated with the section of road between mileposts 51 and 59: 133.59 per 100,000 AADT, an average of 14.84 WVCs per 100,000 AADT per mile.
    - Gap # 4 an area that showed high number of WVCs is located within this range (Fig. 6.10).

The area north of the Toutle River is one of only three locations where black-tail deer, CWTD and elk LCPs converge on one area that also has a high number of WVCs (WHCWG, 2010). The closest large associated structures are the Toutle River bridge at the southern boundary, and the Cowlitz River structure at the northern most boundary. There are two culverts that exist just north and south of this location, but they were not considered priority locations for this thesis. The Toutle represents an opportunity for monitoring and enhancement for wildlife crossing. But more importantly, this location has been identified as the most advantageous location for further research into the possibility of a new wildlife only crossing structure, like an overpass. Therefore, it is recommended that this location is further researched and analyzed for the validity of placing such a structure.

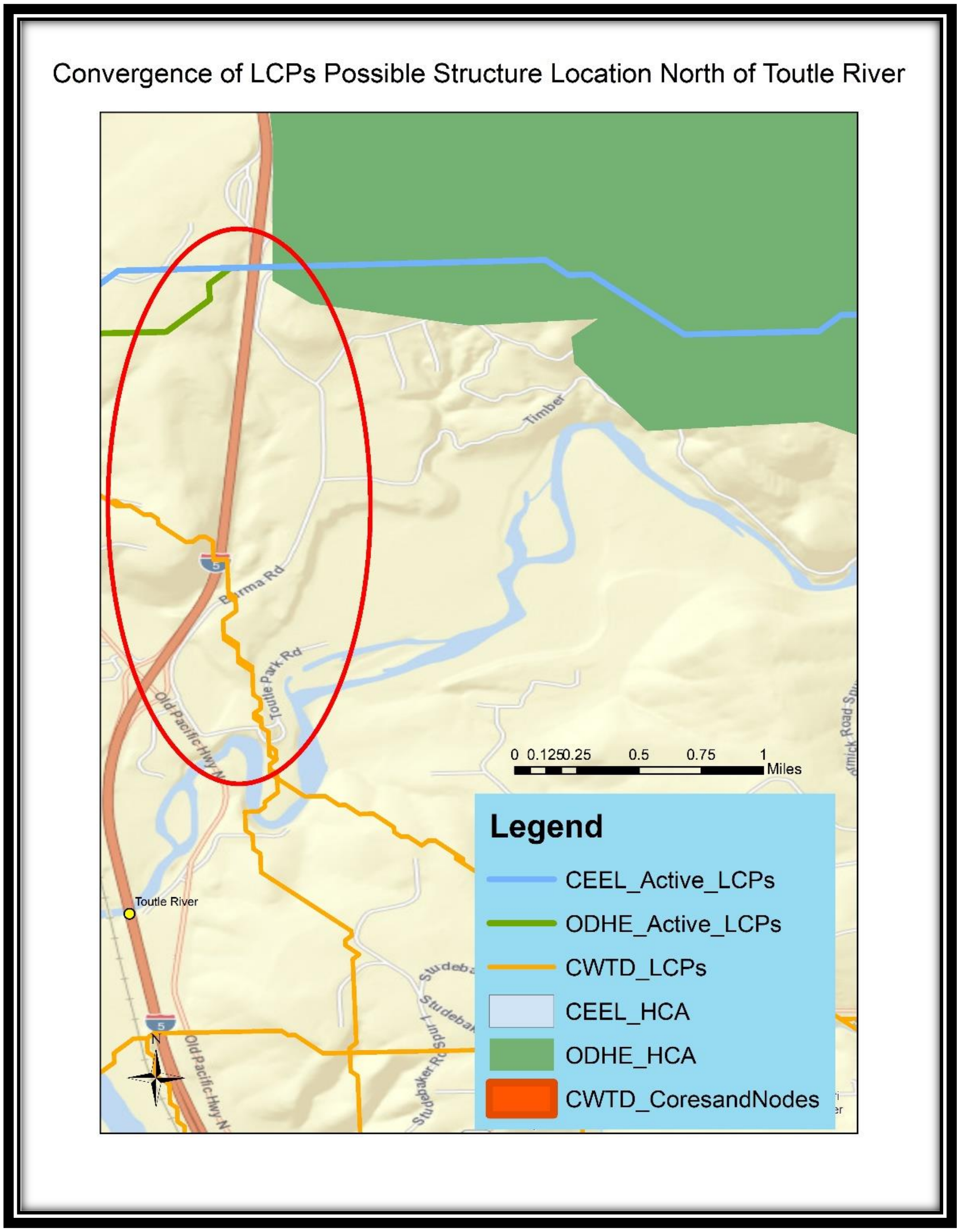

Figure 6.7 Convergence of LCPs north of the Toutle River. Elk LCPs are represented by blue lines (CEEL_Active_LCPs). Black-tail deer LCPs are represented by green lines (ODHE_Active_LCPs), while black-tail habitat is represented by solid green shapes (ODHE_HCA). CWTD LCPs are represented by orange lines (CWTD_LCPs). The red circle encompasses the area where further research into the possibility of a wildlife only structure should be conducted (ESRI et al., n.d; WHCWG 2010; WSDOT 2016).

5. **Owl Creek (LCP convergence) (PAS results appendix B.2) (Fig 6.8)**

- Two associated structures
- MP: 35.81
- 2014 through 2017 WVCs associated with the location: 14.08 per 100,000 AADT

Owl creek has elk, black-tailed deer, and CWTD LCPs passing near it within 0.3 miles (WHCWG, 2010; WSDOT, 2016). However, this location presents problems for many non-adaptable species like elk. For example, this location has a gravel road that is used frequently by semi-trucks accessing a private commercial business to the west of the structure. Furthermore, human foot traffic is also frequent both day and night through the structure, and the eastside frontage road is active. The south bank may represent an opportunity to facilitate movement of some species, but overall this location would benefit from prohibiting commercial traffic, restoring the creek, removing the gravel commercial road and limiting human access. This location might benefit from wildlife fencing to make the freeway safer and to help connect the overall landscape (Appendix B). Lastly, the only ungulate captured on the camera traps for this location was black-tailed deer, both elk and CWTD were apparently not using this structure during the time of the monitoring.

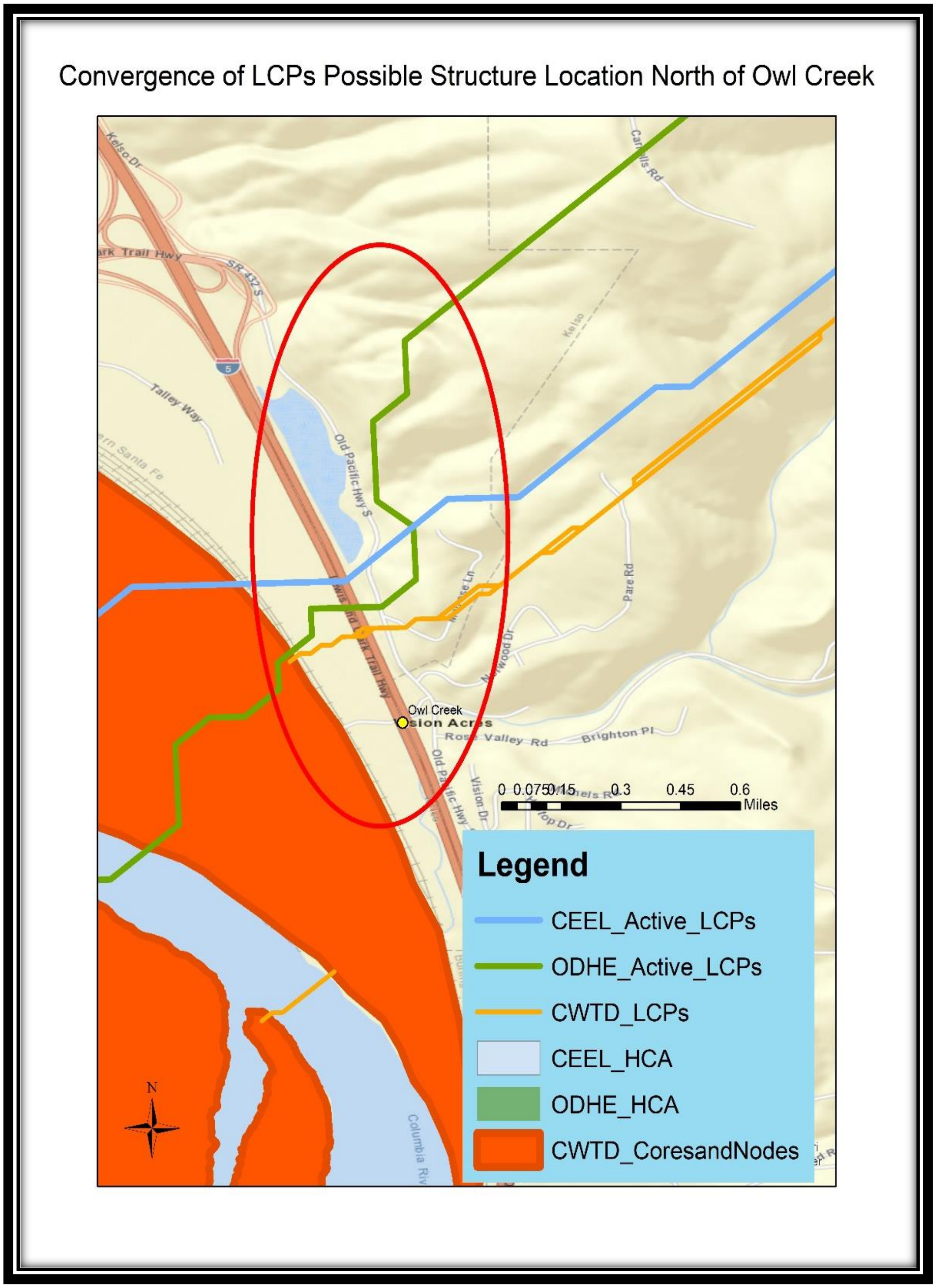

Figure 6.8 Convergence of LCPs at Owl Creek. Elk LCPs are represented by blue lines (CEEL_Active_LCPs). Black-tail deer LCPs are represented by green lines (ODHE_Active_LCPs). CWTD LCPs are represented by orange lines (CWTD_LCPs) while CWTD habitat is represented by solid orange shapes (CWTD_Coresandnodes) The red circle encloses the sections of I-5 where the convergence exists (ESRI et al., n.d WHCWG, 2010; WSDOT, 2016).

6. **South of Prairie Creek MP 84-87 (LCP convergence) (Possible location for a wildlife only structure) (Fig 6.9).**
    - 2014 through 2017 WVCs AADT associated with 15-mile area between Salzer Creek and Scatter Creek between mileposts 80-95: 193.21 per 100,000 AADT, an average of 12.1 WVC per 100,000 AADT per mile.
    - 2014 through 2017 WVCs associated with proposed wildlife only structure location 3-mile area between mileposts 84-87: 58.83 per 100,000 AADT, and average of 14.7 WVC per 100,000 AADT per mile.

Between Scatter Creek and Salzer Creek there is a wide expanse where each focal species has an LCP represented. Interestingly, they are all crossing I-5 at slightly different locations. The elk LCP crosses near Salzer Creek, which is not an optimal structure as it is surrounded by private agriculture land and bordered by a highly traveled frontage road, an unlikely location for elk and other wildlife to cross. CWTD LCP crosses just north of the city of Chehalis and does not come near any specific structure. While black-tailed deer LCPs are shown just north of Scatter Creek, which may be used by deer to cross I-5. Importantly, north of Scatter Creek and south of Salzer Creek are fairly developed areas, not advantageous for new crossing structures. However, there is a small area south of Prairie Creek and the Hwy 12 off/on ramps that should be further analyzed, researched and monitored.

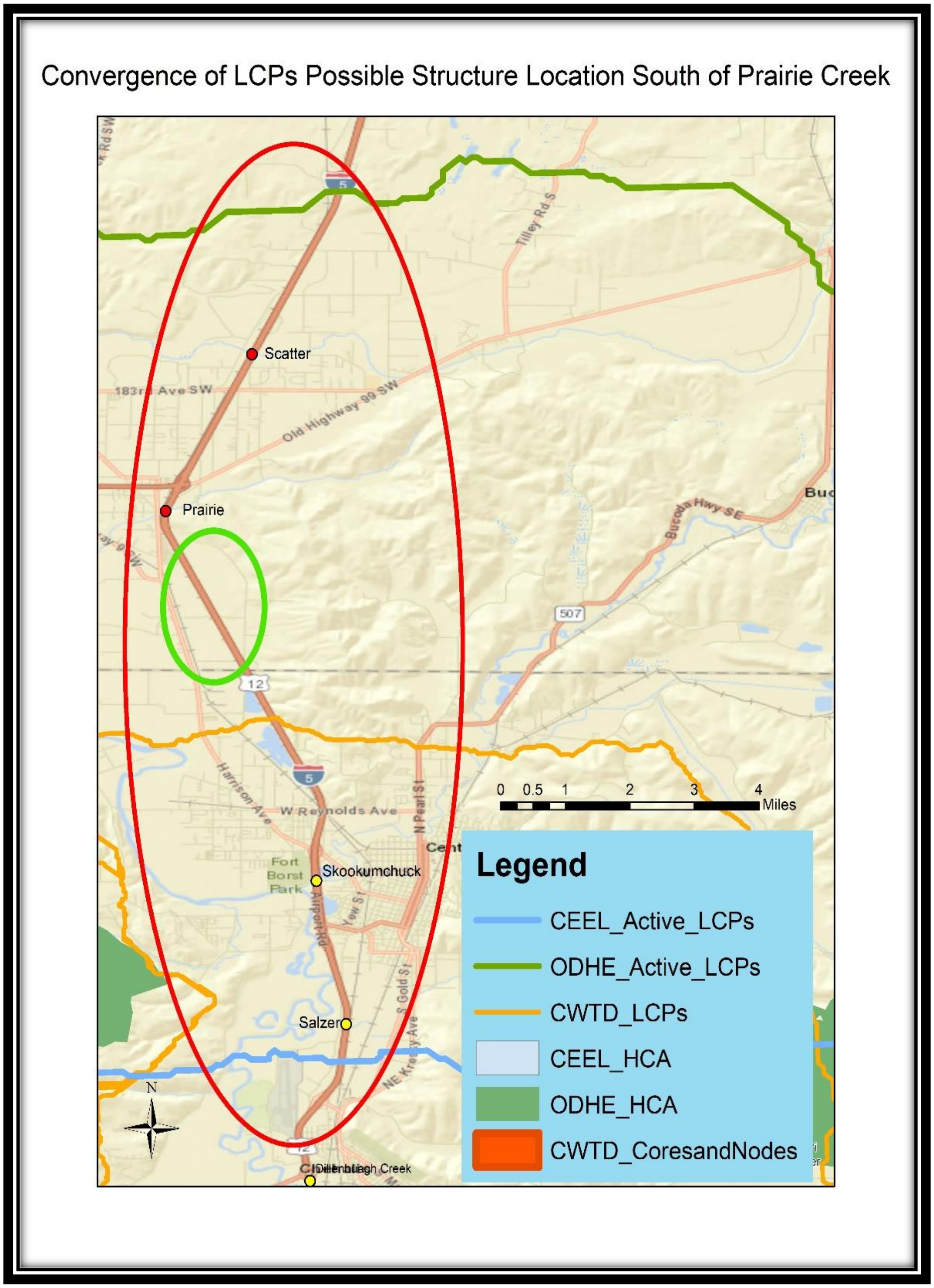

Figure 6.9 South of Prairie creek LCP convergence. Elk LCPs are represented by blue lines (CEEL_Active_LCPs). Black-tail deer LCPs are represented by green lines (ODHE_Active_LCPs), while black-tailed deer habitat is represented by solid green shapes (ODHE_HCA). CWTD LCPs are represented by orange lines (CWTD_LCPs). The red circle encloses the convergence area, while the green circle encloses the area that should be further analyzed for the viability of a wildlife crossing structure (ESRI et al., n.d WHCWG, 2010; WSDOT, 2016).

WVC Priority Locations

Four locations showed the highest number of WVCs per 100,000 AADT and should be considered priority locations for further research or for allocation of resources. Enhancing these locations would have the potential to increase safety for both motorists and wildlife.

1. **Skookumchuck River (PAS results appendix B.3)**
    - Three associated structures
    - MP: 82.28
    - 2014 through 2017 WVCs per 100,000 AADT associated with the location: 42

    This location is situated between known LCPs for both deer and elk. It is an ideal location for improvements aimed at reducing WVCs, restoration and monitoring. However, due to its high rate of human usage it may not be an ideal location for crossing wildlife, particularly those wary of humans. Interestingly, this structure sits between three LCPs one for deer to the north and one for elk to the south and CWTD centrally located. Proximity to anthropogenic development may prohibit many species like elk from approaching or using it as a crossing structure (Appendix B).

2. Newaukum River (PAS results appendix B.7)

- Two associated structures
- MP: 72.24
- 2014 through 2017 WVCs per 100,000 AADT associated with the location: 37.93

The Newaukum River bridge is a large structure and may pass wildlife presently. However, it has large cliffs on its westside and commercial/ residential land use not far from the location. That being said, this location should be monitored and researched for possible enhancements that may encourage movement of wildlife. In addition, due to its high volume of WVCs, investments in this location may benefit both motorist safety and landscape connectivity. Importantly, the structure sits in an area where the Chehalis Basin water retention facility project may have future impacts. This location should be monitored until the Chehalis Basin flood protection plan project is completed to fully understand opportunities and limitations the proposed retention facility project and associated restoration plans might have for improving wildlife connectivity at this location.

3. **Cowlitz River (PAS results appendix B.9)**

    - One associated structure
    - MP: 59.06
    - 2014 through 2017 WVCs per 100,000 AADT associated with the location: 24.44

    The Cowlitz River bridge is a large viaduct that allows ecological processes to pass under it. It could benefit from limiting human use and restoring native vegetation. Again, like many locations on I-5 this location gets a high volume of human visitors, something that should be addressed if enhancing strictly for wildlife permeability. It is another ideal location for improvements, restoration and monitoring to reduce the high number of WVCs (Appendix B).

4. **Kalama River (PAS results appendix B.11)**

    - Two associated structures
    - MP: 31.82
    - 2014 through 2017 WVCs per 100,000 AADT associated with the location: 22.54

    The Kalama river bridge is a large viaduct that allows for the passing of ecological processes underneath it. It could also benefit from limiting human use. In fact, this location was inundated with seasonal recreators at the time of its assessment, boating, fishing, camping etc.……. This location may pass animals that are highly adapted to humans during the summer months but may have the potential to pass more wary species when seasonal human use has decreased. This location should be monitored to better understand both human and wildlife presence.

Gaps (Fig. 6.10)

Five sections of I-5 that did not have an associated large structure and exceeded the mean of 13.23 WVC per 100,000 AADT per mile have been reported. Notably one section comprising of only 0.76 miles is associated with a WVC per 100,000 AADT of 17.8. While the other above average sections are all ≥7 miles in length. This area's high rates could be affected by the proximity of large structures, which may in fact have higher than average WVCs associated with them. Locations are listed from 1 to 5, with the highest number of WVCs per 100,000 AADT as 1 and the lowest as 5.

1. Section (gap) 1 (Fig. 6.9, green box) is an 11.33-mile section starting at milepost 39.9 in the south and ending at milepost 51.23 in the north. The section has an AADT of 52,250 and is associated with 23.65 WVC per 100,000 AADT. An average of 2.1 WVC per 100,00o AADT per mile
2. Section (gap) 2 (Fig. 6.9, blue box) is a 9.91-mile section starting at milepost 61.84 in the south and ending at milepost 71.75 in the north. The section has an AADT of 48,091 and is associated with 20.98 WVC per 100,000 AADT. An average of 2.1 WVC per 100,000 AADT per mile.

3. Section (gap) 3 (Fig. 6.9, red arrow) is a 0.76-mile section starting at milepost 80.74 in the south and ending at milepost 81.50 in the north. The section has an AADT of 66,500 and is associated with 17.80 WVC per 100,000 AADT. An average of 23.42 WVC per 100,000 AADT per mile.
4. Section (gap) 4 (Fig. 6.9, purple box) is a 7.0-mile section starting at milepost 52.25 in the south and ending at milepost 59.25 in the north. The section has an AADT of 44,875 and is associated with 15.28 WVC per 100,000 AADT. An average of 2.18 WVC per 100,000 ADDT per mile.
5. Section (gap) 5 (Fig. 6.9, red box) is a 10.88-mile section starting at milepost 20.44 in the south and ending at milepost 31.32 in the north. The section has an AADT of 69,250 and is associated with 14.07 WVC per 100,000 AADT. An Average of 1.3 WVC per 100,000 AADT per mile.

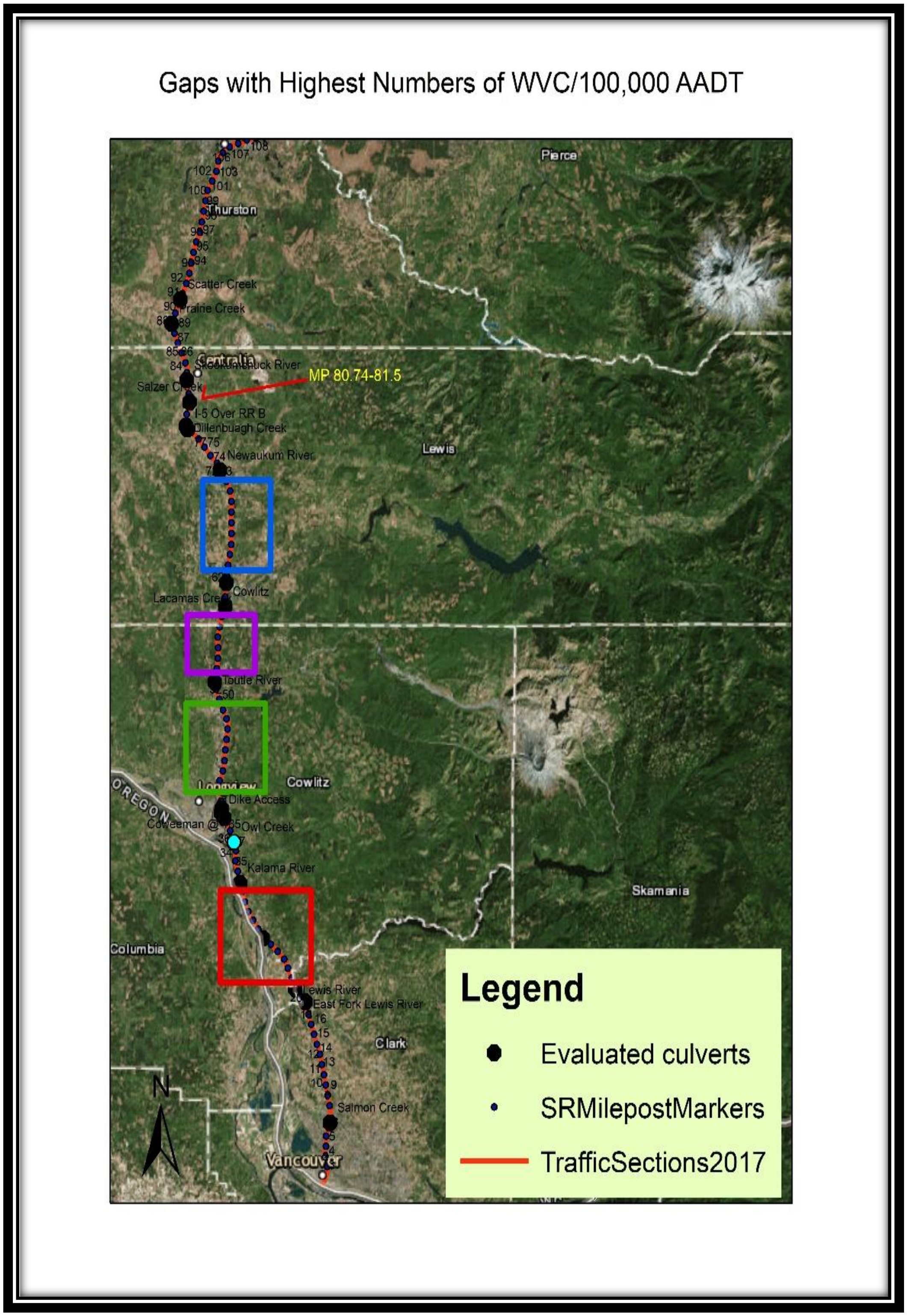

Figure 6.10 Gaps with above average WVCs per 100,000 AADT. Black dots represent PAS evaluated structures and blue dots for mileposts, for reference. The red box is highlighting gap #5. The green box represents gap # 1. The purple box represents gap # 4. The blue box represents gap # 2. The red arrow points to gap # 3.

Resistance Layer (PAS as a Proxy)

The Pacific Northwest Coast Landscape Conservation Design and Washington Habitat Connectivity Working Group are making a combined effort with others to map S.W. Washington for terrestrial connectivity, the final products are nearly a year away from completion. Regardless, preliminary prototypes have utilized PAS averages to make basic landscape resistance changes where structures are known to exist. Once basic values are decided on species specific considerations will need to be made, as averages will not reflect species' specific structure resistance (Fig. 6.11).

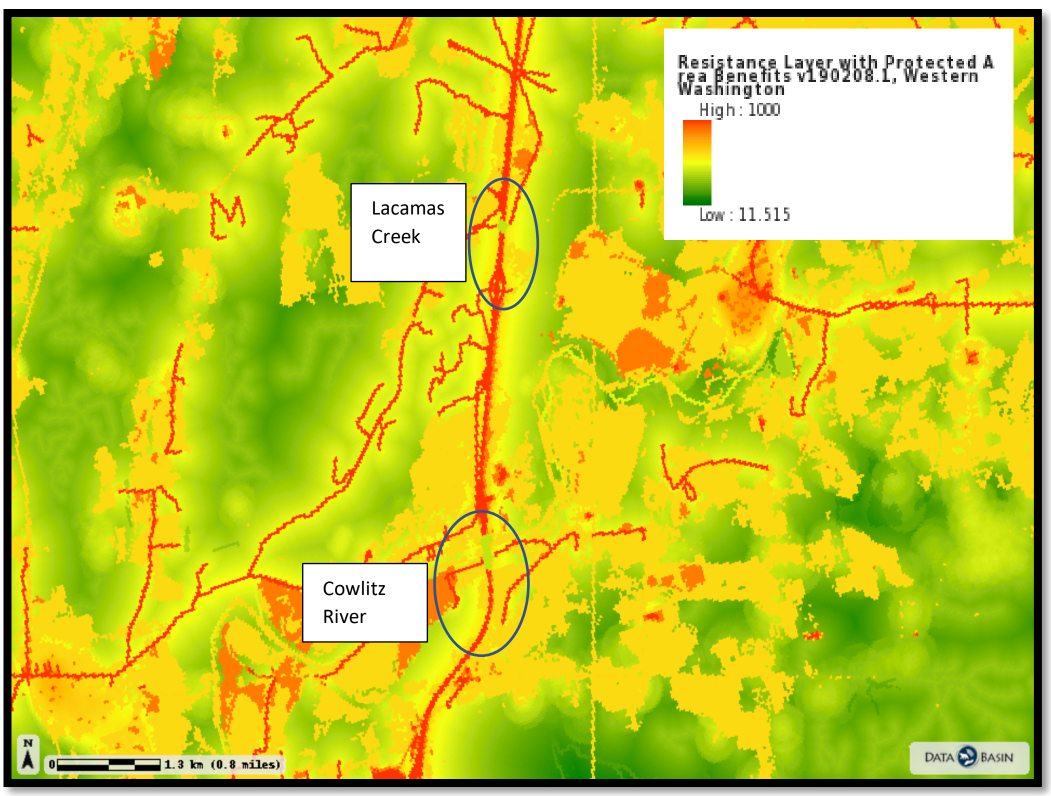

Figure 6.11 Prototype resistance layer showing light green breaks (highlighted with blue circles) in I-5 where PAS has been used as a proxy for resistance values. Dark green represents the low resistance vale of 11.5, while dark red represents the highest resistance value of 1000. Map is a prototype only, is not published and is strictly for illustrative purposes (Gallo, Unpublished).

Camera Results (Lacamas Creek and Owl Creek)

Lacamas Creek

Figure 6.12 Black-tailed doe feeding fawn on the southernmost abutment. Lacamas creek. C3

Camera photo analysis at Lacamas Creek revealed heavy usage by black-tailed deer which represented 68 % of total expanded crossings. As a testament to the human presence in and around this location domestic dogs and humans combined, made up 21% of total crossings at this location. Species captured using this structure are highly adapted to human presence and can utilize human dominated landscapes (Table 6.1, Fig 6.13, Appendix E).

Table 6.1 Species' expanded crossing numbers Lacamas Creek March 1st 2017 to February 28th, 2018. Raw data (Appendix E-1)

Species	**Did not cross**	**Unknown**	**Did Cross**	**Grand Total**
Black-tailed Deer	7		556	563
Coyote			1	1
Dark-Eyed Junco		1		1
Domestic Cat			24	24
Domestic Dog			129	129
Human			40	40
Opossum			51	51
Porcupine			1	1
Raccoon			19	19
Robin			1	1
Steller's Jay			1	1
Grand Total	**7**	**1**	**823**	**831**

Expanded Crossings. Species' Percentages Lacamas creek

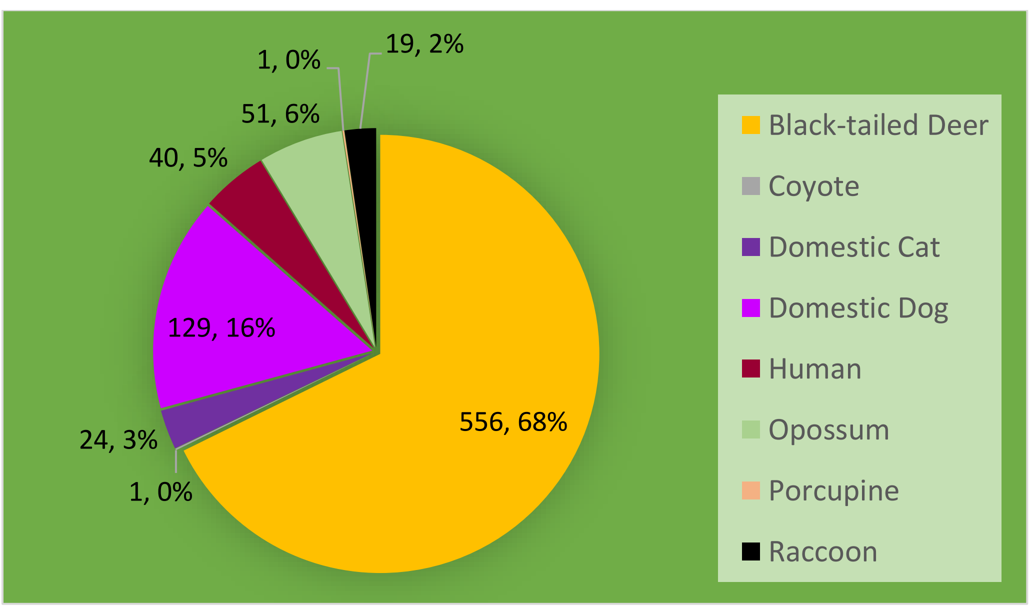

Fig. 6.13 Expanded crossings species percentages Lacamas Creek March 1st 2017 to February 28th 2018. Raw (appendix E-1).

Owl Creek

Figure 6.14 Male Black-tailed deer at the Owl creek south side of creek. C2

Owl Creek had 88 fewer Black-tailed deer crossings than Lacamas Creek, making up only 38% of expanded crossings. While 20% of crossings were human and 21 % were raccoon. Similar to the Lacamas Creek location human presence may be discouraging some species usage of this structure, as only the most human adapted species were captured in abundance at this location. However, Owl Creek did capture more diversity, but this may be due to the fact that one camera is pointed down at a 45-degree angle to capture smaller wildlife (Table 6.2, Fig 6.15, Appendix E).

Table 6.2 Species' expanded crossing numbers Owl Creek August 1st 2017 to July 31st , 2018. Raw data (Appendix E-1)

Species	Did Not Cross	Unknown	Did Cross	Grand Total
American Robin			1	1
Beaver	1		1	2
Black-tailed Deer	3	2	468	473
Bushy-tailed Woodrat			3	3
Common Garter snake			3	3
Coyote			10	10
Dark-eyed Junco			1	1
Deer Mouse		4	42	46
Domestic Cat		2	34	36
Domestic Dog	5	3	77	85
Great Blue Heron		4	4	8
Human	16	18	220	254
Mallard Duck			2	2
Opossum	1	4	75	80
Raccoon	2	3	251	256
Snowshoe Hare			1	1
Song Sparrow	1	3	2	6
Grand Total	**29**	**43**	**1195**	**1267**

Expanded Crossings. Species' Percentages Owl Creek

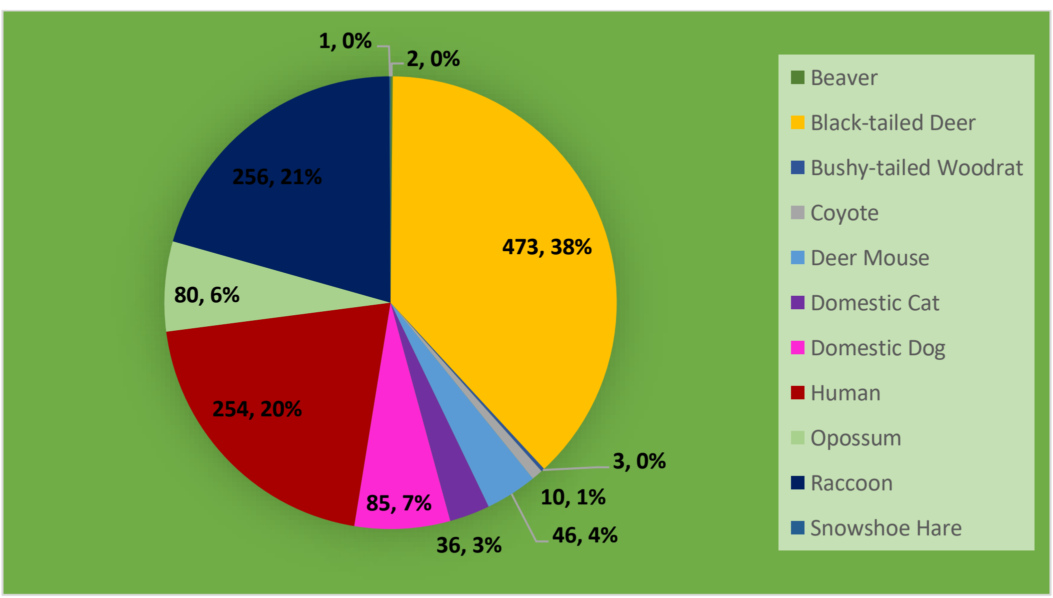

Figure 6.15 Expanded crossings species percentages Owl Creek August 1st 2017 to July 31st 2018. Raw data (Appendix E-1).

Wildlife-Vehicle Conflicts

Due to the fact there were too few CWTD incidents to report, all deer have been aggregated as one result. Deer represented 65% of the carcass removal data (Fig. 6.16), 92% of the collision data (Fig. 6.17) and overall 71.5 % of the combined WVC data (n=755). Elk represent 2.8 % of the carcass data, 3.9 % of the collision data, and 3.0 % of the overall combined WVC data. Finally, all other animals (mostly small vertebrates) are represented by the other categories, which made up 32.4 % of the carcass data, 3.4 % of the collisions data, and 25.5 % of the total combined WVC data.

Carcass Data

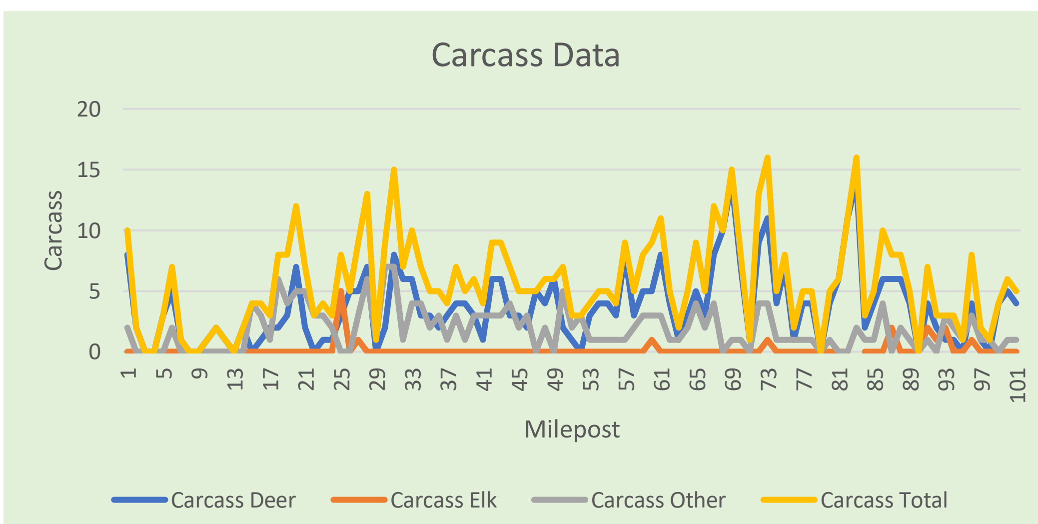

Figure 6.16 Carcass data from Jan 2014- Dec 2017 by milepost. The blue line represents deer, the brown line elk, the gray line other and the orange total.

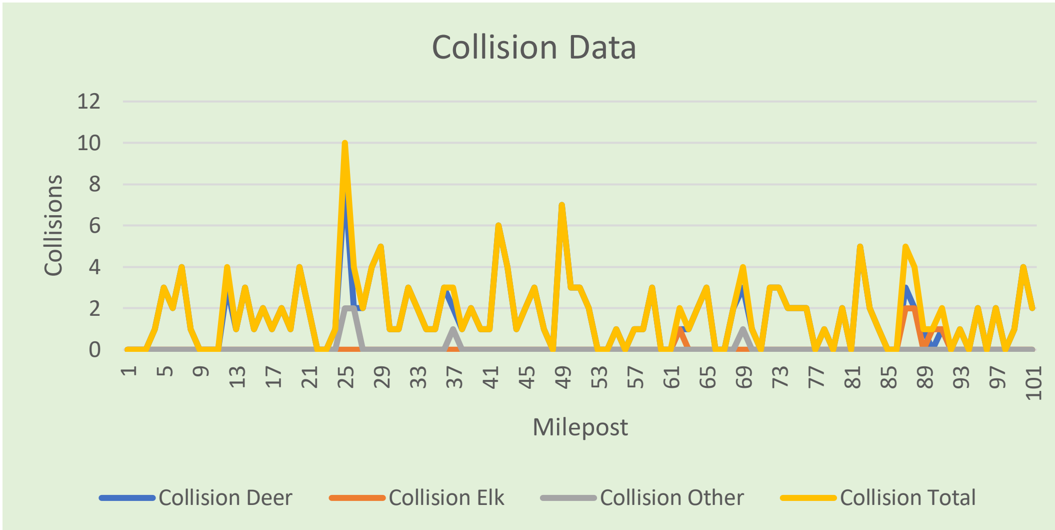

Figure 6.17 Collision data from Jan 2014- Dec 2017 by milepost. The blue line represents deer, the brown line elk, the gray line other and the orange total.

Statistical Results

Wildlife-vehicle conflicts not associated with structures and not assigned by milepost (Gap Non-Structure Data (GNSD) per 100,000 AADT) $\bar{x}$=13.2 were not significantly different then WVCs associated with structures (Structure Location Data (SLD) per 100,000 AADT) $\bar{x}$ =16.3, df=29, t=1.96, p=0.3 Fig. 6.18).

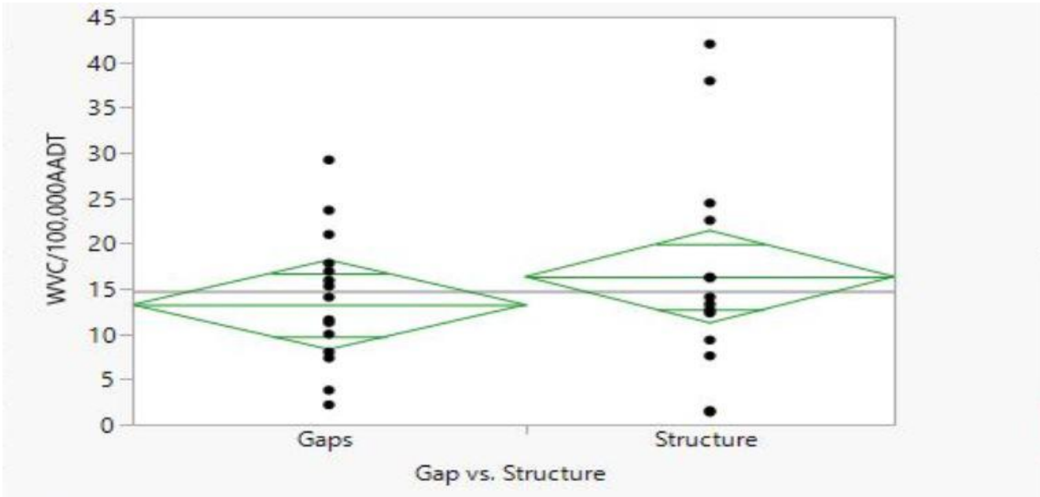

Figure 6.18 Visual comparison of the gap non-structure data (GNSD) on the left, and structure location data (SLD) used in the t-test analysis. JMP readout.

However, milepost specific WVC data not associated with a structure (Mile Non-Structure Data (MNSD) per 100,000 AADT) $\bar{x}$ =11.7 was significantly less than mean WVC data associated with structures. Structure location data (SLD) per 100,000 AADT) $\bar{x}$= 16.3, a significant relationship was shown df=99, p=0.04 (Fig. 6.19)

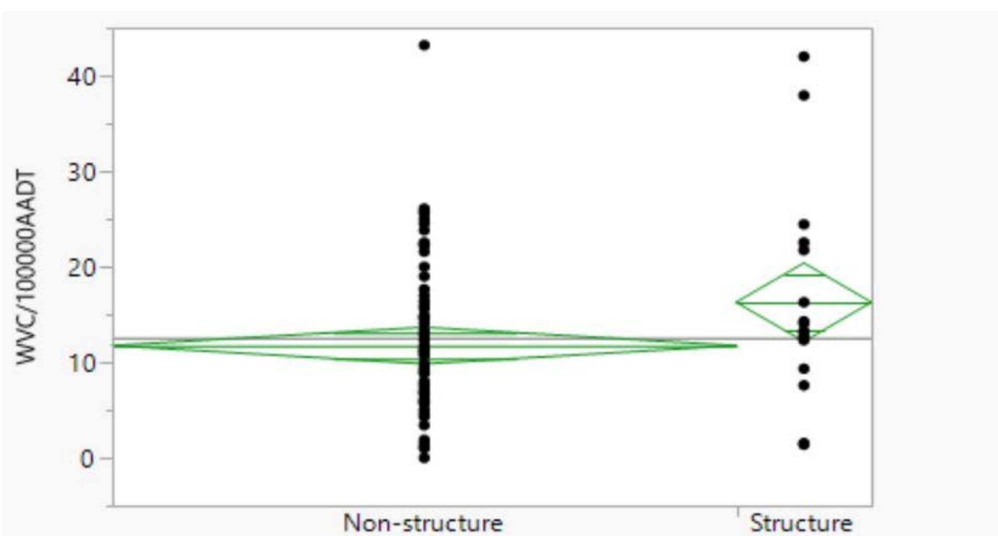

Figure 6.19 Visual comparison of the MNSD (non-structure) vs SLD (large structure) data.

Plotting the milepost specific WVC data (MNSD) per 100,000 AADT, revealed a non-linear relationship (Fig 6.20). The polynomial regression equation Y= 0.092 + 0.623·(MP) -0.0056·(MP^2) was a significant fit to the data ($F_{2,98}$=18.6, p=<0.001, adj. R^2= 0.26).

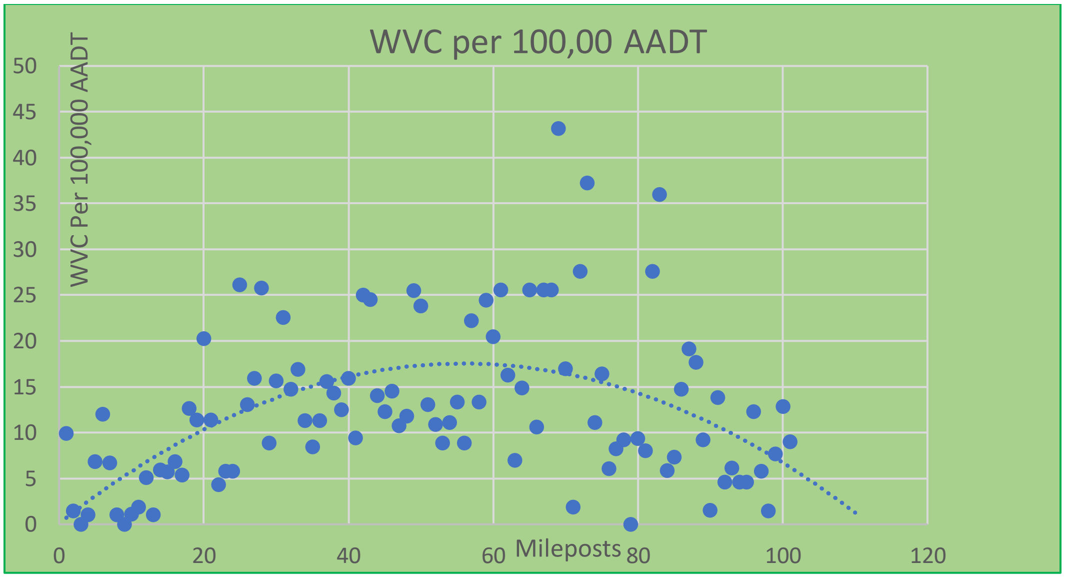

Figure 6.20 Polynomial regression line used to create the predicting equation. X=Mile sections of I-5 not associated with a structure Y= WVC per 100,000 AADT associated to with the mile section. MNSD per 100,000 AADT.

Chapter 7: Discussion and Recommendations

Funding Needs

Collisions with wildlife on state roadways cost citizens millions of dollars annually, cause injuries to motorists and wildlife and can also be fatal to motorists, and to a larger extent wildlife. One way to decrease the danger of a collision with wildlife on I-5 is to invest in wildlife fencing and other wildlife infrastructure at locations with high numbers of conflicts. This thesis has identified large structures as having the highest rate of these incidents; therefore, these locations should be further evaluated to determine the validity of installing infrastructure that can make roads safer. In addition, sections on I-5 were identified as having high rates of WVCs with no associated large structures, therefore these areas also need to be further evaluated to determine the validity of installing infrastructure that can make roads safer. Funding is needed to begin the process of deeper financial and practical analysis of enhancing the interstate for wildlife permeability. Transportation funding, and non-profit funding combined with agency and stakeholder cooperation has the potential to secure and allocate the necessary funds needed to begin to take the next steps towards a safer I-5 for both wildlife and motorists.

Another way to make I-5 safer for wildlife and motorists is to invest in connecting habitat for local species. Funneling wildlife (via fencing) to wildlife-only structures might help to minimize attempted crossings at locations with a high rate of accidents. Furthermore, by facilitating ecological corridors with crossing structures or overpasses designed specifically for wildlife, the state will actually be conserving and preserving ecological connectivity while helping animals adapt to, and migrate in, a changing climate. Building new structures and retrofitting old ones has the potential to 1) increase habitat connectivity, 2) create a landscape that gives wildlife a chance to adapt to climate change, 3) increase motorists' safety, and 4) conserve Washington State's natural beauty. Admittedly, new structures and large retrofit projects will require reliable sources of funding. However, these types of improvements can have a great overall benefit for the environment and wildlife, while incurring relatively low costs. Therefore, funding is immediately needed to continue to refine the prioritization of locations that might be best suited for a new structure or be best suited for wildlife enhancements or retrofits. Also, funding will be needed to complete these projects, one way to achieve this is to invest in I-5's infrastructure as it is aging. Including wildlife infrastructure with necessary I-5 revitalization projects can minimize costs and maximize the overall benefits for the community and the environment.

Monitoring the structures and corridors around I-5 is a key component to understanding where funds should be allocated. Camera monitoring projects are not free, requiring equipment and labor hours. In order to gain a better understanding of which animals are using what structures, cameras must be placed at numerous structures between mileposts 0 and 100. There are 33 large structures at 20 locations within the study area, including smaller structures that still need to be assessed. Therefore, it could require over a hundred camera traps, and possible telemetry data to accurately determine abundance and structure use for all local wildlife. Currently, WSDOT does not have any extra cameras that could be dedicated to I-5 and certainly not in the numbers required. This means that funding for equipment is desperately needed if WSDOT is going to better understand which animals are crossing, and at which locations. Unfortunately, even if WSDOT had every camera they needed for comprehensive monitoring, they currently do not have the staff to commit to such a project.

Without more funding, WSDOT staff, monitoring projects and research, I-5 will remain a mostly impermeable surface for some wildlife, it will prohibit migrations and dispersals related to climate change and increase the chance of having wildlife-vehicle conflicts. Immediate funding should be sought from legislators and non-profits to begin the process of making I-5 permeable and safe. In addition, a collaboration of agencies, non-profits and stakeholders should be created, assembling a coalition dedicated to increasing habitat connectivity across I-5 in S.W. Washington.

PAS Discussion

Due to the subjective nature and far reaching implications of the PAS, it is not likely that the rankings for each guild will encompass all the possible local guild members. Nevertheless, because PAS evaluates so many different variables it is just as likely that these rankings are applicable to all local guild members. It must also be noted that there are undoubtedly species that are present, but because they have unique or narrow sets of structure or habitat preferences, they may not be represented by this analysis at all. Lastly, there are populations, subpopulations, and individual animals that become habituated or acclimated to structures that are not currently known to be suitable for their species. This suggests that recommendations or enhancements made at these structures may not have the desired effect due to the unknown behavior of individual animals. This makes monitoring structures before resources are allocated a paramount step in enhancing or implementing permeable solutions at identified structures. Researchers and practitioners should use wildlife monitoring techniques to determine what species are present, and which species are currently using a given structure. If monitoring does not follow PAS and preempt enhancement investment, there is a possibility resources could be wasted and no ecological value obtained, in fact structures could be made less permeable for species currently using the structure. It has been documented that many projects of enhancement or new construction were in fact done without monitoring the structures, leading to waste and inefficient investments (Kintsch & Cramer, 2011; Kintsch et al., 2015; McAllister & Carey, 2016; McCollister & van Manen, 2010).

PAS Recommendations

PAS, as suggested by the creators, is always in need of refinement (Kintsch & Cramer, 2011; Kintsch et al., 2015). During the course of this research some aspects of the process were found to be in need of improvement. Notably, some of the issues are not directly PAS issues, but may be issues with the way WSDOT has digitized the survey. The first area of PAS that could be more specific is the fact that one can only enter percentages in increments of ten when assessing habitat and land cover/use, this leads to some subjective decisions on the ground that may not truly reflect of the proportion of land cover/use percentages. This rating system may have consequences when assessing very rare or limited habitat.

Another limitation that could be improved, is the applicability of PAS for very large viaducts that have large deep rivers separating the far sides of the structure. One way to account for these structures is to do a PAS on both sides of the structure, treating each side as a separate structure. However, this method would not only be more time consuming, but would replicate many aspects of the assessment like size, traffic volume, inlets, outlets etc., replicating work and creating unnecessary redundancy. One way to address this would be to make a copy option within Survey 123 (ESRI) that would duplicate the attributes that are identical and give the assessor the ability to simply add the few characteristics that are different. In addition, this could be under the file for one structure, but would have a north/south or east/west bank option that could be analyzed as one structure, but with separate sides. Ultimately, this thesis used one structure assessment for each structure regardless of river gaps, by making rankings that reflect the average of both sides of the river.

Annual average daily traffic (AADT) is an associated characteristic that should be included in the PAS database. Presently, PAS asks assessors to count cars for fifteen minutes and give an approximation of traffic at the time of the assessment (Kintsch & Cramer, 2011). This omits changes in traffic seasonally, and biases towards the time of day/week/month/year the assessor was physically at the location. One solution to this is to use AADT values from WSDOT's Environmental Workbench. This estimate is more representative of the volume of traffic found at a location throughout the year. In order to accomplish this an assessor would simply have to either collect the data before assessments are done or add in the information when the data is uploaded from the mobile collection device to the main server.

WSDOT Improvements

WSDOT is advised to monitor all the prioritized locations within the study area to better inform future research and to more efficiently allocate resources. One of the major limitations to this research is the lack of camera monitored locations, understanding how animals are currently using these structures is the next step in understanding the permeability of I-5. More importantly, monitoring should be used to help inform PAS results and add credibility to the analysis. Unfortunately, the number of miles and cameras necessary to do this would require great economic cost and many work hours, which may need to come from outside of WSDOT. In addition, some locations get lots of human use and cameras at these locations may be at risk of theft or vandalism. Currently, WSDOT struggles with resources and personnel when it comes to habitat connectivity. In fact, many hours are spent just trying to keep pace with camera data, carcass removal, and collision databases. With that in mind, it is understood without more public and government support, more cameras, staff, and resources may not be obtainable. Regardless, these recommendations are still being made with the foresight that resources may be gained in the future that can help facilitate the monitoring of structures on I-5 for wildlife permeability and to enhance existing structures.

WSDOT currently uses raw collision data to generate kernel density maps by species to partially inform ecological rankings that prioritize sections of state roads for permeability/monitoring resource allocation. However, this data only represents the number of collisions, not the probability of hitting an animal while driving in a given area. This thesis evaluates the WVC data per 100,000 AADT, to account for one aspect of the probability of hitting an animal. For example, currently the area around Olympia has a large number of collisions when compared to other areas within the study area, however it also has the highest volume of traffic, >100,000 AADT. In contrast areas in the Chehalis Basin have somewhat lower collision numbers but have roughly half the AADT (~58,000), and when the comparison is made, one finds that some of the areas with lower AADT have a higher probability of a WVC. Interestingly, the bulk of structures and the highest rates of WVCs are found between the Toutle River area and Prairie Creek. Evaluating wildlife-vehicle conflicts (collisions and/or carcass data) in this manner can be more representative of the probability of an incident. Lastly, aggregate datasets of both carcasses and collisions can help to better capture the WVCs in an area and should be scrutinized as a way of understanding the minimum number of collisions that have occurred in a given area.

WSDOT is also advised to include aerial fauna in future PAS assessments. Aerial fauna's PAS ranking is not something WSDOT currently evaluates when employing PAS. Unfortunately, this leaves out a great deal of important wildlife permeability information, especially when evaluating large underpasses and viaducts. Furthermore, it has been shown that highways impact birds in four main ways “direct mortality, indirect mortality, habitat fragmentation, and disturbance”(Sandra L Jacobson, 2005). However, it has also been shown that enhancements of structures can lessen the impacts of highways on bird populations (Sandra L Jacobson, 2005). In fact, during the research for this thesis many birds including herons, hawks, sparrows, and eagles were witnessed flying and/or sitting under structures. Hawks and owls made up a small portion of WVCs, suggesting they are being hit on I-5. Endangered species such as the marbled murrelet (*Brachyramphus marmoratus*) and northern spotted owl (*Strix occidentalis caurina),* may move over and under structures to migrate or seek nesting grounds that can only be accessed by crossing I-5. These endangered birds are not being considered when PAS is being applied. By including birds, WSDOT will not only have a better idea of how permeable these sites are for aerial species, and a better plan for implementing connectivity enhancements for aerial species, WSDOT will have a better understanding of how structures like I-5 are inhibiting or prohibiting movement of key endangered local species. Finally, camera traps could be set up in the exoskeleton of some of these structures to capture aerial species movement under and over bridges and viaducts on I-5.

Creating a PAS Inventory

Currently, most state transportation agencies have limited information related to the value of roadway structures (as wildlife passages) within their state, while WSDOT has begun to develop a robust inventory of both PAS data and camera monitoring data to better understand how bridges and culverts function to provide safe passages for wildlife . PAS, and WSDOT's implementation of it, can help to create a living inventory of structures' attributes that encourage/discourage safe passage for wildlife. This would be an invaluable tool for budgeting, mitigating or advocating for resources intended to improve landscape connectivity. Moreover, PAS surveys should be coupled with statistical analysis of relevant data like location associated WVCs or LCPs. For example, prioritizing locations for assessment by comparing sections of roadways and their probability of creating a WVC. LCPs can be used in the same manner, to help identify areas where the most LCPs converge to prioritize locations for assessment.

Importantly, randomly choosing locations or basing location choices on known species' habitat may not be the most effective way to create an inventory. For the purpose of this thesis, one section of continuous road was chosen, and structures of a maximum size were scrutinized and evaluated. By analyzing large sections of interstate section by section, comparisons can be made that cannot be done without a full sample size of structures within a section. It is then suggested that when creating an inventory, it should be done in 50-100-mile segments of roadway (depending on entire length of road being evaluated). If state agencies, conservation groups, and stakeholders had access to robust PAS databases combined with associated statistical analysis and camera data, more informed decisions, policies, and easement agreements could be made.

Camera Trap Discussion

Black-tailed deer were the most frequently photographed species utilizing both Owl and Lacamas creeks. There were 88 more detected deer crossings at Lacamas than at Owl creek. This may be due to the fact that Lacamas Creek sees less traffic through the structure, while Owl Creek has a continuous stream of semi-truck use most of the time. In addition, Owl Creek showed a much broader range of species' use. There are two factors that may be driving this difference 1) Owl Creek has one camera pointed down at a 45 degree angle, to photograph smaller mammals and birds; 2) the total area of Owl creek is smaller than Lacamas creek, meaning small animals can move through Lacamas creek with less chance of triggering one of the three cameras. Lastly human presence is prevalent at both locations, unsurprisingly all of the species captured are generalists and human adapted. Further monitoring should be done on I-5 at locations where human presence is not as frequent.

Future Research

The structures evaluated for this thesis were chosen by minimum size and relative "naturalness", guaranteeing only structures large enough to possibly pass ungulates were evaluated. This left numerous small culverts <8 ft diameter that have not been evaluated. Many are inundated part of the year or are in extremely urban areas and will not be suitable for wildlife usage. However, there may be many structures that would be attractive to small cover obligates, or small generalists. These structures should be assessed to help create a truly all-encompassing picture of the permeability of I-5 in S.W. Washington for all species. More research is needed into the permeability of I-5 for smaller species within the study area. Furthermore, this thesis has identified 2-5 priority locations in need of a PAS assessment. Most of those locations were simply locations that busy roadways ran under I-5. Nevertheless, there remains some locations that could benefit from a PAS. One such priority 2 structure in need of monitoring and a PAS assessment, is the Hill creek Culvert, between the Toutle and Cowlitz Rivers.

Future Resistance Models: A Criteria for Using PAS

Future research should be conducted to better understand how PAS might be used as a proxy for resistance values used in connectivity modeling. Future research can help to determine; 1) on what type of roads and interstates is PAS an applicable proxy for resistance values? 2) what are the limitations that PAS presents? 3) is PAS a reliable resistance proxy for all species, or just some? and 4) what types of connectivity modeling best compliment the PAS?

PAS may be used to inform future connectivity modeling around the I-5 area, by using the individual PAS guild rankings as a proxy for resistance values. However, due to the complex nature of the interaction between most roads and wildlife, PAS may not be an appropriate proxy for many roads. High speed, high volume, no access Interstates like I-5 present a unique set of circumstances that makes using PAS as a resistance proxy possible. There are two basic criteria that need to be meet for PAS to represent on the ground permeability. First, the interstate must have existing structures large enough to pass focal species presently. If the structure lacks passable openings, then PAS will not be able to inform the permeability or connectivity of those locations. Second, the roadway must be nearly impossible to cross, I-5 is a good candidate because an animal will most likely never cross the road, meaning it cannot become habituated to successful crossings across the road surface. This implies that if an animal uses the road surface it will be hit or turned around, so the only locations an animal could successfully move across the interstate is through existing structures. Combining these two criteria can help to determine whether or not a road's resistance in the landscape can successfully be modeled with PAS.

WVC Statistical Data

This thesis has shown that WVCs at large/natural structures are significantly higher than at locations without large/natural structures. One hypothesis to explain this phenomenon is that wildlife are habituated to these structures and when spooked, lost or seeking daily needs they find themselves on the roadway close to these structures. There are no doubt numerous causes for this relationship, but naturalness and size of structure are clearly one variable affecting where WVCs are occurring on I-5 in S.W. Washington. This represents an opportunity to invest in these locations with the knowledge that fencing in these areas will have the greatest overall impact on decreasing WVCs. Also, it makes some intuitive sense that protecting these mostly "natural" often riparian corridors will increase overall connectivity for native wildlife. More research should be allocated to investigating if this statistical relationship is applicable to all major highways, or just I-5. Furthermore, it has been estimated that less than 50 % of

WVCs get reported, therefore, as technology and techniques improve and more data is collected, these analyses should be duplicated with the latest data.

Finally, the milepost-specific data showed a curvilinear relationship, with WVCs decreasing towards the end points of the study area (Fig. 6.20). This might be explained by the locations of more urbanized areas at both ends of the study area: Longview/Vancouver in the south and Tumwater/Olympia in the north. The peak in the modeled relationship suggests that as one gets further away from these areas, the more probable a WVC. Admittedly, there are two small cities (Chehalis/Centralia) near the middle of the study area, but structures within that area showed extremely high rates of WVCs. One hypothesis may be that there is more "naturalness" and/or there is greater access to at-grade crossings with these areas. Ultimately, it may simply be that the greatest concentrations of large/natural structures are found within the middle of the study area, increasing WVCs.

Chapter 8: Conclusion

I-5 is a high speed, high traffic volume interstate that fragments landscapes between the Cascades and the Pacific Coast, as well as the Olympic Peninsula in S.W. Washington State. Fragmented habitat and associated habitat loss are responsible for numerous negative effects on the ecosystems through which I-5 runs. Furthermore, climate change is occurring faster than previously predicted, with the potential to exacerbate the negative impacts of a fragmented landscape on wildlife. Providing migratory routes and dispersal opportunities for native species will be critical if the current level of biodiversity in Washington State is to be maintained. Removing barriers and increasing access to the landscape is one way to help local wildlife adapt in response to climate change.

Another important issue related to the permeability of I-5 is that of motorists' safety. Wildlife-vehicle collisions cost citizens money, cause injuries, and in some cases may be fatal. Increasing connectivity across I-5 for local wildlife, can potentially decrease the danger of a motorist having a collision or conflict with wildlife. This thesis has provided research and advisement on how to make I-5 more permeable for ungulates and other wildlife, on where and how to lessen WVCs in some areas and suggests the next steps for evaluating I-5 as a barrier to local wildlife.

I-5 may appear to be a homogenous structure that creates a linear barrier to local wildlife. However, I-5 is actually a mosaic of unique underpasses and large bridges suitable for ungulates and other species. Although, structures in and of themselves may be optimal for an animal to cross, local factors such as topography, human use, and habitat quality can prohibit an animal from using any given structure. Regardless, this thesis has assembled an inventory of structures and their PAS rankings that might inform where resources should be allocated for increased wildlife permeability and further research. Lastly, general and specific enhancement recommendations were made for each structure; however, WSDOT biologists and engineers should deeply evaluate the structure data before making final recommendations.

PAS provided a ranking system that was used not only for ranking structures for permeability and potential enhancements but was also used as a proxy for informing GIS landscape resistance layers. The S.W. Coastal Connectivity Mapping Group, the Pacific Northwest Coast Landscape Conservation Design, and the Washington Habitat Connectivity Working Group are currently developing connectivity models for SW Washington. PAS rankings have been utilized as proxies for creating resistance layers that may be included in the final analysis. This approach could change how large interstates are modeled for landscape resistances. In order to utilize PAS as a proxy for resistance, it requires that the road is near impermeable where structures do not exist, limiting the chance of successful wildlife crossings. It also requires a researcher to visit and evaluate each structure prior to a mapping project. Ultimately, using PAS as a proxy for resistance values has the potential to better model the actual resistance presented to wildlife by a structure like I-5.

This thesis used wildlife collision data and carcass data to create an aggregated data set called wildlife-vehicle conflicts (WVCs). WVCs can better inform where to allocate resources to increase safety of motorists and ungulates, and to a lesser extent all wildlife. This data set was used in two different ways; 1) to help prioritize sections of interstate and structures with high numbers of WVCs; 2) to compare areas associated with large structures to areas without an associated large structure. The former was used to prioritize sections of I-5 (gaps) and identify structures associated with above average WVCs. The latter used a normalized value of WVCs per AADT, and it was shown that on average WVCs per 100,000 AADT are higher when within one half mile of either side of a large "natural" structure, than when at a location not associated with such structures. One hypothesis that might explain this is that wildlife maybe habituated to crossing at these locations, as many are riparian corridors or "natural" areas. This could imply that when an animal is spooked or gets lost, it finds its way to the at grade crossings on the interstate. Admittedly, more research needs to be done to explain any type of causation for this finding. What one can conclude is that allocating minor resources on enhancements and research like camera monitoring and wildlife fencing near large structures can help to decrease conflicts and increase safety, while keeping project costs down.

This thesis utilized local ungulate connectivity models to inform where further research should be done. Also, the maps generated for this thesis were used to help validate PAS rankings, and to a lesser extent validate the LCP models themselves with on the ground data. Camera data for this research failed to capture elk or CWTD at Owl Creek, a location all the models pointed to as a possible LCP corridor for all three focal species, and a location that was ranked C (not optimal, in need of enhancement/retrofit) for elk and A (decent structure, may be in need of enhancement retrofit) for deer. Nor did cameras pick up elk or CWTD at the Lacamas Creek location. It doesn't mean these species are not present, as they may have not been captured on cameras in such large structures or may have simply not attempted to cross through the structure. There are many factors and variables on the ground that might influence a LCP path, that is why engaging in more monitoring at locations where LCPs appear to exist can help to better inform future mapping products, research, and resource allocation.

Another goal of this thesis was to locate areas where structures or enhancements should be made to improve permeability. One way this goal was achieved was by creating location prioritizations based on the present LCP maps for each ungulate species within the study area. Current LCPs were then analyzed with the PAS structure data to locate areas that should be evaluated for further ungulate habitat connectivity. The locations identified in this thesis may be suitable places for structure enhancements and areas where new structures could potentially be constructed. Importantly, after the current S.W. Washington coastal connectivity work is completed this analysis may need to be revisited in order to incorporate more species and variables into the overall analysis. Which would then inform enhancements or retrofits that would benefit the greatest number of species with the least amount of financial investment.

Two sections of I-5 were identified that should be further evaluated for the validity and practicality of constructing wildlife only structures (overpasses, wildlife bridges). North of Toutle River, and South of Prairie Creek are both sections of interstate that may be suitable for new wildlife crossing structures. One of the next steps would be to incorporate land-use, cover, and ownership (including protected status), to identify locations that could benefit from further robust research into whether placing new structures would be applicable or even possible.

I-5 will continue to fragment landscapes for some species like elk and may continue to offer passage for species like Columbian black-tailed deer. Regardless, I-5 has the potential for the enhancement of current structures and placements of new ones making I-5 more permeable for all local wildlife. By using WVC data, and connectivity maps (which can be better informed by using PAS rankings as proxies for resistance values), WSDOT can continue to evaluate state roadways in need of wildlife infrastructure, research, and monitoring. Furthermore, understanding where WVCs are likely to occur on I-5 (large underpasses) WSDOT can allocate minimal resources to achieve maximum benefit for motorist and wildlife safety. Ultimately, more research, funds, and monitoring are needed to truly understand I-5's role in landscape connectivity in the region. However, this thesis helps guide precious resources to areas on I-5 where they will be most advantageous, with the goal of improving landscape connectivity, species' ability to adapt to climate change, damaged ecological processes, economic impacts of accidents, and human/wildlife safety.

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Appendices

Appendix A: PAS questions

Appendix B: Survey results for all 33 structures at 20 locations

Appendix C: Ranking Maps for all guilds

Appendix D: WVC raw data compared to WVC per 100,000

Appendix E: Raw Camera Data

Appendix A: PAS Survey Questions

Structure name/stream name:

Collect as many photos of the location as possible while answering the following questions.

Type: MP:

Lat: Long: Date/time:

No. of lanes: Road surface type:

Traffic volume conditions: Vehicles observed:

Parallel infrastructure within 50 yds: Local road topography:

Slop direction: Slope north/west:

Underpass material north/west slope:

Slope south/east: underpass material:

Overpass edge treatment north/west:

Overpass edge treatment south/east:

Structure substrate:

Structure width: Height: Length

Openness ratio:

Environmental conditions during assessment:

Preliminary questions, fatal flaws.

Is structure longer than 300ft?

Is the structure a culvert with a dropped inlet, outlet or drop midway through?

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight?

Is the structure a culvert and you cannot see to the other side?

Is the slope too steep for the target guilds to navigate?

Is there a body of deep or fast-flowing water immediately in front of the structure?

Winter conditions

Are average winter conditions likely to improve or inhibit passage for the target guilds?

Exterior conditions

Inlet

Apron: Wing or headwall: Blocked: Pooling:

Structure in fill slope: slope situated: Veg cover within 25 feet:

Predominate type of veg:

Land use % Rd/hwy: Agriculture: Residential:

Recreation: Logging: Comm/industry: Natural: Other:

Habitat Type % Meadow/grassland: Wetland: Stream/river:

Shrub/steppe: Forest: Developed: Other:

Outlet

Apron: Wing or headwall: Blocked: Pooling:

Structure in fill slope: Slope situated: Veg cover within 25 feet:

Predominate type of veg:

Land use % Rd/hwy: Agriculture: Residential:

Recreation: Logging: Comm/industry:

Natural: Other:

Habitat Type % Meadow/grassland: Wetland: Stream/river:

Shrub/steppe: Forest: Developed: Other:

Inside structure

Is the structure darker than the outside? Clear line of sight?

Skylight in structure? Water flow through?

Current water depth:

Current flow conditions similar to annual average:

Dry pathway during average flows: Pathway substrate:
Is pathway level? Min width of dry pathway:

Evidence of seasonal inundation: Natural substrate through length:

Natural substrate through width: Veg cover or woody debris:

Obstructions: Road or trail:

Sound of passing traffic:

Human use:

Notes:

Fencing and row

Inlet Left

Maintained Vegetation zone width: Barrier type: Barrier height:

Fencing mesh size: Barrier connected:

Barrier reach ground: Fencing condition:

Barrier distance extends: Barrier Break type:

Row barrier same: Row barrier same:

Row barrier type:

Inlet right

Maintained Vegetation zone width: Barrier type: Barrier height:

Fencing mesh size: Barrier connected:

Barrier reach ground: Fencing condition:

Barrier distance extends: Barrier Break type:

Row barrier same: Row barrier same:

Row barrier type:

Outlet left

Maintained Vegetation zone width: Barrier type: Barrier height:

Fencing mesh size: Barrier connected:

Barrier reach ground: Fencing condition:

Barrier distance extends: Barrier Break type:

Row barrier same: Row barrier same:

Row barrier type:

Outlet right

Maintained Vegetation zone width: Barrier type: Barrier height:

Fencing mesh size: Barrier connected:

Barrier reach ground: Fencing condition:

Barrier distance extends: Barrier Break type:

Row barrier same: Row barrier same:

Row barrier type:

Wildlife/human activity

Signs of wildlife use inside the structure:

Signs of wildlife within 30 feet:

Signs of human activity within structures:

Wildlife/Human activity:

Notes:

Field rankings

Cover obligates:

Openness obligates:

Semi-aquatic obligates:

Medium-structure generalists:

Large-structure generalists:

Arboreal Specialists:

Enhancements

Appendix B: Synthesized PAS Results for all Structures

B.1 Location: Scatter Creek

One associated structure

Lat: 46.829667 Long: -122.990956

AADT: 65,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 associated with the location:

12.31

Structure name/stream name: Scatter Creek

Figure B.1 Scatter Creek facing east, interior. Shows utter dryness during summer, which will no doubt have high flow in the winter months, water may go sub-surface after structure.

Type: Structure functional class 3, Single-span Med-Large Underpass (Bridge)

MP: 90.37

Date/time: 7/20/2018 8:41 a.m.

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Very, High (≥105 cars in 15 min)

Parallel infrastructure within 50 yds: None

Local road topography: sloped

Structure Width: ~21.95 meters Height: ~2.8 meters Length: ~36.27 meters

Openness ratio: ~ 1.69

Environmental conditions during assessment: Cool and dry

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Will have extremely high flows of water, stopping most guilds from using it, water appears to then go subsurface beyond the structure making it inadequate for semi-aquatic species even during the high-water period. Area will have more water, in fact the entire structure could be full of water, which may change which species would or would not use this structure.

Inlet exterior conditions

Land use % Rd/hwy: 0 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural:100
Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands: 0 Stream/river: 10

Shrub/steppe: 0 Forest: 60 Developed: 0 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 90

Other: 0

Habitat Type % Meadow/grassland: 40 Wetlands: 0 Stream/river:10

Shrub/steppe: 0 Forest: 50 Developed: 0 Other: 0

Is the structure darker than the outside? Yes, high contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through: Intermittent

Current water depth: 0

Current flow conditions similar to annual average: No, Appears lower

Road or Trail: no

Sound of passing traffic: low rumble

Human use: No obvious use, minor amounts of litter.

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: none

Signs of wildlife within 30 feet: Game trail

Signs of human activity within structures: No Evidence Found

Wildlife/Human activity:

Notes: Scatter Creek presents a ranking challenge as it is not obviously relevant to both resistance layer mapping, and PAS. Because it's usable part of the year and meets minimum size requirements for many species and could technically be retrofitted for better permeability it will receive a C for PAS. Conversely, for resistance values this location is not usable most of the year, and for many species simply too dark, and too small, to be a decent crossing location, so for resistance values it was assigned a F. This is the only location with a duality of guild rankings. In addition, it is a newer structure that could have easily been made more permeable with a wider entrance and raised and dry pathways, unfortunately it was made very small and made to be inundated during the wettest parts of the season

Field rankings

Cover obligates: C

Openness obligates: F

Semi-aquatic obligates: F

Medium-structure generalists: F (for PAS C)

Large-structure generalists: F (for PAS C)

Arboreal Specialists: F

Enhancements: Dig out creek bed and dredge it low enough to create some kind of shelf for a dry pathway or widen structure to allow passage year round. Also, change current rocks on ground for easier use by ungulates. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, dig out inlet for higher ceiling and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000).. Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng, Dole, Sauvajot, Riley, & Valone, 2005). Remove or fill areas that may be seen as predator perches by prey species (Little, Harcour, & Clevenger, 2002).

B.2 Location: Prairie Creek

Two associated structures: Northbound, Southbound

Lat: 46.79745 Long: -123.010008

AADT: 68,000

Jan 1st 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the location: 16.18

Structure name/stream name: Prairie Creek Southbound

Figure B.2 Prairie Creek southbound inlet facing west, interior of structure.

Type: Structure functional class 3, Single-span Large Underpass (Bridge)

MP:87.95

Date/time: 10:05 7/20/2018

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Very High (> 105 cars in 15 min.)

Parallel infrastructure within 50 yds: interstate

Local road topography: sloped

Structure Width: ~21.03 meters Height ~2.44 meters Length: ~19.2 meters

Openness ratio: ~2.67

Environmental conditions during assessment: cool, muddy, overcast.

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Passage looks like water can get very high and close to wall edges during high flows

Inlet exterior conditions

Land use % Rd/hwy: 60 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 40

Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands: 0 Stream/river: 10

Shrub/steppe: 0 Forest: 50 Developed: 0 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 80

Other: 0

Habitat Type % Meadow/grassland: 40 Wetlands: 0 Stream/river: 0

Shrub/steppe: 0 Forest: 50 Developed: 0 Other: 0

Is the structure darker than the outside? low contrast

clear line of sight? yes

Skylight in structure? no

Water flow through? perennial

Current water depth: greater or equal to 3 ft

Current flow conditions similar to annual average? No, appears lower than average

Road or Trail: no

Sound of passing traffic: low rumble

Human use: minimal presence

Notes: Not much human activity presence, loud car noise specifically when semi-trucks pass. Minimal litter with some minor graffiti. Good locations for future camera trapping.

Wildlife/human activity

Signs of wildlife use inside the structure: game trail, tracks, scat

Signs of wildlife within 30 feet: tracks game trail

Notes: Deer & coyote

Signs of human activity within structures: occasional

Wildlife/Human activity: recreation, night use, graffiti

Field rankings

Cover obligates: C

Openness obligates: F

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: F

Enhancements: Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, dig out inlet for higher ceiling and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts

(Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Prairie Creek Northbound

Figure B.3 Prairie Creek Northbound inlet facing west, interior of structure.

Type: Structure functional class 3, Single-span Large Underpass (bridge)

MP: 87.95

Date/time: 7/20/2018   9:39 a.m.

No. of lanes: 3   Road surface type: Paved

Traffic volume conditions: Very high (≥_105_cars per 15 min)

Parallel infrastructure within 50 yds: Interstate

Local road topography: Below-grade (i.e., cut slopes)

Structure Width: ~20.11 meters   Height: ~2.74 meters   Length: ~19.81 meters

Openness ratio: ~2.78

Environmental conditions during assessment: cool, muddy, overcast.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Much higher water flow could make this structure very difficult for many guilds if water level gets too high.

Inlet exterior conditions

Land use % Rd/hwy: 0 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural:100

Other: 0

Habitat Type % Meadow/grassland: 10 Wetlands: 10 Stream/river: 20

Shrub/steppe: 0 Forest: 60 Developed: 0 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 80

Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands:10 Stream/river:10

Shrub/steppe: 0 Forest: 50 Developed: 0 Other: 0

Is the structure darker than the outside? Yes, low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? perennial

Current water depth: < 3 inches

Current flow conditions similar to annual average? lower

Road or Trail: no

Sound of passing traffic: low rumble

Human use:

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Game trail, tracks

Signs of wildlife within 30 feet: Game trail, tracks

Species evidence at time if assessment: Deer and coyote

Signs of human activity within structures: Yes, occasional

Wildlife/Human activity: Minimal human activity, possible recreation

Field rankings

Cover obligates: C

Openness obligates: F

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: F

Enhancements: Excellent location for future monitoring efforts. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, dig out inlet for higher ceiling and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005).

Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.3 Location: Skookumchuck River

Three associated structures: Main, Northbound ramp, Southbound ramp

Lat: 46.720821 Long: -122.976617

AADT: 50,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 42

Structure name/stream name: Skookumchuck Main

Figure B.4 Skookumchuck River main NB/SB interior facing north.

Type: Structure functional class 4, Multi-span Large Underpass (Bridge)

MP: 82.28

Date/time: 7/27/2018 8:36 a.m.

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Morning/ Very High > 105 cars per 15 min

Parallel infrastructure within 50 yds: Interstate, Recreation path, off/on-ramps

Local road topography: Raised roadbed

Structure Width: ~60.96 meters Height: ~7.31 meters Length: ~25.6 meters

Openness ratio: ~ 17.41

Environmental conditions during assessment: Cloudy humid, dry veg, fast flowing water

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Higher water level may be only difference

Inlet exterior conditions

Land use ~% Rd/hwy: 30 Agriculture: 0 Residential:0

Recreation: 20 Logging: 0 Comm/industry: 0

Natural: 50 Other:0

Habitat Type ~% Meadow/grassland:30 Wetlands: 10 Stream/river: 50

Shrub/steppe: 0 Forest: 0 Developed:10 Other:0

Outlet Exterior conditions

Land use ~% Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0

Natural: 70 Other: 0

Habitat Type ~% Meadow/grassland: 40 Wetlands: 10

Stream/river:50 Shrub/steppe: 0 Forest: 0

Developed: 0 Other: 0

Is the structure darker than the outside? There is low contrast

Clear line of sight? yes, clear

Skylight in structure? yes

Water flow through? perennial

Current water depth: > 3

Current flow conditions similar to annual average? No lower than average

Road or Trail: Dirt trail

Sound of passing traffic: Loud and jarring at times

Human use: Hiking, litter, graffiti, bike tracks, camping, possible fishing

Notes: The human presence at this location is likely to keep many human wary species from using this structure.

Wildlife/human activity

Signs of wildlife use inside the structure: Game trail, Live Animal

Signs of wildlife within 30 feet: Game trail, Live Animal

Signs of human activity within structures: Frequent

Human activity: Camping, Occupancy, Dog, Night Use, Recreation

Notes:

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: Specific recommendations for ungulates include possibly using cattle guards on the on-ramp structures in combination with wildlife fencing to keep animals off the Interstate. In addition, this location has many large shrubs and bushes during the summer that lessens the available substrate for animal usage, this could be maintained and widened for easier ungulate access. Because the river is heavily used by humans, this location is not ideal for elk at this time. However, it may be possible to limit human access to one side and heavily fence the other side and make it exclusively for animal passage (although this may not be possible). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans, Patton, & VerCauteren, n.d.). Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Skookumchuck Northbound ramp

Figure B.5 Skookumchuck NB ramp facing east to exterior.

Type: Structure functional class 4, Multi-span Large Underpass (Bridge)

MP: 82.28

Date/time: 7/27/2018 9:03 a.m.

No. of lanes: 1 Road surface type: Paved

Traffic volume conditions: Morning/ High 21-104 cars per 15 min

Parallel infrastructure within 50 yds: Interstate, Recreation path

Local road topography: Raised Roadbed

Structure Width: ~88.09 meters Height: ~7.31 Length: ~12.65

Openness ratio: ~50.83

Environmental conditions during assessment: Cloudy and humid

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Uncertain if anything will change. Water flow may be higher during the winter early spring months.

Inlet exterior

Land use ~% Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry:0 Natural: 80 Other:0

Habitat Type ~ % Meadow/grassland: 30 Wetlands: 20 Stream/river:40

Shrub/steppe: 0 Forest: 10 Developed: 0 Other: 0

Outlet exterior

Land use ~% Rd/hwy: 20 Agriculture :0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 70 Other: 0

Habitat Type ~% Meadow/grassland: 30 Wetlands: 10 Stream/river: 50

Shrub/steppe: 0 Forest: 0 Developed: 10

Other: 0

Is the structure darker than the outside? There is low contrast

Clear line of sight? Yes, clear

Skylight in structure? no

Water flow through? perennial

Current water depth: > 3 feet

Current flow conditions similar to annual average? appears lower than average

Road or Trail: dirt trail

Sound of passing traffic: low rumble

Human use: Hiking, camping, bike riding, fishing, swimming

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Live Animal, Game trail

Signs of wildlife within 30 feet: Game trail, Live Animal

Species: Deer, pigeons, crows

Signs of human activity within structures: Yes Occasional

Human activity: Camping Occupancy, Dog, Night Use, Recreation

Notes: The ramp structures appear to have fewer human artifacts, litter, graffiti etc. They may be newer, or people may not recreate directly under them as they do the main underpass.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: Specific recommendations for ungulates include possibly using cattle guards on the on-ramp structures in combination with wildlife fencing to keep animals off Interstate. In addition, this location has many large shrubs and bushes during the summer that lessens the available substrate for animal usage, this could be maintained and widened for easier ungulate access. Because the river is heavily used by humans, this location is not ideal for elk at this time. However, it may be possible to limit human access to one side and heavily fence the other side and make it exclusively for animal passage (although this may not be possible). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, Watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure (if applicable) (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans from one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Skookumchuck Southbound Ramp

Figure B.6 Skookumchuck SB Ramp exterior facing west

Type: Structure functional class 4, Multi-span Large Underpass (Bridge)

MP: 82.28

Date/time: 7/27/2018

No. of lanes: 1 Road surface type: Paved

Traffic volume conditions: high 21-104 cars per fifteen minutes

Parallel infrastructure within 50 yds: Interstate, Off/on-ramps

Local road topography: raised roadbed

Structure Width: ~84.12 meters Height: ~8.53 meters Length: ~13.41 meters

Openness ratio: ~53.51

Environmental conditions during assessment: Cloudy, humid, dry, dusty, quick flowing water

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Uncertain plenty of room for snow at substrates, possible higher water levels

Inlet exterior conditions

Land use ~% Rd/hwy: 40 Agriculture:0 Residential:0

Recreation: 10 Logging:0 Comm/industry:0

Natural:50 Other:0

Habitat Type~ % Meadow/grassland: 40 Wetlands: 10 Stream/river: 40

Shrub/steppe: 0 Forest: 0 Developed: 10 Other: 0

Outlet exterior conditions

Land use ~% Rd/hwy: 0 Agriculture: 0 Residential:0

Recreation: 20 Logging:0 Comm/industry:0 Natural: 80 Other:0

Habitat Type ~% Meadow/grassland:30 Wetlands:10 Stream/river:40

Shrub/steppe: 0 Forest:0 Developed:0 Other:0

Is the structure darker than the outside? There is low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? perennial

Current water depth: > 3 ft

Current flow conditions similar to annual average? lower

Road or Trail: dirt trail

Sound of passing traffic: Low rumble

Human use: Camping, graffiti, hiking, fishing

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Tracks, Live Animal, Game trail

Signs of wildlife within 30 feet: Live Animal, Game trail

Signs of human activity within structures: Yes Occasional

Human activity: Night Use, Dog, Camping Occupancy, Recreation

Notes: Deer walking through structure at time of assessment, unknown birds flying around

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: Specific recommendations for ungulates include possibly using cattle guards on the on-ramp structures in combination with wildlife fencing to keep animals off Interstate. In addition, this location has many large shrubs and bushes during the summer that lessens the available substrate for animal usage, this could be maintained and widened for easier ungulate access. Because the river is heavily used by humans, this location is not ideal for elk at this time. However, it may be possible to limit human access to one side and heavily fence the other side and make it exclusively for animal passage (although this may not be possible). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Camel-Means, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.4 Location: Salzer Creek

One associated structure

Lat: 46.691193 Long: -122.970009

AADT: 75,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 13.33

Structure name/stream name: Salzer Creek

Figure B.7 Salzer Creek facing south interior.

Type: Structure functional class 3, Multi-span Large Underpass (Bridge)

MP:80.21

Date/time: 7/13/2018 8:56 a.m.

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Very high (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Frontage road, farm road, recreation path

Local road topography: slightly raised

Structure Width: ~40.84 meters Height: ~5.49 meters Length: ~23.77 meters

Openness ratio: ~ 9.43

Environmental conditions during assessment: Sunny, wet clay by creek, dusty north side

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Uncertain, hard to tell if higher water or ice might prohibit use

Inlet exterior conditions

Land use % Rd/hwy: 10 Agriculture: 40 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 50 Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 30 Stream/river: 30

Shrub/steppe: 0 Forest: 0 Developed: 10 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 20 Agriculture: 40 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 40

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 30 Stream/river: 30

Shrub/steppe: 0 Forest: 10 Developed: 0 Other: 0

Is the structure darker than the outside? Yes, low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? perennial

Current water depth: < 3ft

Current flow conditions similar to annual average? l.ower

Road or Trail: dirt road

Sound of passing traffic: low rumble

Human use: Agriculture usage private

Notes: Structure is heavily used by owner of Ag land

Wildlife/human activity

Signs of wildlife use inside the structure: Tracks

Signs of wildlife within 30 feet: Tracks

Species Type: Deer, raccoon tracks

Signs of human activity within structures: Daily

Human activity: Ranching, dog, vehicle and ATV use

Notes: This structure has potential as a crossing location, however it is surrounded by private agricultural land that is constantly being used by humans. This could be a good location for some type of collaboration with the private landowner working the land surrounding this location.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: Notably, the piers that stand within the structure may be too restrictive for elk, a C rank was given with the hope that there may be ways to enhance this structure by increasing lights and possibly decreasing the among of pillars. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, dig out inlet for higher ceiling and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018).. Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans from one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.5 Location: Dillenbaugh Creek

Three associated structures: Main, Southbound ramp, Northbound ramp.

Lat: 46.658778 Long: -122.978049

AADT: 65,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the location: 1.54

Structure name/stream name: Dillenbaugh Creek Main

Figure B.8 Dillenbaugh Creek middle interior.

Type: Structure functional class 3, Multi-span Large Underpass (Bridge)

MP: 77.84

Date/time: 7/13/2018 11:40 a.m.

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Very high (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Interstate, recreation path

Local road topography: Raised roadbed

Structure Width: ~42.06 meters Height: ~3.65 meters Length: ~22.86 meters

Openness ratio: ~ 6.71

Note: Height was taken from substrate, although area was a good 15 feet deeper there was significant evidence that this area is not accessible most of the year.

Environmental conditions during assessment: Sunny, dry.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 80

Other: 0

Habitat Type % Meadow/grassland: 40 Wetlands: 40 Stream/river: 10

Shrub/steppe: 0 Forest: 0 Developed: 10 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 70

Other: 0

Habitat Type % Meadow/grassland: 50 Wetlands: 30 Stream/river: 10

Shrub/steppe: 0 Forest: 0 Developed: 10 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? perennial

Current water depth: < 3 ft

Current flow conditions similar to annual average? lower

Road or Trail: paved trail

Sound of passing traffic: low rumble

Human use: Biking walking recreation

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Tracks, other; Cow remains possible coyote take

Signs of wildlife within 30 feet: Bird nest, live animal, tracks

Specie evidence: Birds and deer

Signs of human activity within structures: Yes, frequent daily

Human activity: Recreation

Notes: Adaptive animals like deer and coyote will be most successful at this crossing, there is a human trail that runs through the structure, as well as a store just off the Northeast corner. Chehalis surrounds this area and urbanization is prevalent.

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: Notably, the piers within the structure may decrease openness enough to preclude elk usage; however, a C rank was given with the hope that some enhancement might be made to make the structure more attractive to elk. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, dig out inlet for higher ceiling and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Dillenbaugh Creek Northbound

Figure B.9 Dillenbaugh Creek NB, interior of structure.

Type: Structure functional class 3, Multi-span Large Underpass (Bridge)

MP: 77.84

Date/time: 7/12/2018 12:14 p.m.

No. of lanes: 1 Road surface type: Paved

Traffic volume conditions: High (21-104 cars per 15 min)

Parallel infrastructure within 50 yds: Interstate off/on ramps

Local road topography: Raised roadbed

Structure Width: ~35.66 meters Height: ~3.66 meters Length: ~7.32 meters

Openness ratio: ~17.83

Note: Height was taken from substrate, although area was a good 15 feet deeper there was significant evidence that this area is not accessible most of the year.

Environmental conditions during assessment: Sunny, dry

Preliminary questions, fatal flaws.

Is structure longer than 300ft: no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight: no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use % Rd/hwy:10 Agriculture: 0 Residential: 0

Recreation:10 Logging: 0 Comm/industry:10 Natural:70

Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands: 30 Stream/river: 20

Shrub/steppe: 0 Forest: 10 Developed: 10 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 30 Stream/river: 20

Shrub/steppe: 0 Forest: 10 Developed: 20 Other: 0

Is the structure darker than the outside? Yes, low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? perennial

Current water depth: < 3 ft

Current flow conditions similar to annual average? lower

Road or Trail: paved trail

Sound of passing traffic: low rumble

Human use: Biking hiking recreation

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Tracks, bird nest, live animal

Signs of wildlife within 30 feet: Live animal

Species evidence: Birds & deer

Signs of human activity within structures: Yes, frequent daily

Human activity: Recreation

Notes: Adaptive animals like deer and coyote will be most successful at this crossing, there is a human trail that runs through the structure, as well as a store just off the Northeast corner. Chehalis surrounds this area and urbanization is prevalent.

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, dig out inlet for higher ceiling and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Dillenbaugh Creek Southbound

Figure B.10 Dillenbaugh Creek SB, pathway leading out of structure.

Type: Structure functional class 3, Multi-span Large Underpass (Bridge)

MP: 77.84

Date/time: 7/13/2018 11:05 a.m.

No. of lanes: 1 Road surface type: Paved

Traffic volume conditions: High (21-104 cars per 15 min)

Parallel infrastructure within 50 yds: Interstate frontage road, off/on ramps, recreation path

Local road topography: Raised roadbed

Structure Width: ~38.4 meters Height: ~3.35 meters Length: ~20.1 meters

Openness ratio: ~6.4

Note: height was taken from substrate, although area was a good 15 feet deeper there was significant evidence that this area is not accessible most of the year.

Environmental conditions during assessment: Sunny, dusty

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use % Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 40 Wetlands: 10 Stream/river: 30

Shrub/steppe: 0 Forest: 0 Developed: 20 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 70 Other: 0

Habitat Type % Meadow/grassland: 40 Wetlands: 30 Stream/river:20

Shrub/steppe: 0 Forest: 0 Developed: 10 Other: 0

Is the structure darker than the outside? Yes, low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? perennial

Current water depth: < 3 ft

Current flow conditions similar to annual average? lower

Road or Trail: paved trail

Sound of passing traffic low rumble

Human use: Walking biking, recreation

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Tracks

Signs of wildlife within 30 feet: Other; Snake skin shed

Signs of human activity within structures: Yes, frequent daily

Human activity: Recreation

Notes: Adaptive animals like deer and coyote will be most successful at this crossing, there is a human trail that runs through the structure, as well as a store just off the Northeast corner. Chehalis surrounds this area and urbanization is prevalent.

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, dig out inlet for higher ceiling and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing. Could add signage for drivers making them aware of possible Wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.6 Location: I-5 Over Railroad A

One associated structure

Lat: 46.65485 Long: -122.975143

AADT: 72,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the

location: 1.38

Structure name/stream name: I-5 Over railroad A

Figure B.11 Railroad crossing structure, facing east.

Type: Structure functional class 4, Multi-span bridge/viaduct

MP: 77.51

Date/time: 8/3/2018 9:18 a.m.

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Very high (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Railroad, frontage road

Local road topography: Raised roadbed

Structure Width: ~49.38meters Height: ~8.23 meters Length: ~24.69 meters

Openness ratio: ~ 16.46

Environmental conditions during assessment: cool, muddy, overcast.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 10

Recreation: 0 Logging: 0 Comm/industry: 10 Natural: 60

Other: 10

Habitat Type % Meadow/grassland: 50 Wetlands: 10 Stream/river: 0

Shrub/steppe: 0 Forest: 30 Developed: 10 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 60 Natural: 20
Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands: 0 Stream/river: 0

Shrub/steppe: 0 Forest: 0 Developed: 70 Other: 0

Is the structure darker than the outside? Yes, low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? no

Current water depth: N/A

Current flow conditions similar to annual average? N/A

Road or Trail: railroad

Sound of passing traffic: unobtrusive

Human use: Railroad dirt road recreation and commercial

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Uncertain

Signs of wildlife within 30 feet: Uncertain

Signs of human activity within structures: Yes, frequent daily

Human activity: Recreation vehicle, ATV use , occupancy

Notes: There is low number of WVCs at this location, this is most likely due to the fact the freeway surrounding the area is lifted, and access to the roadway is very difficult to access. Another consideration for this location is that the east side is very natural with good habitat, while the west side backs up the veteran's war museum and leads into private land, and then into a suburban area. That beings said, because of the stability of the ownership of such a property, it may be valuable to considered collaborating with the museum to create a more wildlife friendly passage.

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: F

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: F

Enhancements: Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.7 Location: Newaukum River

Two associated structures: Northbound, Southbound

Lat: 46.598194 Long: -122.901884

AADT: 58,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 37.93

Structure name/stream name: Newaukum River Northbound

Figure B.12 Newaukum River NB, from interior facing west, SB in background

Type: Structure functional class 4, Multi-span Large Underpass (Bridge)

MP: 72.24

Date/time: 8/3/2018 11:11 a.m.

No. of lanes: 2 Road surface type: Paved

Traffic volume conditions: Very high (> 105 cars per 15 mi)

Parallel infrastructure within 50 yds: Interstate

Local road topography: Raised Roadbed

Structure Width: ~81.07 meters Height: ~8.23 meters Length: ~9.75 meters

Openness ratio: ~ 68.43

Environmental conditions during assessment: Damp, cloudy

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Inhibit Uncertain, Snow or ice could make some sections slippery and water flow may be higher

Inlet Exterior conditions

Land use ~% Rd/hwy: 0 Agriculture: 0 Residential:0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 100 Other: 0

Habitat Type ~% Meadow/grassland:20 Wetlands: 20 Stream/river: 40

Shrub/steppe: 0 Forest: 20 Developed: 0 Other: 0

Outlet exterior conditions

Land use ~% Rd/hwy: 20 Agriculture:10 Residential: 0

Recreation: 0 Logging:0 Comm/industry:0

Natural: 70 Other: 0

Habitat Type ~% Meadow/grassland:10 Wetlands: 10 Stream/river:40

Shrub/steppe: 0 Forest: 30 Developed: 10 Other:0

Is the structure darker than the outside: There is low contrast?

Clear line of sight? Yes, clear

Skylight in structure? no

Water flow through? perennial

Current water depth: < 3 ft

Current flow conditions similar to annual average: appears lower

Road or Trail: None

Sound of passing traffic: Low Rumble

Human use: Occupancy, litter

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Game trail

Signs of wildlife within 30 feet: uncertain

Signs of human activity within structures: Occasional

Wildlife/Human activity: Camping Occupancy, Night Use, Recreation

Notes: There were a lot of signs of constant human presence here including mounds of litter.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: General enhancements/recommendations can be used at this location and would benefit most guilds including ungulates. The structures have compartmentalized sections that are cutoff from each other, and the different sides of the river are very different, it may be wise to limit human usage to only the northside of this area. This location also has piles of trash that should be cleaned up to be more attractive to wildlife. Also, much of the ROW fencing has been damaged or cut for easy human access, these fences should be kept up to date. Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Camel-Means, et al., 2016; McCollister & van Manen, 2010). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006) Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Newaukum Southbound

Figure B.13 Newaukum river SB inlet side, facing west from northside.

Type: Structure functional class 4, Multi-span Large Underpass (Bridge)

MP: 72.24

Date/time: 8/3/2018 8:45 a.m.

No. of lanes: 2 Road surface type: Paved

Traffic volume conditions: Very high > 105 cars per 15 min

Parallel infrastructure within 50 yds: Interstate

Local road topography: Raised Roadbed

Structure Width: ~97.84 meters Height: ~7.31 meters Length: ~11.89 meters

Openness ratio: ~60.15

Environmental conditions during assessment: Cloudy, damp

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Uncertain, possible higher water flows

Inlet exterior conditions

Land use ~% Rd/hwy: 20 Agriculture:0 Residential: 0

Recreation: 0 Logging:0 Comm/industry: 0 Natural: 80 Other: 0

Habitat Type ~% Meadow/grassland: 10 Wetlands: 20 Stream/river: 30

Shrub/steppe: 0 Forest: 40 Developed: 0 Other: 0

Outlet exterior conditions

Land use ~% Rd/hwy: 0 Agriculture: 20 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0

Natural: 80 Other: 0

Habitat Type ~% Meadow/grassland: 20 Wetlands: 0 Stream/river: 40

Shrub/steppe: 0 Forest: 40 Developed: 0 Other: 0

Is the structure darker than the outside? There is low contrast.

Clear line of sight? Yes, clear

Skylight in structure? no

Water flow through? perennial

Current water depth: > 3ft

Current flow conditions similar to annual average? lower than average

Road or Trail: No

Sound of passing traffic: Low Rumble

Human use: Camping Occupancy, Night Use, Recreation

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Road kill

Signs of wildlife within 30 feet: Uncertain

Signs of human activity within structures: Uncertain

Human activity: Yes - Occasional

Notes: There were many signs of constant human presence here including a lot of litter. Deer and coyote carcasses found stacked in pile at southwest abutment under the structure

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: This structure has unique landscape feature on the southwest bank, there is a large dirt wall making passage difficult. It appears to be a privately-owned raised area that flows into Ag land. It may be possible to build a pathway or ramp for passage, which would require collaboration with property owners. In addition, the structures have compartmentalized sections that are cutoff from each other, and the different sides of the river are very different, it may be wise to limit human usage to only the northside of this area. This area is also packed with human trash and should be cleaned out. Also, much of the ROW fencing has been damaged or cut for easy human access, these fences should be kept up to date. Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Camel-Means, et al., 2016; McCollister & van Manen, 2010). General enhancements/recommendations can be used at this location and would benefit most guilds including ungulates. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006) Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003;

Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.8 Location: Lacamas Creek

One associated structure   Camera monitored location

Lat: 46.445517   Long: -122.887765

AADT: 43,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the

location: 16.28

Structure name/stream name: Lacamas Creek

Figure B.14 Lacamas Creek, exterior of inlet facing east.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 61.31

Date/time: 6/13/20   8:36 a.m.

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Very high (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Frontage road

Local road topography: Raised roadbed

Structure Width: ~55.77meters Height: ~13.72 meters Length: ~ 27.28 meters

Openness ratio: ~ 28.05

Environmental conditions during assessment: Light rain. 55 degrees cool, muddy, overcast.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use % Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 70

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 0 Stream/river: 20

Shrub/steppe: 0 Forest: 30 Developed:30 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 70

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 0 Stream/river: 20

Shrub/steppe: 0 Forest:30 Developed: 30 Other: 0

Is the structure darker than the outside? Yes, low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? perennial

Current water depth: < 3 ft

Current flow conditions similar to annual average? lower

Road or Trail: paved road

Sound of passing traffic: low rumble

Human use: paved road had 3 cars in an hour move through it. Some recreation, like fishing

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Game trail, tracks,

Signs of wildlife within 30 feet: Live animal

Species: Live black-tailed deer

Signs of human activity within structures: Yes, Occasional

Human activity: Other, recreation, graffiti, litter

Notes: This location has a paved road going through the northside of the structure, and a large dirt pathway on its southern side. The traffic volume on the road under the freeway is extremely low and camera evidence shows that ungulates use both sides. However, the wildlife tends to move up the creek bed, or move along the southern side.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Install a sound barrier, prohibit human use, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals. Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.9 Location: Cowlitz River

One associated structure

Lat:46.41289 Long: -122.889966

AADT: 45,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 24.44

Structure name/stream name: Cowlitz River

Figure B.15 Cowlitz river Inlet south of river, interior.

Type: Structure functional class 4, Multi-span Viaduct

MP: 59.06

Date/time: 8/10/2018

No. of lanes: 4 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Frontage road

Local road topography: Raised roadbed

Structure Width: ~212.1 meters Height: ~13.75 meters Length: ~22.86 meters

Openness ratio: ~127.58

Environmental conditions during assessment: Dry, calm, overcast.

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: not applicable

Inlet exterior conditions

Land use ~% Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 20 Logging:0 Comm/industry:0 Natural: 70
Other: 0

Habitat Type ~% Meadow/grassland: 10 Wetlands: 0 Stream/river: 60

Shrub/steppe: 0 Forest: 30 Developed: 0 Other: 0

Outlet exterior conditions

Land use ~% Rd/hwy: 10 Agriculture: 10 Residential:10

Recreation: 30 Logging:0 Comm/industry:0

Natural: 40 Other: 0

Habitat Type ~% Meadow/grassland:10 Wetlands: 0 Stream/river:50

Shrub/steppe: 0 Forest: 30 Developed:10 Other: 0

Is the structure darker than the outside? There is low Contrast

Clear line of sight? yes

Skylight in structure? yes

Water flow through? perennial

Current water depth: > 3 ft

Current flow conditions similar to annual average: lower than average

Road or Trail: paved road northside

Sound of passing traffic: loud and jarring

Human use: Fishing, camping, boating, swimming, ATV use

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Game trail, Tracks, Bird nest

Signs of wildlife within 30 feet: tracks

Species: Deer

Signs of human activity within structures: frequent

Human activity: Camping Occupancy, Dog, Night Use, Recreation, Vehicle ATV use

Notes: This location was packed with recreation, hiking, boating, camping, picnic, angling and more. This area is dominated by human presence during much of the warmer months

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: A very large and open viaduct, allows for plenty of light and allows for ecological processes to flow beneath. However, the intense human use at this location may keep all but the most adaptable and human acclimated species away. Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Camel-Means, et al., 2016; McCollister & van Manen, 2010). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006) Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.10 Location: Toutle River

One associated structure

Lat: 46.310436 Long: -122.913783

AADT: 46,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 13.04

Structure name/stream name: Toutle River

Figure B.16 Toutle river NB inlet facing east.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 51.71

Date/time: 7/6/2018 11:25

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Active Bridge, roads

Local road topography: Raised roadbed

Structure Width: ~93.27 Meters Height: ~12.49 meters Length: ~34.21 meters

Openness ratio: ~34.05

Environmental conditions during assessment: Sunny, dry,

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 80

Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 10 Developed:10 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 70

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 0 Stream/river: 60

Shrub/steppe: 0 Forest: 10 Developed: 10 Other: 0

Is the structure darker than the outside? low contrast

Clear line of sight? yes

Skylight in structure? yes

Water flow through? perennial

Current water depth: > 3ft

Current flow conditions similar to annual average: lower

Road or Trail: dirt road

Sound of passing traffic: Loud and jarring

Human use: Graffiti, fishing, all types of recreation

Notes: Location is heavily frequented by humans, litter, graffiti and fishing gear were found when location was visited.

Wildlife/human activity

Signs of wildlife use inside the structure. Tracks, bird nest, game trail

Signs of wildlife within 30 feet? Game trail

Signs of human activity within structures: Yes, occasional

Human activity: Dogs, camping, occupancy, recreation, night use, vehicle, ATV use.

Species evidence: Deer, swallows

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: This location could benefit greatly from cleanup and restoration. Furthermore, camera monitoring should be initiated, as this location is near a convergence of LCPs, and high relatively high rates of WVCs. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005).

Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.11 Location: Kalama River

Two associated structures: Northbound, Southbound

Lat: 46.034846 Long: -122.857012

AADT: 71,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 22.54

Structure name/stream name: Kalama River Northbound

Figure B.17 Kalama River NB interior, facing south

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 31.82

Date/time: 8/13/2018 10:35 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Interstate, Frontage road, Recreation path

Local road topography: Raised Roadbed

Structure Width: ~121.62 meters Height: ~6.1 meters Length: ~14.63

Openness ratio: ~50.71

Environmental conditions during assessment: Cloudy, dry, warm, slow river flow, very high veg.

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use ~% Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 20 Logging: 0 Comm/industry: 0

Natural: 60 Other: 0

Habitat Type ~% Meadow/grassland:0 Wetlands: 0 Stream/river: 40

Shrub/steppe: 0 Forest: 40 Developed:20 Other: 0

Outlet exterior conditions

Land use~ % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 20 Logging: 0 Comm/industry: 0

Natural: 60 Other: 0

Habitat Type ~% Meadow/grassland: 10 Wetlands: 0 Stream/river:40

Shrub/steppe: 0 Forest: 40 Developed: 10 Other: 0

Is the structure darker than the outside? There is low Contrast

Clear line of sight? Yes, clear

Skylight in structure? no

Water flow through? perennial

Current water depth: > 3ft

Current flow conditions similar to annual average:

Road or Trail: Dirt road and paved roads

Sound of passing traffic: unobtrusive

Human use: Atvs, dirt bike, bicycles, off-roading

Notes: Lots of human activity, fishing, boating, hiking etc...

Wildlife/human activity

Signs of wildlife use inside the structure: Scat, Game trail, Tracks, Live Animal

Signs of wildlife within 30 feet: Game trail, Tracks, Live Animal

Species: Deer, lizard, heron, dead fish

Signs of human activity within structures: Yes, Frequent Daily

Human activity: Camping Occupancy, Dog, Night Use, Recreation, Vehicle, ATV us

Notes: This location was packed with recreation, hiking, boating, camping, picnic, angling and more. This area is dominated by human presence during much of the warmer months, the overall rankings are low simply due to the human presence, and there is another road crossing within 25 yards of this structure, slightly smaller.

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: F

Enhancements: The nearby camp site is the main source of the intense recreation at this location, I may be that the only way to make this structure more inviting to species like elk, would be suspend the activities at this particular camp ground. Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Camel-Means, et al., 2016; McCollister & van Manen, 2010). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006) Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Kalama Southbound

Figure B.18 Kalama River, interior facing north.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 31.82

Date/time: 8/31/2018 9:52 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Railroad, Recreation path, Interstate, Frontage road

Local road topography: Raised Roadbed

Structure Width: ~121.62 meters Height: ~6.1 meters Length: ~14.63

Openness ratio: ~50.71

Environmental conditions during assessment: Cloudy, dry, slow river flow, high vegetation.

Preliminary questions, fatal flaws:

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not applicable

Inlet exterior conditions

Land use ~% Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 20 Logging: 0 Comm/industry: 0

Natural: 50 Other: 0

Habitat Type~ % Meadow/grassland: 0 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 30 Developed:20 Other: 0

Outlet exterior conditions

Land use ~% Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 20 Logging: 0 Comm/industry: 0

Natural: 50 Other: 0

Habitat Type~ % Meadow/grassland: 10 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 30 Developed: 10 Other: 0

Is the structure darker than the outside? There is low contrast

Clear line of sight? Yes, Clear

Skylight in structure: No

Water flow through? perennial

Current water depth: > 3ft

Current flow conditions similar to annual average: lower

Road or Trail: Dirt road

Sound of passing traffic: Unobtrusive

Human use: Atv use, Off-road bikes, bicycles, Human waste and litter are everywhere.

Wildlife/human activity

Signs of wildlife use inside the structure: Scat, tracks, live Animal

Signs of wildlife within 30 feet: Game trail, Tracks

Species: Deer, lizard, birds

Signs of human activity within structures: Yes, Frequent Daily

Human activity: Camping Occupancy, Dog, Night Use, Recreation, Vehicle ATV use

Notes: This location was packed with recreation, hiking, boating, camping, picnic, angling and more. This area is dominated by human presence during much of the warmer months, the overall rankings are low simply due to the human presence

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: F

Enhancements: The nearby camp site is the main source of the intense recreation at this location, I may be that the only way to make this structure more inviting to species like elk, would be suspend the activities at this particular camp ground. Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Camel-Means, et al., 2016; McCollister & van Manen, 2010). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006) Install a sound barrier, widen substrates for larger dry pathways, and remove highway lighting near structure

(Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Remove highway lighting near structure. Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.12 Location: Coweeman River @185

Two associated structures: Northbound, Southbound

Lat: 46.136975 Long: -122.89803

AADT: 56,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the location: 14.29

Structure name/stream name: Coweeman River@185 Northbound

Figure B.19 Coweeman River @ 185 Southside of structure, facing east, frontage road in background.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 39.35

Date/time: 6/22/2018 10:29 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Frontage road, Interstate

Local road topography: Raised roadbed

Structure Width: ~143.56 meters Height: ~9.14 meters Length: ~20.11 meters

Openness ratio: ~ 65.25

Environmental conditions during assessment: Sunny

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: may inhibit, higher water level possible snow pack

Inlet exterior conditions

Land use % Rd/hwy: 30 Agriculture: 0 Residential: 10

Recreation: 0 Logging: 0 Comm/industry: 0 Natural:60

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 20 Developed: 10

Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 40 Agriculture: 0 Residential: 40

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 20

Other: 0

Habitat Type % Meadow/grassland:20 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 20 Developed: 10 Other: 0

Is the structure darker than the outside? low contrast

Clear line of sight? yes

Skylight in structure? yes

Water flow through? perennial

Current water depth: > 3 ft

Current flow conditions similar to annual average: lower

Road or Trail: paved road

Sound of passing traffic: low rumble

Human use: Cars, graffiti, trash, recreation

Wildlife/human activity

Signs of wildlife use inside the structure: Bird nest

Signs of wildlife within 30 feet: Road kill

Species: Deer, birds

Signs of human activity within structures: Yes, frequent daily

Human activity: Night use, recreation, vehicle, ATV, dog

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: It might be beneficial to wildlife fence the road that crosses under the structure, to keep animals closer to the river and away from access to the freeway, while at the same time, making the roadway that crosses under the structure safer. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Coweeman River @ 185 Southbound

Figure B.20 Coweeman River @185 SB, facing north, taken on road that crosses through the structure.

Type: Structure functional class 4, Multi-span Viaduct

MP: 39.35

Date/time: 6/22/2018 9:52

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Frontage road, Interstate

Local road topography: Raised roadbed

Structure Width: ~143.56 meters Height: ~9.14meters Length: ~20.11 meters

Openness ratio: ~65.25

Environmental conditions during assessment: Sunny

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: inhibit, Higher water flow, possible issues with snow accumulation

Inlet exterior condition

Land use % Rd/hwy: 20 Agriculture: 0 Residential:40

Recreation: 0 Logging: 0 Comm/industry:20 Natural:20

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 20 Developed:10 Other: 0

Outlet exterior conditions

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 40

Recreation: 0 Logging: 0 Comm/industry: 0 Natural: 40

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 0 Stream/river:50

Shrub/steppe: 0 Forest: 20 Developed: 10 Other: 0

Is the structure darker than the outside? low contrast

Clear line of sight? yes

Skylight in structure: no

Water flow through? perennial

Current water depth: > 3 ft

Current flow conditions similar to annual average: lower

Road or Trail: paved road

Sound of passing traffic: low rumble

Human use: Roads, graffiti, litter,

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Bird nest, game trail, roadkill

Signs of wildlife within 30 feet: Bird nest

Species: Deer, pigeon

Signs of human activity within structures: Yes, frequent daily

Human activity: Night use, dog, recreation vehicle, ATV use

Species: Deer, pigeon

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: It might be beneficial to wildlife fence the road that crosses under the structure, to keep animals closer to the river and away from access to the freeway, while at the same time, making the roadway that crosses under the structure safer. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010) . Create a dry shelf or lip in structure. Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.13 Location: Coweeman River @ 165

Two associated structures: Northbound, Southbound

Lat: 46.131826 Long: -122.898864

AADT: 56,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 12.5

Structure name/stream name: Coweeman River @ 165 Northbound

Figure B.21 Coweeman River @ 165 NB, facing north, taken from Southbank.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 38.99

Date/time: 8/17/2018 9:54 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate

Local road topography: Raised roadbed

Structure Width: ~94.1 meters Height: ~7.92 meters Length: ~18.29 meters

Openness ratio: ~ 40.78

Environmental conditions during assessment: cool, muddy, overcast.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Higher water level, possible icy rocks could create difficult movement for some guilds.

Inlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 10

Recreation: 10 Logging: 0 Comm/industry: 20 Natural: 50

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 10 Stream/river: 40

Shrub/steppe: 0 Forest: 10 Developed: 20 Other: 0

Outlet

Land use % Rd/hwy: 20 Agriculture: 10 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 10 Stream/river: 50

Shrub/steppe: 0 Forest: 0 Developed: 20 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? yes

Skylight in structure? no

Water flow through? Perennial

Current water depth: ≥3_ft€ •

Current flow conditions similar to annual average: No, appears lower

Road or Trail: Paved trail

Sound of passing traffic: Low rumble

Human use: Camping, hiking, graffiti

Notes: Unable to access the northern bank due to extreme dense and thick blackberries, and some fencing

Wildlife/human activity

Signs of wildlife use inside the structure: Bird nest, game trail, tracks

Signs of wildlife within 30 feet: Uncertain

Species seen: Dog, pigeon

Signs of human activity within structures: Yes, frequent daily

Wildlife/Human activity: Camping, occupancy, dog, night use, recreation

Notes: The dirt/paved pathway is clearly frequented by humans and pets.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: C

Enhancements: The northside of the structure is mostly overgrown with shrubs and filled with riprap and blackberries, removing vegetation could create a wider dirt path, leaving enough vegetation to create cover for cover obligate guild member. The southside has more than enough room, but it should be dug out in order to create a higher ceiling. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Coweeman River @ 165 Southbound

Figure B.22 Coweeman River @ 165 SB, from Southbank facing north, interior.

Type: Structure functional class 4, multi-span Viaduct (Bridge)

MP: 39

Date/time: 8/17/2018 9:25 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate

Local road topography: Raised roadbed

Structure Width: ~76.8 meters Height: ~ 9.45 meters Length: ~ 15.54 meters

Openness ratio: ~ 46.7

Environmental conditions during assessment: cool, muddy, overcast, smoky, Calm River, large veg

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Higher water slippery rocks possible snow

Inlet

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 20 Natural:50

Other: 0

Habitat Type % Meadow/grassland:10 Wetlands: 10 Stream/river: 60

Shrub/steppe: 0 Forest: 0 Developed: 20 Other: 0

Outlet

Land use % Rd/hwy: 10 Agriculture: 10 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 70

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 10 Stream/river: 40

Shrub/steppe: 0 Forest: 20 Developed: 10 Other: 0

Is the structure darker than the outside? Low Contrast

Clear line of sight? Yes, clear

Skylight in structure? no

Water flow through? Perennial

Current water depth: ≥3_ft

Current flow conditions similar to annual average? No, appears lower

Road or Trail: Paved trail

Sound of passing traffic: Low rumble

Human use: Camping, hiking, walking, jogging

Notes: Unable to access the northern bank due to extreme dense and thick blackberries, and some fencing

Wildlife/human activity

Signs of wildlife use inside the structure: Bird nest, game trail, tracks

Signs of wildlife within 30 feet: Uncertain

Species seen: Pigeon

Signs of human activity within structures: Yes - Frequent/Daily

Wildlife/Human activity: Night use, camping, occupancy, dog, recreation

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: C

Enhancements: The northside of the structure is mostly overgrown with shrubs and filled with riprap and blackberries, removing vegetation could create a wider dirt path, leaving enough vegetation to create cover for cover obligate guild member. The south side has more than enough room, but it should be dug out in order to create a higher ceiling. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, separate human trails, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.14 Location: Dike Access

One associated structure

Lat: 46.13103 Long: -122.899142

AADT: 56,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the location: 10.71

Structure name/stream name: Dike Access Tunnel

Figure B.23 Dike Access tunnel facing east.

Type: Structure functional class 3, Concrete Box-culvert

MP: 38.88

Date/time: 8/17/2018 10:32 am

No. of lanes: 6 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstates

Local road topography: Raised roadbed

Structure Width: ~4.27 meters Height: ~4.27 meters Length: ~73.15 meters

Openness ratio: ~0.25

Environmental conditions during assessment: Cloudy, high veg, warm, dry

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Not Applicable

Inlet

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 10

Recreation: 10 Logging: 0 Comm/industry: 0 Natural:60

Other: 0

Habitat Type % Meadow/grassland: 50 Wetlands: 0 Stream/river: 30

Shrub/steppe: 0 Forest: 0 Developed: 20 Other: 0

Outlet

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 20 Logging: 0 Comm/industry: 0 Natural: 30

Other: 0

Habitat Type % Meadow/grassland: 50 Wetlands: 0 Stream/river: 0

Shrub/steppe: 0 Forest: 10 Developed: 40 Other: 0

Is the structure darker than the outside? High contrast

Clear line of sight? Yes, clear

Skylight in structure? N/A

Water flow through? N/A

Current water depth? N/A

Current flow conditions similar to annual average? N/A

Road or Trail: Paved trail

Sound of passing traffic: Unobtrusive

Human use: Hiking, recreation, vehicle use, graffiti, litter, jogging.

Wildlife/human activity

Signs of wildlife use inside the structure: Uncertain

Signs of wildlife within 30 feet: Scat

Signs of human activity within structures: Yes - Frequent/Daily

Wildlife/Human activity: Dog,

camping occupancy, recreation, night use, vehicle ATV use

Notes: This location was almost omitted because it had no natural path through it, however it is surrounded by a river, and "natural" grass areas, making it worth including in the analysis. This location is nearly an island and is very difficult to access as the river cuts off one side. However, due to its location it maybe trapping animals and turning them around when they interact with it. Human presence is obvious and frequent.

Field rankings

Cover obligates: C

Openness obligates: F

Semi-aquatic obligates: F

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: F

Enhancements: This structure has a small entrance and is extremely dark and very long, although it is possible some species may use this tunnel in an emergency, it is overall unlikely to be passing very many animals, especially those in the large generalist and openness guilds. . Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.15 Location: Coweeman River @ 135

Two associated structures: Northbound, Southbound

Lat: 46.124719 Long: -122.892008

AADT: 56,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the

location: 12.5

Structure name/stream name: Coweeman River @ 135 Northbound

Figure B.24 Coweeman River @ 135 NB, inlet facing south, exterior of structure.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 38.35

Date/time: 8/17/2018 11:28 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate

Local road topography: Raised roadbed

Structure Width: ~149.35 meters Height: ~8.23 meters Length: ~ 30.18 meters

Openness ratio: ~40.73

Environmental conditions during assessment: Dry, sunny, high veg, calm water

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate
? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Higher faster water

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 20

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 10 Wetlands:10 Stream/river: 50

Shrub/steppe: 0 Forest: 20 Developed: 10 Other: 0

Outlet

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 10 Stream/river: 60

Shrub/steppe: 0 Forest: 0 Developed: 10 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: ≥3_ft

Current flow conditions similar to annual average? No, appears lower

Road or Trail: Paved trail

Sound of passing traffic: Low rumble

Human use: Hiking, boating, fishing.

Wildlife/human activity

Signs of wildlife use inside the structure: Bird nest, game trail, live animal, scat

Signs of wildlife within 30 feet: Bird nest game trail

Species: Barn swallow

Signs of human activity within structures: Yes - Frequent/Daily

Wildlife/Human activity:

Notes: There is private land on the southside making human access difficult. There is lots of water recreation during the summer months. There are also trails that lead into the structure, mostly dirt and gravel trails, but they appear to be heavily used.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: Could dig out substrate and create a more open and attractive structure. Make south bank more attractive by removing vegetation and creating a more accessible substrate. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000).. Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Coweeman River @ 135 Southbound

Figure B.25 Coweeman River @ 135 SB, outlet exterior facing southwest. Picture taken from near same altitude as the freeway.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 38.35

Date/time: 11:07 11:07 am

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate

Local road topography: Raised roadbed

Structure Width: ~149.35 meters Height: ~8.23 meters Length: ~30.18 meters

Openness ratio: ~ 40.73

Environmental conditions during assessment: Warm, dry, Smokey, sunny, high veg, calm water

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Snow/ice could make for slippery rocks, also higher faster water

Inlet

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 10

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 20 Wetlands: 10 Stream/river: 40

Shrub/steppe: 0 Forest: 20 Developed: 10 Other: 0

Outlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 10

Recreation: 10 Logging: 0 Comm/industry: 10 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 10 Wetlands: 20 Stream/river: 50

Shrub/steppe: 0 Forest: 10 Developed:10 Other: 0

Is the structure darker than the outside? Low Contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: ≥3_ft

Current flow conditions similar to annual average? No, appears lower

Road or Trail: Paved trail

Sound of passing traffic: Low rumble

Human use: Hiking, boating, fishing, general recreation

Notes: Unable to access southern bank due to private property and in accessible areas cutoff by vegetation

Wildlife/human activity

Signs of wildlife use inside the structure: Live animal, game trail, bird nest, scat

Signs of wildlife within 30 feet: Game trail, live animal

Species: Frog? Birds.

Signs of human activity within structures: Yes - Frequent/Daily

Wildlife/Human activity:

Camping, occupancy, dog, night use, recreation, vehicle ATV use

Notes: There is private land on the southside making human access difficult but may provide an opportunity for private landowner collaboration There is lots of water recreation during the summer months. There are also trails that lead into the structure, mostly dirt and gravel trails, but they appear to be heavily used.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: Could dig out substrate and create a more open and attractive structure. Remove some of the heavy vegetation and create a dry substrate on Southbank of river. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gap in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.16 Location: Owl Creek

Two associated structures: Northbound, Southbound Camera monitored

Lat: 45.09109 Long: -122.8707

AADT: 71,000

Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 14.08

Structure name/stream name: Owl Creek Northbound

Figure B.26 Owl Creek NB, facing south, interior, picture taken from northside gravel road.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 35.81

Date/time: 7/6/2018 8:55 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate, roads

Local road topography: Raised roadbed

Structure Width: ~34.75 meters Height: ~ 5.49 meters Length: ~ 14.63 meters

Openness ratio: ~ 13.04

Environmental conditions during assessment: Sunny light clouds.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Creek may have more water but would not stop animals from using it

Inlet

Land use %   Rd/hwy: 20   Agriculture: 0   Residential: 0

Recreation: 0   Logging: 0   Comm/industry: 10   Natural: 70

Other: 0

Habitat Type %   Meadow/grassland: 20   Wetlands: 10   Stream/river: 40

Shrub/steppe: 0   Forest: 10   Developed: 20   Other: 0

Outlet

Land use %   Rd/hwy: 20   Agriculture: 0   Residential: 0

Recreation: 0   Logging: 0   Comm/industry: 10   Natural: 70

Other: 0

Habitat Type %   Meadow/grassland: 20   Wetlands: 10   Stream/river: 40

Shrub/steppe: 0   Forest: 10   Developed: 20   Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: <3_ft

Current flow conditions similar to annual average: No, appears lower

Road or Trail: Dirt road

Sound of passing traffic: Low rumble from above, semis moving through structure can be extremely loud.

Human use: Semi trucks Passing through, walking, jogging, berry picking

Wildlife/human activity

Signs of wildlife use inside the structure: Game trail, bird nest, tracks, deer tracks

Signs of wildlife within 30 feet: Tracks, scat

Signs of human activity within structures: Yes, frequent daily Graffiti, litter, foot prints

Wildlife/Human activity: Dog, night use, other

Notes: The dirt road is a primary artery for commercial trucking, and during certain days and times there are trucks passing through constantly. Despite this many adaptive species still use this structure.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: Limiting or removing commercial use could be beneficial but it may require stopping commercial traffic or removing the road altogether. This location could use some water way restoration, and possible channel restoration as well, this could make it far more attractive to semi-aquatic and possibly even aquatic species. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Owl Creek Southbound

Figure B.27 Owl Creek SB, outlet entrance, facing east.

Type: Structure functional class 4, Multi-span Viaduct

MP: 35.81

Date/time: 7/6/2018

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Railroad, roads, interstate
Local road topography: Raised roadbed

Structure Width: ~34.75 meters Height: ~ 5.49 meters Length: ~14.63 meters

Openness ratio: ~13.04

Environmental conditions during assessment: Sunny, dry,

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: Creek may have more water, but it would not stop animals from using it

Inlet

Land use % Rd/hwy: 30 Agriculture: 0 Residential: 0

Recreation: 0 Logging: 0 Comm/industry: 10 Natural:60

Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands:10 Stream/river: 40

Shrub/steppe: 0 Forest: 10 Developed: 10 Other: 0

Outlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 0 Logging:0 Comm/industry: 10 Natural: 80

Other: 0

Habitat Type % Meadow/grassland: 30 Wetlands:10 Stream/river: 40

Shrub/steppe: 0 Forest: 10 Developed: 10 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight: Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: <3_ft

Current flow conditions similar to annual average: No, appears lower

Road or Trail: Dirt road

Sound of passing traffic: Low rumble

Human use: Semi trucks Passing through, walking, jogging, berry picking

Wildlife/human activity

Signs of wildlife use inside the structure: Bird nest, game trail, scat, tracks

Signs of wildlife within 30 feet: N/A

Signs of human activity within structures: Yes frequent daily

Wildlife/Human activity: Graffiti, litter, foot prints, Dog, night use, other

Notes: The dirt road is a primary artery for commercial trucking, and during certain days and times there are trucks passing through constantly. Despite this many adaptive species still use this structure.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: A

Arboreal Specialists: F

Enhancements: Limiting or removing commercial use could be beneficial but it may require stopping commercial traffic or removing the road altogether. This location could use some water way restoration, and possible channel restoration as well, this could make it far more attractive to semi-aquatic and possibly even aquatic species. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.17 Location: I-5 Over Railroad B

One associated structure

Lat: 45.959.681 Long: -122.80614

AADT: 69,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the location: 21.74 (Attributed to both NB & SB, this structure only exists in the SB section, far removed from the NB section)

Structure name/stream name: I-5 Over Railroad B

Figure B.28 I-5 Over Railroad B, facing east, interior.

Type: Structure functional class 4, Multi-span Large Underpass

MP: 26.01

Date/time: 8/31/2018 11:40am

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: Railroad

Local road topography: Raised roadbed

Structure Width: ~44.5 meters   Height: ~9.14 meters   Length: ~20.12 meters

Openness ratio: ~ 20.22

Environmental conditions during assessment: Dry, warm, high veg.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: May make riprap more difficult to navigate

Inlet

Land use %   Rd/hwy: 10   Agriculture: 0   Residential: 0

Recreation: 0   Logging: 0   Comm/industry: 10   Natural: 80

Other: 0

Habitat Type %   Meadow/grassland: 10   Wetlands: 0   Stream/river: 0

Shrub/steppe: 0   Forest: 50   Developed: 40   Other: 0

Outlet

Land use %   Rd/hwy: 10   Agriculture: 0   Residential: 0

Recreation: 0   Logging: 0   Comm/industry: 10   Natural: 60

Other: 0

Habitat Type %   Meadow/grassland: 10   Wetlands: 0   Stream/river: 0

Shrub/steppe: 0   Forest: 60   Developed: 30   Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? N/A

Current water depth? N/A

Current flow conditions similar to annual average: N/A

Road or Trail: Railroad

Sound of passing traffic: Unobtrusive

Human use: Railroad double track, graffiti, litter

Notes: Primarily used for Railroad

Wildlife/human activity

Signs of wildlife use inside the structure: Uncertain

Signs of wildlife within 30 feet: Uncertain

Signs of human activity within structures: Yes - Frequent/Daily

Wildlife/Human activity: Night use/day use, mostly RR activity

Notes: This structure crosses under I-5 only on the southbound side, there is no corresponding structure on the northbound side, which is a good distance away from this location. In addition, an active railroad runs through this location, which may make crossing difficult when the train is present.

Field rankings

Cover obligates: C

Openness obligates: C

Semi-aquatic obligates: F

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: C

Enhancements: Due to the current use this location may not represent an area worthy of resource allocation, since there is no corresponding structure in the northbound lanes. However, structure enhancement could make the area safer and allow passage of smaller animals with small home ranges. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.18 Location: Lewis River

Two associated structures: Northbound, Southbound

Lat: 45.889626 Long: -122.733004

AADT: 79,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the

location: 12.65

Structure name/stream name: Lewis River Northbound

Figure B.29 Lewis River NB, interior facing south.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 19.83

Date/time: 9/14/2018 11:05 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate, roads

Local road topography: Raised roadbed

Structure Width: ~269.75 meters Height: ~11.89 meters Length: ~15.54 meters

Openness ratio: ~ 206.39

Environmental conditions during assessment: Cloudy, damp slow river high veg.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: N/A

Inlet

Land use % Rd/hwy: 0 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 90

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 10 Stream/river: 50

Shrub/steppe: 0 Forest: 40 Developed: 0 Other: 0

Outlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 30 Natural: 50

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 10 Stream/river: 40

Shrub/steppe: 0 Forest: 30 Developed: 20 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: ≥3_ft

Current flow conditions similar to annual average: No, appears lower

Road or Trail: None

Sound of passing traffic: Loud and jarring

Human use: Litter, graffiti

Wildlife/human activity

Signs of wildlife use inside the structure: Live animals

Signs of wildlife within 30 feet: N/A

Species: Cat, bird, deer

Signs of human activity within structures: Yes - Frequent

Wildlife/Human activity: Recreation, camping, occupancy, Dog, night use, recreation, vehicle ATV use

Notes:

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: A

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: This location could be an excellent place for monitoring and future enhancements. The sound is overbearing when trucks drive over the freeway, could benefit from sound barriers. Both sides of the river could use some veg maintenance to provide a better path for larger animals, including ungulates. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: Lewis River Southbound

Figure B.30 Lewis River SB, interior facing south.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 19.87

Date/time: 9/14/2018

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High ($\geq$ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate, bridge, road

Local road topography: Raised roadbed

Structure Width: ~269.75 meters Height: ~ 11.89 meters Length: ~ 15.54 meters

Openness ratio: ~206.39

Environmental conditions during assessment: Cloudy damp, slow water flow.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: N/A

Inlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 0 Natural: 80

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 10 Stream/river: 40

Shrub/steppe: 0 Forest: 40 Developed: 10 Other: 0

Outlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 10 Logging: 0 Comm/industry: 20 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 10 Stream/river: 40

Shrub/steppe: 0 Forest: 40 Developed: 10 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: ≥3_ft

Current flow conditions similar to annual average: No, appears lower

Road or Trail: N/A

Sound of passing traffic: Loud and jarring

Human use: Camping, fishing, hiking, dumping, graffiti

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Live_Animal,Game_trail

Signs of wildlife within 30 feet: Scat,Game_trail,Live_Animal

Signs of human activity within structures: Yes_Occasional

Wildlife/Human activity:
Dog,Night_Use,Camping_Occupancy,Recreation,Vehicle_ATV_use

Species: Deer,birds

Notes: Human recreation is prevalent, and the west side has some commercial operations near it.

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: A

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: This location could be an excellent place for monitoring and future enhancements. The sound is overbearing when trucks drive over the freeway, location could benefit from sound barriers. Both sides of the river could use some veg maintenance to provide a better path for larger animals, including ungulates Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.19 Location: East Fork Lewis River

Two associated structures: Northbound, Southbound

Lat: 45.871708 Long: -122.710307

AADT: 79,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the

location: 7.60

Structure name/stream name: East Fork Lewis River Northbound

Figure B.31 East Fork Lewis River NB, middle of structure exterior facing east

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 18.21

Date/time: 9/21/2018 9:34 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: interstate

Local road topography: Raised roadbed

Structure Width: ~245.69 meters Height: ~16.15 meters Length: ~ 15.54 meters

Openness ratio: ~255.33

Environmental conditions during assessment: Overcast, high veg, slow water, dry

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: N/A

Inlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 0

Recreation: 30 Logging: 0 Comm/industry: 0 Natural: 60

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 0 Stream/river: 60

Shrub/steppe: 0 Forest: 30 Developed: 10 Other: 0

Outlet

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 40 Logging: 0 Comm/industry: 0 Natural: 40

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 0 Developed: 40 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: ≥3_ft

Current flow conditions similar to annual average: No, appears lower

Road or Trail: Paved road/dirt trail

Sound of passing traffic: Loud and jarring

Human use: Driving, all types of recreation

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Uncertain

Signs of wildlife within 30 feet: Uncertain

Signs of human activity within structures: Yes, Frequent daily, heavy seasonal use

Wildlife/Human activity: Camping occupancy, dog, night use, recreation, vehicle ATV use, frisbee golf

Notes: This location is heavily recreated, with a Frisbee golf course, state park, camping, picnicking etc.….

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: A

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: During part of the year this location, especially on the south bank this location is inundated with human recreation, it may beneficial to create a wildlife only passage way. The north bank of the river is not very permeable due to riprap (could be filled over to make a crossable path) and human presence (better ROW fencing). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Structure name/stream name: East Fork Lewis River Southbound

Figure B.32 East Fork Lewis River SB, inlet exterior, NB in background.

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 18.21

Date/time: 9/21/2018 9:09 a.m.

No. of lanes: 3 Road surface type: Paved

Traffic volume conditions: High (21-104 cars per 15 min)

Parallel infrastructure within 50 yds: interstate

Local road topography: Raised roadbed

Structure Width: ~ 245.06 meters Height: ~17.37 meters Length: ~10.97 meters

Openness ratio: ~388.03

Environmental conditions during assessment: High veg, slow river, dry, overcast

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: N/A

Inlet

Land use % Rd/hwy: 20 Agriculture: 0 Residential: 0

Recreation: 40 Logging: 0 Comm/industry:0 Natural: 40

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 0 Stream/river: 50

Shrub/steppe: 0 Forest: 30 Developed: 20 Other: 0

Outlet

Land use % Rd/hwy: 10 Agriculture: 10 Residential: 0

Recreation: 30 Logging: 0 Comm/industry: 0

Natural: 50 Other:0

Habitat Type % Meadow/grassland: 20 Wetlands: 0 Stream/river: 40

Shrub/steppe: 0 Forest: 20 Developed: 20 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: ≥3_ft

Current flow conditions similar to annual average? No, appears lower

Road or Trail: Paved road

Sound of passing traffic: Loud and jarring

Human use: Driving, biking, all types of recreation

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Live animal

Signs of wildlife within 30 feet: Uncertain

Species: Pigeon

Signs of human activity within structures: Yes, frequent daily

Wildlife/Human activity: Dog, camping, occupancy, night use, recreation, vehicle ATV use

Notes: This location is heavily recreated, with a frisbee golf course, state park, camping, picnicking etc.….

Field rankings

Cover obligates: A

Openness obligates: C

Semi-aquatic obligates: A

Medium-structure generalists: A

Large-structure generalists: A

Arboreal Specialists: C

Enhancements: During part of the year this location, especially on the south bank is inundated with human recreation, it may beneficial to create a wildlife only passage way. The north bank of the river is not very permeable due to riprap (could be filled over to make a crossable path) and human presence (better ROW fencing). Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, Fairbank, Camel-Means, Graham, watson, et al., 2016; McCollister & van Manen, 2010). Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

B.20 Location: Salmon Creek

One associated structure

Lat: 45.705231 Long: -122.654913

AADT: 75,000

Jan 1st, 2014-Dec 31st 2017, WVCs per 100,000 AADT associated with the location: 9.33

Structure name/stream name: Salmon Creek

Figure B.33 Salmon Creek, facing north from south bank

Type: Structure functional class 4, Multi-span Viaduct (Bridge)

MP: 6.32

Date/time: 9/21/2018 11:40 a.m.

No. of lanes: 6 Road surface type: Paved

Traffic volume conditions: Very High (≥ 105 cars per 15 min)

Parallel infrastructure within 50 yds: roads

Local road topography: Raised roadbed

Structure Width: ~ 85.04 meters Height: ~ 14.02 meters Length: ~38.1 meters

Openness ratio: ~31.29

Environmental conditions during assessment: cool, muddy, overcast.

Preliminary questions, fatal flaws.

Is structure longer than 300ft? no

Is the structure a culvert with a dropped inlet, outlet or drop midway through? no

Is the structure a culvert with a jog or split midway through, preventing a clean line of sight? no

Is the structure a culvert and you cannot see to the other side? no

Is the slope too steep for the target guilds to navigate? no

Is there a body of deep or fast-flowing water immediately in front of the structure? no

Winter conditions: N/A

Inlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 20

Recreation: 40 Logging: 0 Comm/industry: 0 Natural: 30

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 10 Stream/river: 30

Shrub/steppe: 0 Forest: 20 Developed: 40 Other: 0

Outlet

Land use % Rd/hwy: 10 Agriculture: 0 Residential: 20

Recreation: 40 Logging: 0 Comm/industry: 0 Natural: 30

Other: 0

Habitat Type % Meadow/grassland: 0 Wetlands: 10 Stream/river: 30

Shrub/steppe: 0 Forest: 20 Developed: 40 Other: 0

Is the structure darker than the outside? Low contrast

Clear line of sight? Yes, clear

Skylight in structure? No

Water flow through? Perennial

Current water depth: <3_ft

Current flow conditions similar to annual average: No, appears lower

Road or Trail: Paved road & trail

Sound of passing traffic: Low rumble

Human use: Hiking, fishing, automobiles, bike, litter, graffiti

Notes:

Wildlife/human activity

Signs of wildlife use inside the structure: Uncertain

Signs of wildlife within 30 feet: Live animal

Species: Geese, fish

Signs of human activity within structures: Yes, Frequent Daily

Wildlife/Human activity: Camping, occupancy, dog, night use, recreation

Notes: This location is both urbanized and part of a state park, it is heavily used by humans, and the noise and lighting are constant through the night.

Field rankings

Cover obligates: C

Openness obligates: F

Semi-aquatic obligates: C

Medium-structure generalists: C

Large-structure generalists: C

Arboreal Specialists: F

Enhancements: This location may simply be in too much of an urbanized area to make any significant changes that would pass more wildlife. Arboreal ladders, bridges, ropes, and platforms. Plant vegetation or woody debris to create cover (Ehinger et al., 2006). Install wildlife fencing or add enhancements to right of way fencing, maintain existing fencing (Huijser, et al., 2016; McCollister & van Manen, 2010) . Install a sound barrier, prohibit human use, and remove highway lighting near structure (Forman, 2003; Hartmann, 2003; Jackson, 2000; Shilling et al., 2018). Possible jump outs or escape ramps to be placed if new fencing was to be implemented to avoid trapped animals (Bissonette & Hammer, 2000). Add electro mats to on and off ramps where there is gaps in fencing (Seamans et al., n.d.). Remove garbage and limit illegal human use of structure, maybe exclude humans form one side entirely. Could add signage for drivers/hikers/recreators to limit human activity, or to simply make them aware of possible wildlife-vehicle conflicts (Clevenger & Waltho, 2004). Maintain or enhance native vegetation in and around structure (Ng et al., 2005). Remove or fill areas that may be seen as predator perches by prey species (Little et al., 2002).

Appendix C: Guild Ranking Maps

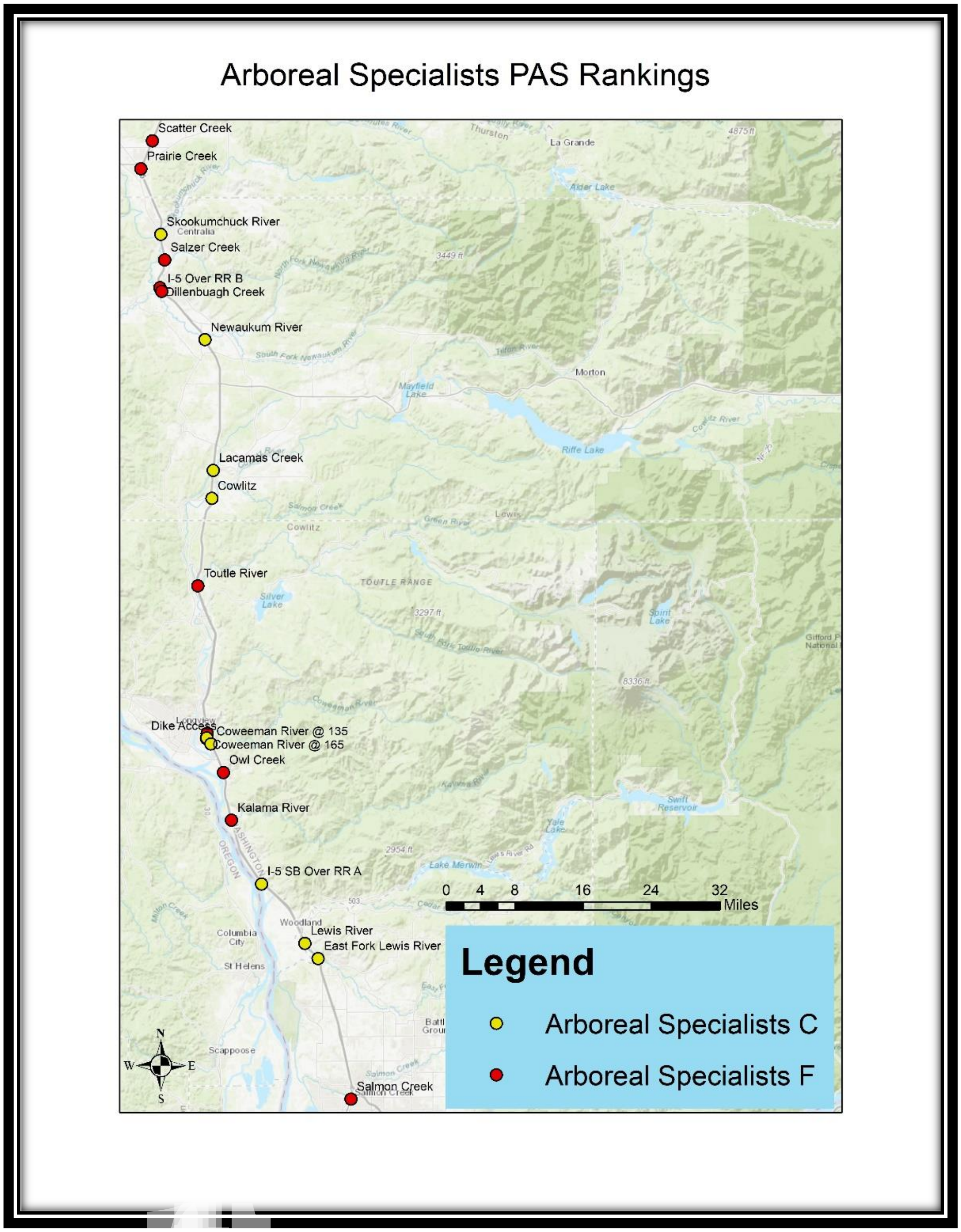

Figure C-1 Arboreal PAS rankings. Yellow represents a ranking of C. Red represents a ranking of F.

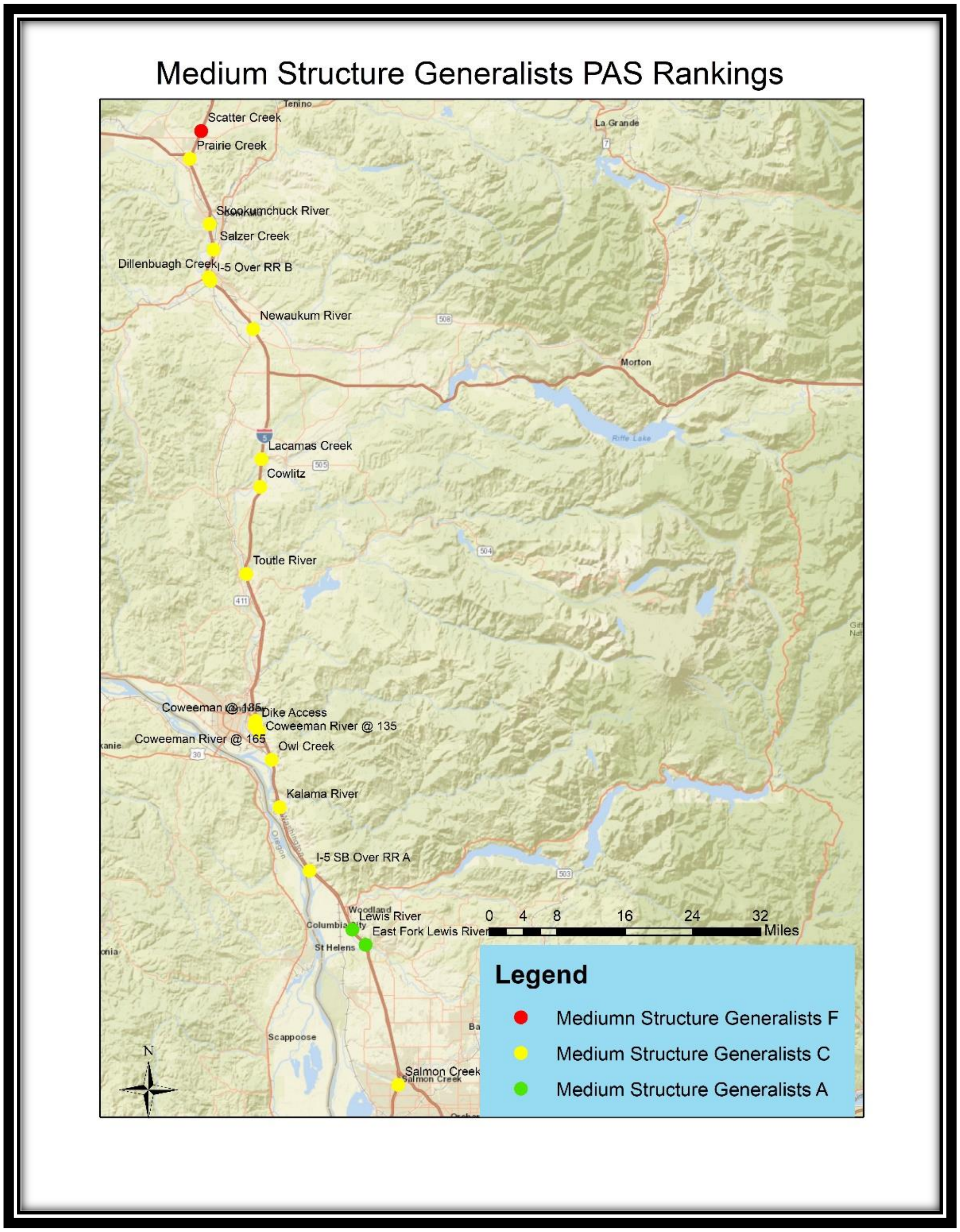

Figure C-2 Medium Structure Generalist PAS rankings. Green represents an A ranking. Yellow represents a ranking of C. Red represents a ranking of F.

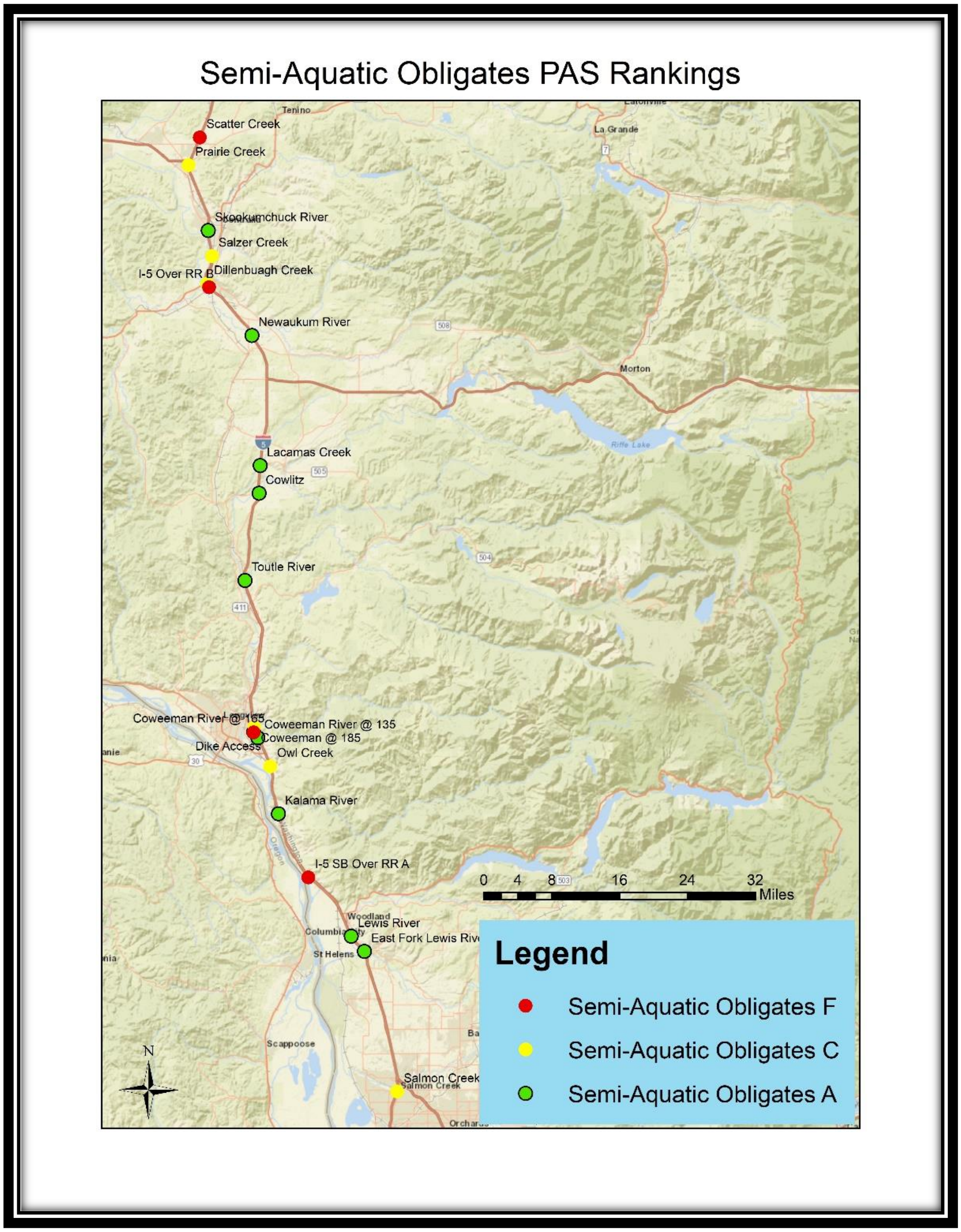

Figure C-3 Semi-aquatic obligates Generalist PAS rankings. Green represents an A ranking. Yellow represents a ranking of C. Red represents a ranking of F.

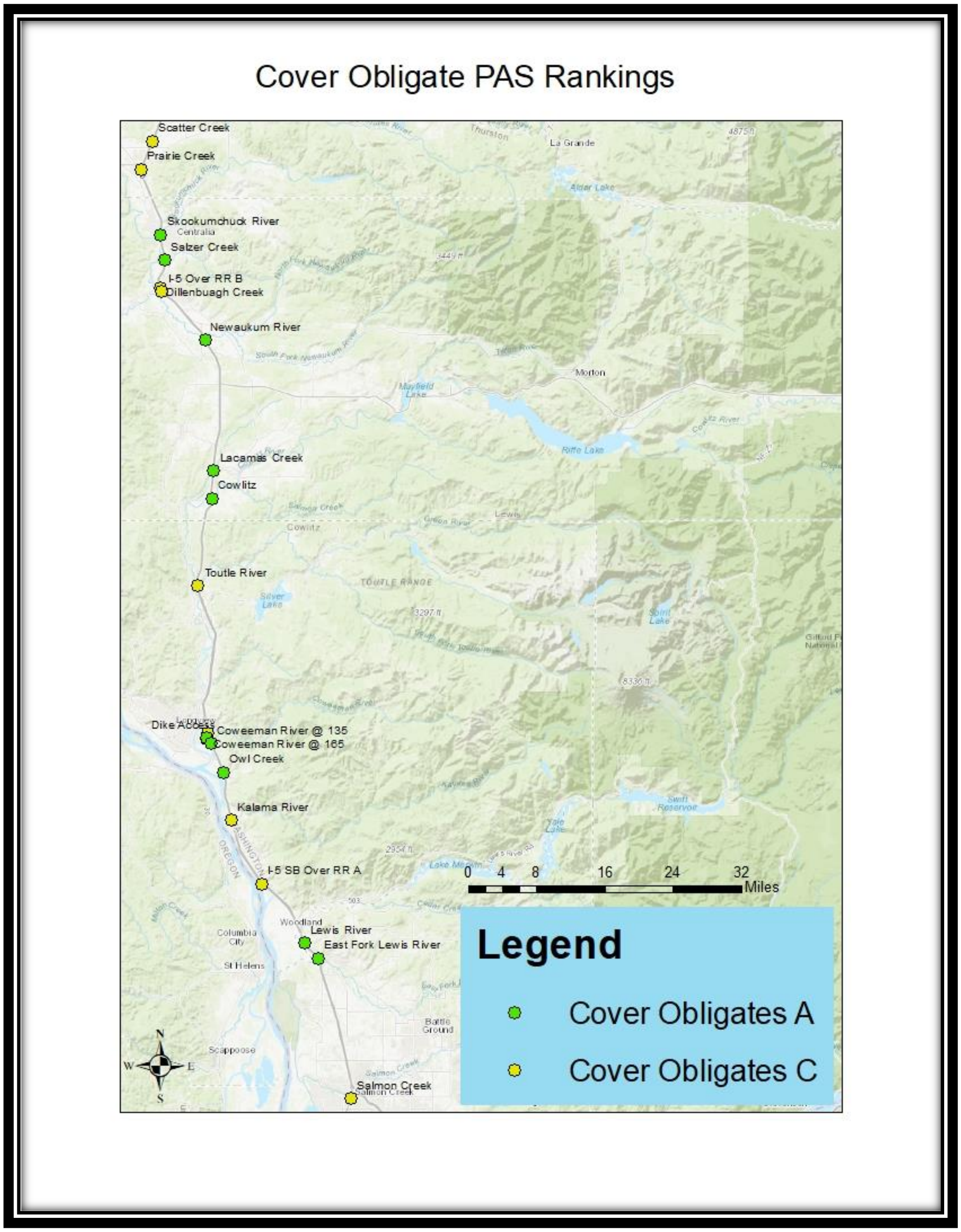

Figure C-4 2 Medium Structure Generalist PAS rankings. Green represents an A ranking Yellow represents a ranking of C. Red represents a ranking of F.

Appendix D: Raw WVC data vs. WVC per 100,000 AADT

Table D-1. An example of the change represented for each milepost (MP) by using AADT as a normalizer.

MP	AADT	WVC total	WVC per 100,000 AADT
	101000	10	9.9
1	135000	2	1.5
2	100000	0	0.0
3	100000	1	1.0
4	88000	6	6.9
5	75000	9	12.0
6	75000	5	6.7
7	95000	1	1.1
8	95000	0	0.0
9	90000	1	1.1
10	107000	2	1.9
11	99000	5	5.1
12	99000	1	1.0
13	84000	5	5.6
14	88000	5	5.7
15	88000	6	6.8
16	75000	4	5.3
17	79000	10	12.7
18	79000	9	11.4
19	79000	16	20.3
20	79000	9	11.4
21	70000	3	4.9
22	69000	4	5.8
23	69000	4	5.8
24	69000	18	26.9
25	69000	9	13.0
26	69000	11	15.9
27	66000	17	25.8
28	68000	6	8.8
29	64000	10	15.6
30	71000	16	22.5
31	68000	10	14.7
32	71000	12	16.9
33	71000	8	11.3
34	71000	6	8.5
35	71000	8	11.3
36	45000	7	15.6
37	56000	8	14.3

38	56000	7	12.5
39	44000	7	15.9
40	53000	5	9.4
41	60000	15	25.0
42	53000	13	24.5
43	57000	8	14.0
44	57000	7	12.3
45	55000	8	14.5
46	56000	6	10.7
47	51000	6	11.6
48	51000	13	25.5
49	42000	10	23.8
50	46000	6	13.0
51	46000	5	10.9
52	45000	4	8.9
53	45000	5	11.1
54	45000	6	13.3
55	45000	4	8.9
56	45000	10	22.2
57	45000	6	13.3
58	45000	11	24.4
59	44000	9	20.6
60	43000	11	25.6
61	43000	7	16.3
62	43000	3	7.0
63	47000	7	14.9
64	47000	12	25.5
65	47000	5	10.6
66	47000	12	25.5
67	47000	12	25.5
68	44000	19	43.2
69	53000	9	17.0
70	53000	1	1.9
71	58000	16	27.6
72	51000	19	37.3
73	63000	7	11.1
74	61000	10	16.4
75	66000	4	6.1
76	61000	5	8.2
77	65000	6	9.2
78	64000	0	0.0
79	75000	7	9.3
80	75000	6	8.0

81	58000	16	27.6
82	50000	18	36.0
83	68000	4	5.9
84	68000	5	7.4
85	68000	10	14.7
86	68000	13	19.1
87	68000	12	17.5
88	65000	6	9.2
89	65000	1	1.5
90	65000	9	13.8
91	65000	3	4.6
92	65000	4	6.2
93	65000	3	4.6
94	65000	3	4.6
95	65000	8	12.3
96	69000	4	5.8
97	69000	1	1.4
98	65000	5	7.7
99	78000	10	12.8
100	78000	7	9.0

Appendix: E Raw Camera Data

Table E-1 Lacamas Creek Camera Data

Species	Crossings	Expanded # of Crossings	Expanded # of Species Repelled	Repel Rate (%)	# of Crossings per hundred trap days	# of Expanded Crossings per hundred trap days
Black-tailed Deer	317	556	7	1.24	86.85	152.33
Coyote	1	1	0	0.00	0.27	0.27
Dark-Eyed Junco	0	0	0	0.00	0.00	0.00
Domestic Cat	24	24	0	0.00	6.58	6.58
Domestic Dog	69	129	0	0.00	18.90	35.34
Human	25	40	0	0.00	6.85	10.96
Opossum	46	51	0	0.00	12.60	13.97
Porcupine	1	1	0	0.00	0.27	0.27
Raccoon	14	19	0	0.00	3.84	5.21
Robin	1	1	0	0.00	0.27	0.27
Steller's Jay	1	1	0	0.00	0.27	0.27

Table E-1 Raw Camera Lacamas Creek

Table E-2 Owl Creek Camera Data

Species	Crossings	Expanded # of Crossings	Expanded # of Species Repelled	Repel Rate (%)	# of Crossings per hundred trap days	# of Expanded Crossings per hundred trap days
American Robin	1	1	0	0.00	0.27	0.27
Beaver	1	2	1	33.33	0.27	0.55
Black-tailed Deer	261	473	3	0.63	71.51	129.59
Bushy-tailed Woodrat	3	3	0	0.00	0.82	0.82
Common Garter Snake	3	3	0	0.00	0.82	0.82
Coyote	10	10	0	0.00	2.74	2.74
Dark-eyed Junco	1	1	0	0.00	0.27	0.27
Deer Mouse	41	46	0	0.00	11.23	12.60
Domestic Cat	34	36	0	0.00	9.32	9.86
Domestic Dog	62	85	5	5.56	16.99	23.29
Great Blue Heron	4	8	0	0.00	1.10	2.19
Human	158	254	16	5.93	43.29	69.59
Mallard Duck	1	2	0	0.00	0.27	0.55
Opossum	75	80	1	1.23	20.55	21.92
Raccoon	234	256	2	0.78	64.11	70.14
Snowshoe Hare	1	1	0	0.00	0.27	0.27
Song Sparrow	1	6	1	14.29	0.27	1.64

Table E-2 Raw camera data Owl Creek.