Figure 1 Newaukum River southbound structure facing the west. (Stewart 2019)

Recommendations for Improving and Maintaining Habitat Connectivity Over/Under I-5 in Southwest Washington

PREPARED FOR CONSERVATION NORTHWEST
BY: BRIAN STEWART

Table of Contents

Abstract

Landscape and habitat connectivity between the Cascades and the Coast in S.W. Washington are limited in some areas and non-existent in others due to Interstate 5 (I-5). The Interstate has adverse impacts on the ecosystems through which it runs, having ramifications for both the local environment and local wildlife. Furthermore, climate change compounds the negative impacts roads have on ecosystems, while contributing unique challenges of its own. In addition, I-5 crosses over and creates pinch points at numerous riparian corridors, which provide climate refugia and access to climate resilient pathways for local wildlife when landscapes are intact. Impacts on the environment are not the only repercussions of such a large Interstate, there is also the danger of wildlife-vehicle conflicts (WVCs). WVCs can be both expensive and dangerous for motorists, and dangerous for wildlife as well. In order to identify structures and locations that might benefit from camera monitoring, conservation efforts and wildlife infrastructure, this document ("whitepaper") seeks to expand on previous thesis research. By utilizing current WSDOT data, previous I-5 research and land-use/landcover patterns this paper will make recommendations as to where camera monitoring, future conservation efforts and wildlife infrastructure should be employed to increase the permeability of I-5 for terrestrial species in S.W. Washington. Five locations have been selected for analysis based on; 1) high volumes of WVCs that may represent areas of high wildlife habituation, or accessible at grade crossing; 2) locations with a convergence of known ungulate least-cost paths, to determine which locations may be best suited for future wildlife only structures and/or conservation efforts. Ultimately, three locations have been

identified for further monitoring, research, conservation efforts, and wildlife infrastructure to increase connectivity between the Coast to the Cascades.

Introduction

Roads have negative ecological impacts on the environments through which they run, and on the wildlife that live in those environments. Some of those negative impacts include pollution, noise, wildlife-vehicle collisions, habitat loss, decreases in fecundity, decreases in local biodiversity, increases in invasive species, and increases in extirpations and extinctions (Forman, 2003; Spellerberg, 1998). Larger roads, highways, and Interstates like I-5 may exacerbate the environmental impacts of roads. Large highly used roads that run through "natural" areas also tend to have high numbers of wildlife-vehicle conflicts (WVCs[1]) (i.e. collisions, near misses, accidents caused by animals in the roadway) which are made up of mostly large ungulates like deer (*Odocoileus spp.)* or elk *(Cervus elaphus spp.)*. Where, and in what abundance these WVCs occur might help to locate places in need of further permeability research and wildlife infrastructure (WSDOT, 2018; Yinhai Wang, Yunteng Lao, Yao-Jan Wu, & Jonathan Corey, 2010). WVCs are dangerous for wildlife and to a lesser extent, motorists. In fact, the Washington State Department of Transportation (WSDOT) estimates that roughly 3000 deer carcasses are removed from Washington state roadways annually. WVCs have monetary costs associated with them as well, WSDOT estimates Washington tax payers pay roughly a thousand dollars a year on expenses related to WVCs (Forman, 2003;

[1] This paper uses aggregated data of both carcass removals and collisions to generate the WVC data

Forman & Alexander, 1998, WSDOT, 2016). One way to decrease WVCs is to use wildlife fencing in areas where high volumes of WVCs occur. Fencing could also be used to help funnel species into existing crossing structures that pass under the Interstate (Huijser et al., 2016; McCollister & van Manen, 2010). Notably, it has been estimated that over 50% of wildlife-vehicle collisions go unreported, the implication is that current collision data maybe insufficient for describing rates of collisions (Romin & Bissonette, 1996).

Compounding the issues of fragmentation are the current changes in global and regional climate. Barriers like I-5 prohibit species' natural climate adaptations, like migration and dispersal, and could weaken genetic resilience, while increasing extirpations and extinctions (Sgrò, Lowe, & Hoffmann, 2011; Thomas et al., 2004;WHCWG, 2011). Furthermore, climate is changing faster than previously predicted, requiring that connectivity/conservation planning and implementation be expedited as quickly to keep pace (IPCC, 2013; Snover, Mauger, Whitely Binder, Krosby, & Tohver, 2013). Removing wildlife barriers from roadways and connecting the landscape facilitates some species' natural responses to changes in the climate. Moreover, increased permeability of the landscape facilitates dispersals and migrations as wildlife attempt to track climate change through a fragmented landscape (Seavey et al., 2009).

Assisting wildlife adaptation to climate change will require a myriad of complex solutions to be effective. One of those solutions that may assist both flora and fauna's ability to adapt to climate change is to protect, conserve, restore and make permeable riparian corridors. Riparian corridors act as buffers to extreme temperatures and offer climate refugia for some aquatic and terrestrial species. Past studies have shown that restoring riparian corridors may attract fauna that had been previously considered extirpated from the area (Gardali et al., 2006; Golet et al., 2006; Seavey et al., 2009). Therefore conserving, restoring, and unblocking riparian corridors on the landscape will provide climate corridors, while restoring previously diminished habitat. In fact, 91% of federally protected lands are connected in some way by riparian corridors, resulting in expansive networks of semi-protected corridors. An opportunity arises to implement a riparian conservation network (RCN) approach to protect land from the Coast to the Cascades in Washington State (Fremier et al., 2013; Seavey et al., 2009).

Interestingly, I-5 crosses over 13 riparian corridors which originate from the Cascades, corridors that should be prioritized for wildlife monitoring and conservation efforts. Many of the lowland riparian pathways in the region are necessary for local wildlife attempting to disperse or seek climate refugia in a changing climate (Capon et al., 2013; Krosby, Theobald, Norheim, & McRae, 2018; Stewart, 2019; WHCWG, 2011). The Interstate makes narrow pinch points at crossing structures (i.e. bridges and viaducts) creating narrow bottlenecks, condensing and in some cases walling off the small amounts of "naturalness" in the area. In S.W. Washington riparian corridors connect lowland waterways to high altitude mountain ranges (Cascades and Olympics), providing a regional network of "natural" corridors connecting wildlife to more suitable locations (Krosby et al., 2018; Seavey et al., 2009). Importantly, lowland riparian corridors in S.W. Washington have already been identified as locations in need of restoration and conservation to improve local wildlife's ability to track climate change (Krosby et al. 2018).

In summary, I-5 generates numerous negative impacts on ecosystems and the wildlife that exist within them. Climate change increases the adverse influence of habitat fragmentation caused by roads, by prohibiting the movement necessary for some species to adapt to the change naturally. Regionally, I-5 creates pinch points at lowland riparian corridors, which could be key climate refugia, dispersal corridors, and critical habitat for both aquatic and terrestrial species. These corridors should be restored and made usable for diverse wildlife populations. Restoring and conserving these corridors could provide key networks for the movement of wildlife throughout the landscape. Another variable of concern are WVCs, which are dangerous to both wildlife and humans, as well as being financially expensive for tax payers. In order to better enhance ecological connectivity of the landscape, promote wildlife usage of existing structures, and create a safer highway for both motorists and wildlife, this paper will seek to further analyze five previously identified locations on the Interstate where permeability and conservation may be most advantageous. Importantly, this paper will rely heavily on previous thesis work on the permeability of I-5 including its data and methodologies, with the goal of advancing the recommendations provided in the thesis.

Previous Local Research and Maps

A Passage Assessment System (PAS) was used in previous research to evaluate and rank structures on I-5 in S.W. Washington on their permeability and potential for improvement (i.e. retrofitting & enhancement) (Kintsch & Cramer, 2011). PAS is an intense assessment survey of the interactions between roadway structures' (i.e. culverts, bridges, viaducts) attributes, and species' characteristics (i.e. mode of locomotion, behavioral traits) to give structures a ranking (A, C, F). The rankings reflect whether or not a structure can be made more permeable for a given species guild by enhancing or retrofitting it with wildlife infrastructure (i.e. fencing, maintenance, sound barriers, etc.….). Stewart (2019) focused mainly on two (i.e. openness obligates and large structure generalists) of the 8 guilds (Table 1), but reported rankings for 6, excluding aerial and specialists conditional. The results from that analysis was the source for the PAS data incorporated in this paper (Kintsch & Cramer, 2011; Stewart, 2019). Interestingly, PAS has been shown to be useful for ranking actual permeability as well, as PAS rankings were previously used as a proxy for generating resistance values for connectivity mapping over I-5 (Stewart, 2019).

Table 1. PAS guild member's preferred structure attributes

Guild Name	Local Examples of Guild Members	Crossing structure attributes
Cover Obligates	American Pika (*Ochotona princeps*), Jumping Mouse (*Zapus hudsonius preblei*), 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	Platypus (*Ornithorhynchus anatinus*), American Mink (*Neovision 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 pipens*), Christmas island red land crabs (*Gecarcoidea natallis*) etc….	Species specific considerations must be made; typically require specialized structures.
Specialist arboreal	Flying Squirrels (*Glaucomys sabrinus coloratus*) etc…	Large viaducts with canopy; specialized arboreal bridges/ladders
Specialist aerial	Bats (*Order chiroptera*), Royal terns (*Sterna Maxima)* etc…	Viaducts that allow for flight.

(Kintsch & Cramer, 2011; Kintsch, Jacobsen, & Cramer, 2015).

Between 2018 and 2019, GIS maps developed in ArcMap (ESRI) illustrated PAS rankings for 20 locations representing 33 structures on I-5 in S.W. Washington between mileposts 0 and 100. The three rankings are A (good crossing structure in need of minimal retrofitting), C (decent crossing structure, but in need of enhancement), F (poor crossing structure, maybe impossible to use and impossible to retrofit) (ESRI, 2018; Kintsch & Cramer, 2011; Stewart, 2019) (Fig. 2-7).

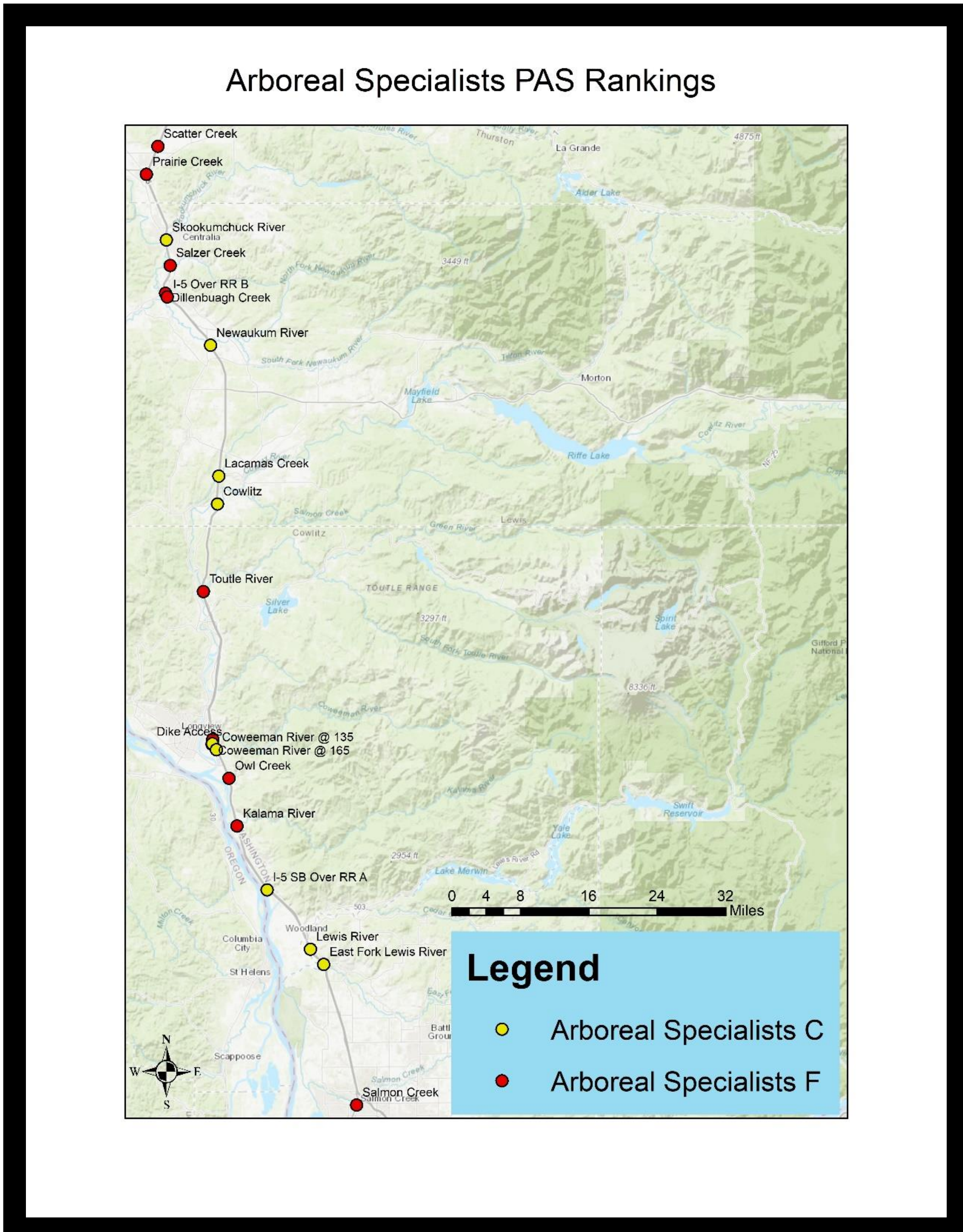

Figure 2 Arboreal specialist rankings for I-5. Yellow dots represent C PAS rankings. Red dots represent F PAS rankings (ESRI et al., n.d.; Kintsch & Cramer, 2011; Stewart, 2019).

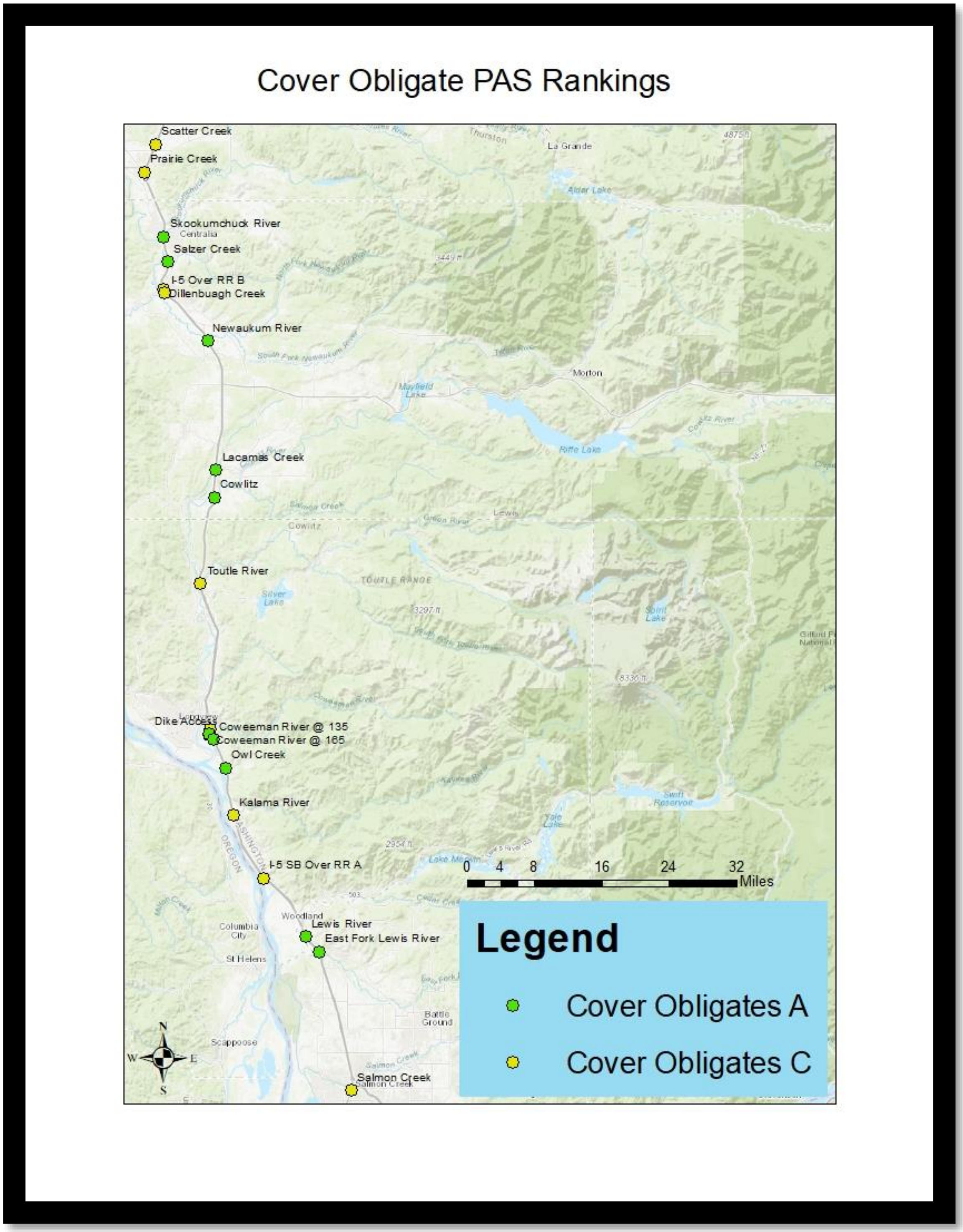

Figure 3 Cover obligate rankings for I-5. Green dots represent A PAS rankings. Yellow dots represent C PAS rankings. Red dots represent F PAS rankings (ESRI et al., n.d.; Kintsch & Cramer, 2011; Stewart, 2019).

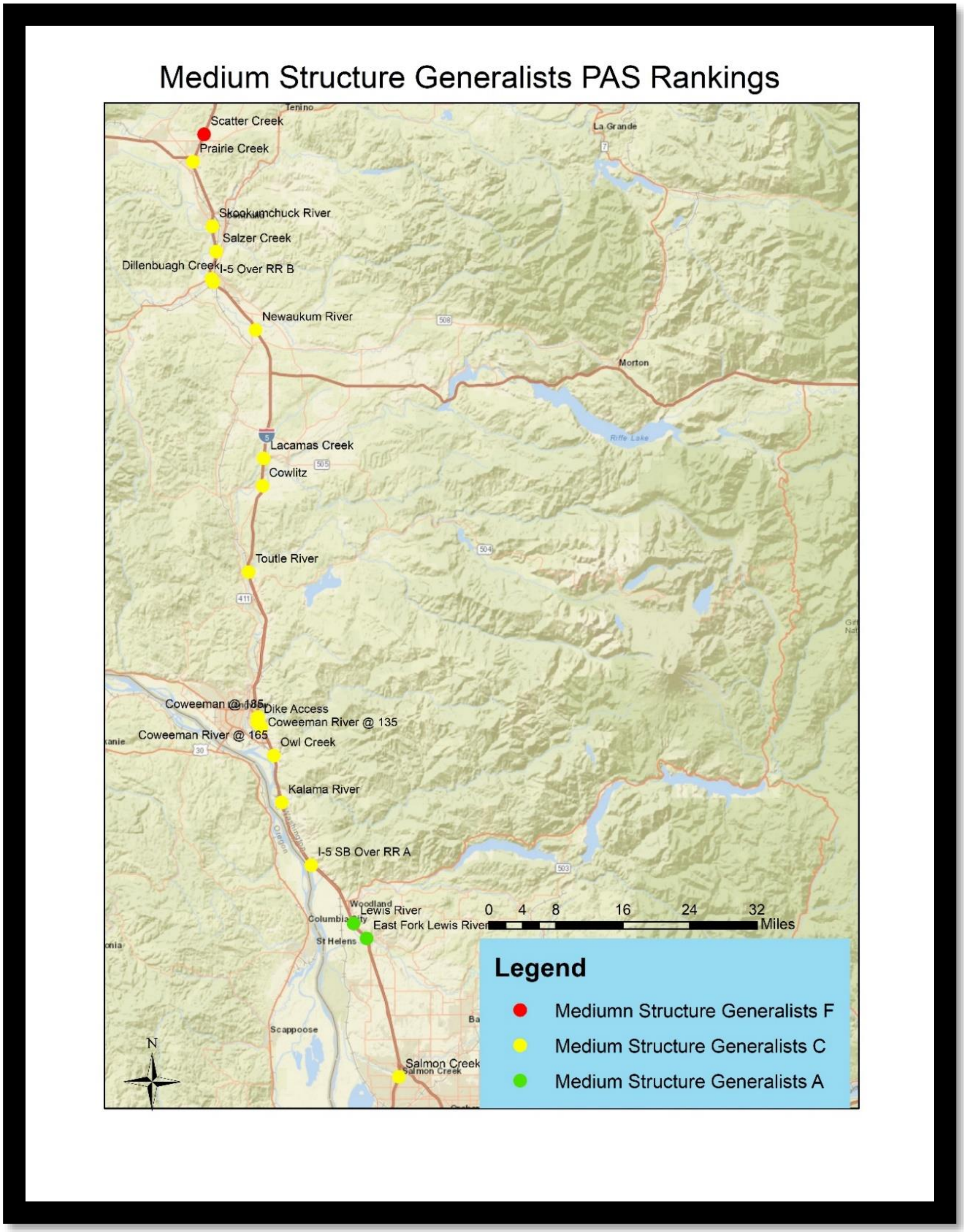

Figure 4 Medium structure generalist rankings for I-5. Green dots represent A PAS rankings. Yellow dots represent C PAS rankings. Red dots represent F PAS rankings. (ESRI et al., n.d.; Kintsch & Cramer, 2011; Stewart, 2019)

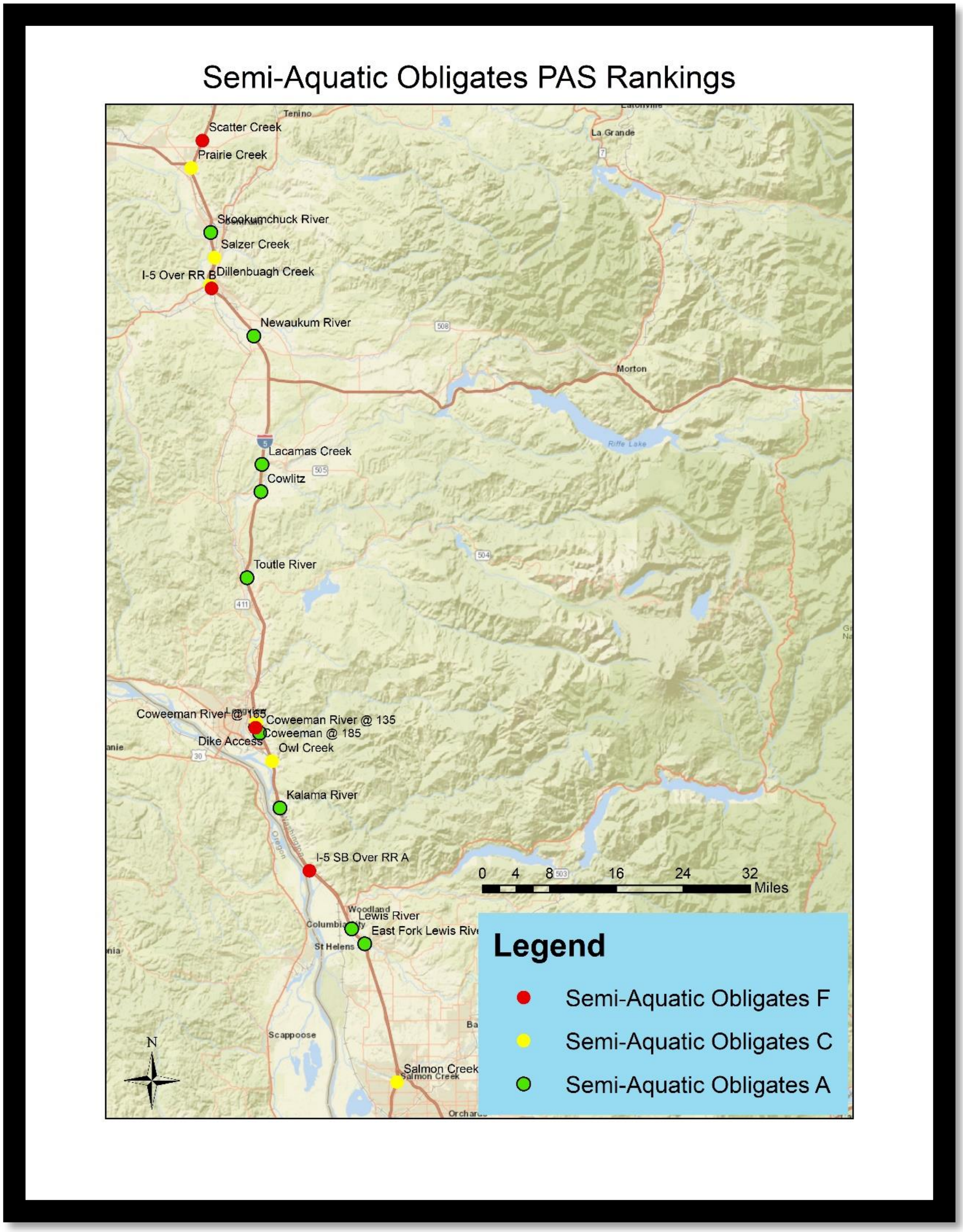

Figure 5 Semi-aquatic obligates rankings for I-5. Green dots represent A PAS rankings. Yellow dots represent C PAS rankings. Red dots represent F PAS rankings.(ESRI et al., n.d.; Kintsch & Cramer, 2011; Stewart, 2019).

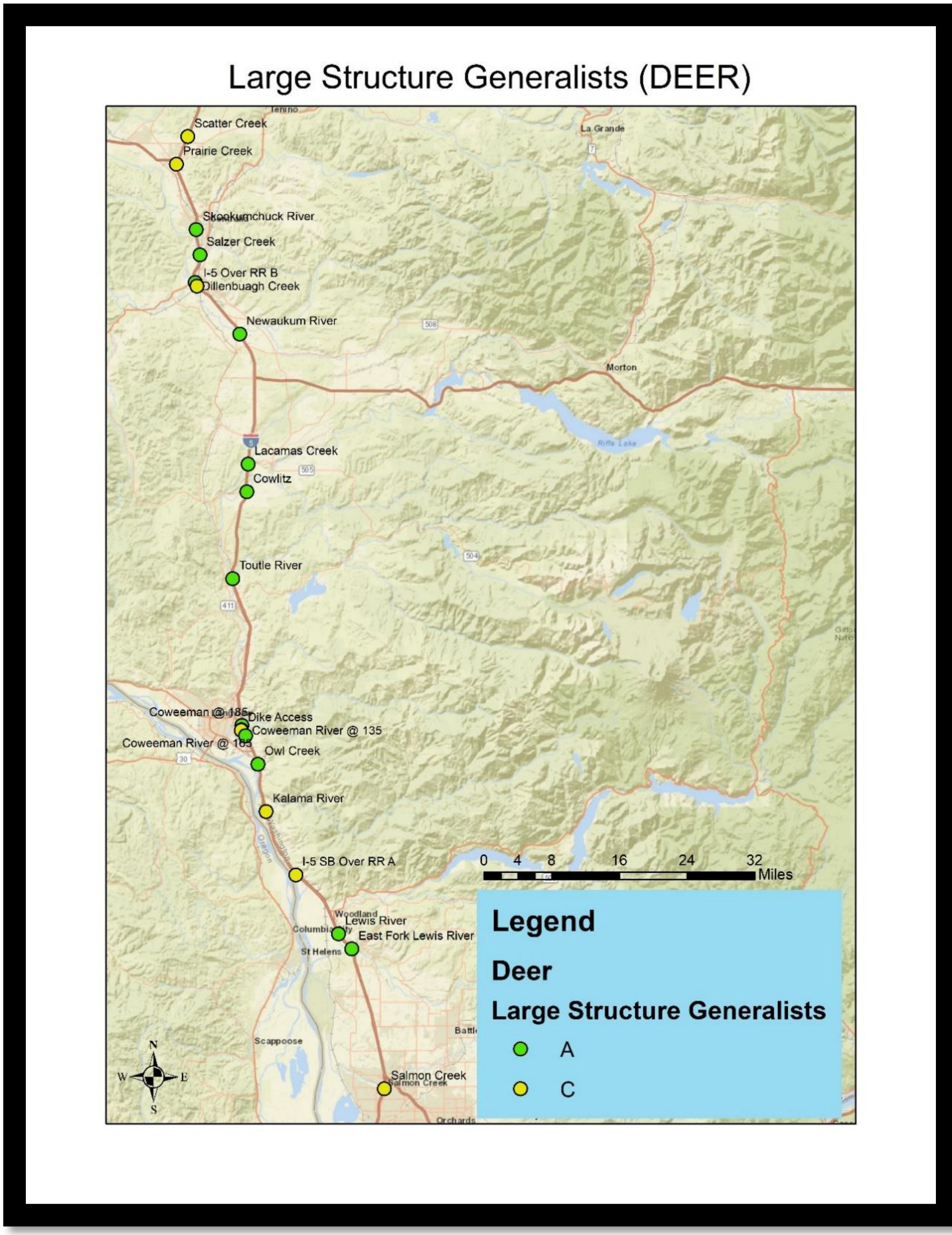

Figure 6 Large structure generalist rankings for I-5. Green dots represent A PAS rankings. Yellow dots represent C PAS rankings. Red dots represent F PAS rankings.(ESRI et al. n.d. ;Kintsch & Cramer, 2011; Stewart, 2019).

Figure 7 Openness obligate rankings for I-5. Green dots represent A PAS rankings. Yellow dots represent C PAS rankings. Red dots represent F PAS rankings. (ESRI et al., n.d.; Kintsch & Cramer, 2011; Stewart, 2019).

Five Focal Locations:

1) Skookumchuck River

2) Newaukum River

3) North of Toutle River

4) South of Prairie Creek

5) Owl Creek

Locations Prioritized Due to Associated WVC Abundance

Previous research on I-5 has highlighted locations with high numbers of WVCs. The area around the cities of Chehalis/Centralia/Winlock experience higher numbers of WVCs than other locations between mileposts 0-100 on I-5. Two locations showing the highest number of WVCs per 100,000 Annual Average Daily Traffic (AADT) during a four year period between mileposts 0 and 100 have been selected for further analysis by this report (Fig.8) (Stewart, 2019). WVCs have been prioritized to identify locations that have high incidents of wildlife conflicts on the roadway, which may help to locate areas where wildlife are attempting to cross, and/or where at grade crossing are accessible (Washington Wildlife Habitat Connectivity Working Group WHCWG, 2010; WSDOT, 2016).

1) Skookumchuck River (Fig. 8)

Data associated with structures

- AADT: 50,000
- Milepost 82.28
- Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 42

Figure 8 Skookumchuck River main structure facing west (Stewart, 2019).

The Skookumchuck River structure has relatively "natural" immediate surroundings, when compared to the developed area it is found in. It has large dry pathways for animals, but some areas are full of shrubs and blackberries making access difficult for some species, especially during the warmer part of the year. This location has the highest number of WVCs than any other area associated with a large structure on I-5 in S.W. Washington. Furthermore, human presence is frequent and daily, which is apparent as there are numerous large piles of trash, litter, and human waste present at the structure. This could be a great location to invest in cleanup, camera monitoring, wildlife fencing and habitat restoration. Further assessment of land-use should be done to better understand the value of improving connectivity at or near this structure (Stewart, 2019).

2) **Newaukum River (Fig. 9)**

Data associated with structures

- AADT: 58,000
- Milepost 72.24
- Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 37.93

Figure 9 Newaukum River structure Southbound outlet exterior facing west (Stewart, 2019)

The Newaukum River structure on I-5 had the second highest number of associated WVCs per 100,000 AADT during the four-year period analyzed. Unlike the Skookumchuck River location, the Newaukum does not have a high frequency of human use, evident by the fact there was almost no litter or human artifacts at the time of assessment (Stewart, 2019). The "natural" landscape extends beyond 100 yards on the eastside but is constrained on the westside by a large embankment on the south bank. With some riparian restoration and ramp building this area could be an excellent place for terrestrial wildlife to utilize while moving through the landscape. Camera monitoring should be deployed at this structure, to catalog and document current wildlife usage. Adding fencing, widening buffers, restoring native vegetation and providing easily accessed pathways could make this location suitable for many different local species. Finally, this location has been selected as a priority location for this paper, due to it being a location associated with a high number of WVCs. Interestingly, this location sits outside of the sprawling development just a few miles to the north, it is probable this is the best structure for enhancement within the Chehalis Basin (Stewart, 2019).

Locations Prioritized Due to Convergence of Ungulate Least-cost Paths

Previous thesis works highlighted structures and areas on I-5 that showed spatial association with known least-cost paths (LCPs) for ungulates. Therefore, locations/structures were prioritized based on their spatial proximity to hypothesized ungulate pathways. Maps of elk (*Cervus elaphus*), Columbian black-tailed deer (*Odocoileus hemionus columbianus*), and Columbian white-tailed deer (*Odocoileus virginianus leucurus*) LCPs were compared and contrasted to locate convergence areas on I-5 where monitoring, conservation, resource allocation and future research should occur (Stewart, 2019; WHCWG, 2010; WSDOT, 2016). Prior thesis work identified three ungulate LCP convergence areas within the study area in need of further evaluation. (Fig. 11,13,15). (Stewart, 2019; WHCWG, 2010; WSDOT, 2016).

3) Toutle River (Fig. 10)

Data associated with structures

- AADT: 46,000
- Milepost 51.71
- Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the structure: 13.04
- WVCs associated with the section of road between mileposts 51 and 59: 133.59 per 100,000 AADT

Figure 10 Toutle River interior of the northbound structure facing east on pathway (Stewart, 2019)

The 8 mile stretch north of the Toutle River bridge had been previously identified as the most likely area for a wildlife only crossing structure (Stewart 2019). The area between mileposts 51-59.3 stands out, due to a convergence of LCPs, and the high number of WVCs found within the area. In addition, when the Toutle River structure was assessed in 2019, the area associated with it was relatively “natural” and had minimal development. Camera monitoring is recommended for the entire area, along with feasibility studies on the validity of a wildlife only structure. Moreover, wildlife infrastructure like fencing and sound barriers, should be installed to connect the Toutle and Cowlitz River bridges (Fig. 11) (Stewart, 2019; WHCWG, 2010; WSDOT, 2016). Lastly, the Hill Creek culvert sits between milepost 53 and 57 and may be a decent crossing structure for some species. Unfortunately, this culvert was ranked as a priority 2 location in the previous research and data is not available for this structure (Stewart, 2019). Therefore, camera monitoring and the employment of PAS at this location is highly recommended.

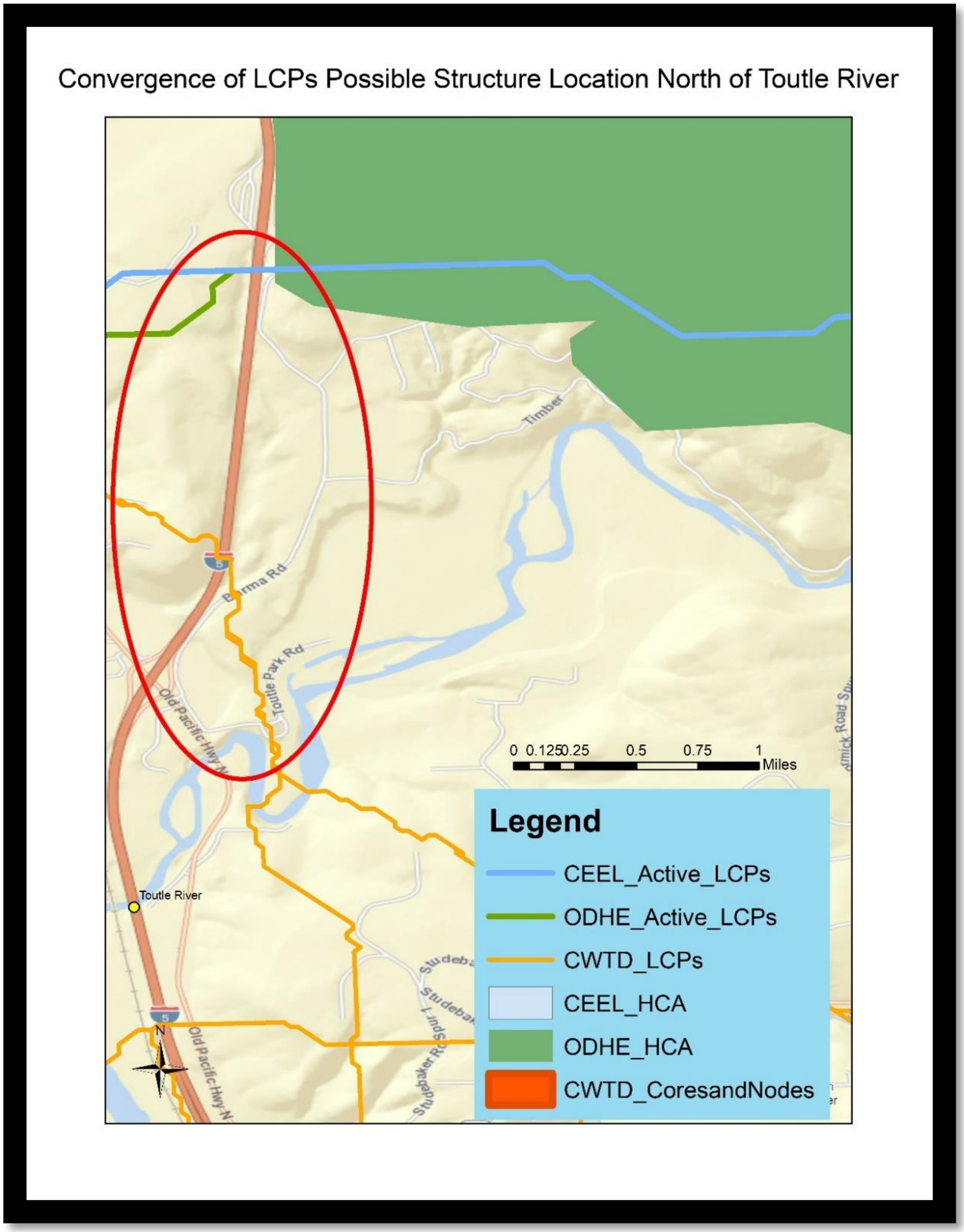

Figure 11 Convergence of LCPs North of Toutle River, Elk (CEEL) is represented by a blue line. Black-tailed deer (ODHE) is represented by a green line. Columbian white-tailed deer (CWTD) is represented by the orange line. The only visible HCAs (habitat) is black-tailed deer (ODHE_HCA) in green. The red circle encompasses the convergence area, and an area where further research should be done (ESRI et al., n.d.; Stewart, 2019; WHCWG, 2010; WSDOT, 2016).

4) **South of Prairie Creek**

Data associated with structures

- AADT: 68,000
- Milepost: 87.95
- Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 16.18
- WVC associated with the section of road between mileposts 80-95: 193.21per 100,000 AADT

Figure 12 Prairie Creek northbound structure interior facing south (Stewart, 2019)

There is a large section of Interstate between Scatter Creek and Salzer Creek between mileposts 80-95 that showed LCP convergences for the three focal ungulate species. The section is roughly 15 miles long and the LCPs are in different locations within the section of Interstate. Importantly, there exists a section that is centrally located between the LCPs that should be further evaluated for the possibility of building a wildlife only crossing structure. Scatter and Prairie Creeks are relatively small bridges that may pass deer and many other species for part of the year and may not pass them when water levels are higher. However, openness obligates like elk may not use these smaller, darker structures, as both are dark, loud and fall below WSDOT's recommended openness index[2] for elk (5.14) (Stewart, 2019). Salzer Creek may pass some species as it is large but is in a highly used agricultural area, has little canopy or cover, has cattle fencing on both the east and the west side, and has a high-volume frontage road to the west. In addition, the Skookumchuck River crossing is in a semi-developed area and is unlikely to pass most wildlife, although human adapted species may find this structure more attractive than human wary species. Camera monitoring could be employed at the Skookumchuck River structure to better understand what, if any, species are currently using it as a crossing structure. Ultimately, it may be best to find a location that sits in between the four mentioned locations for monitoring, further research and/or wildlife infrastructure (Fig. 13) (Stewart, 2019; WHCWG, 2010; WSDOT, 2016).

[2] Openness Index values, Scatter Creek=1.69, Prairie Creek 2.78

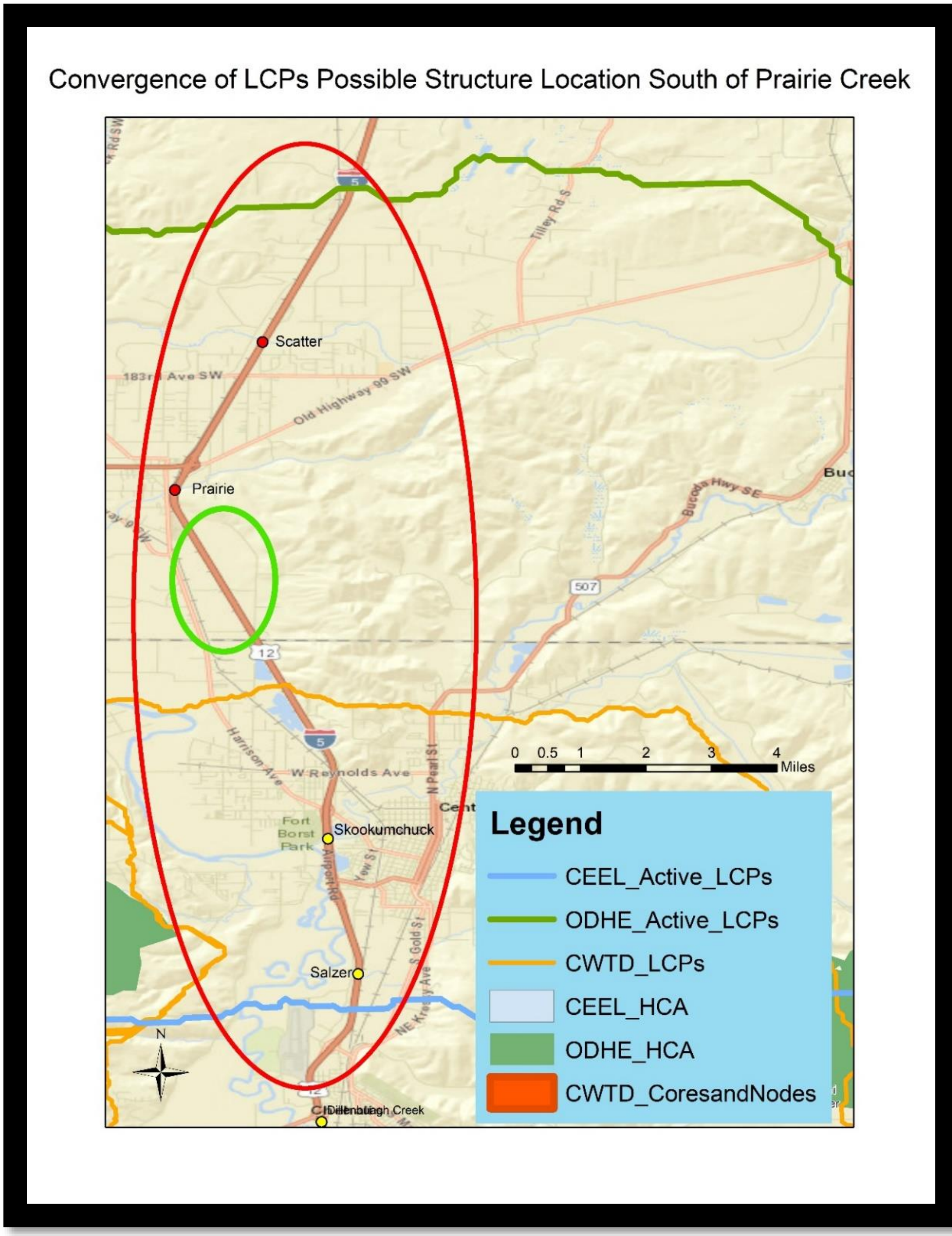

Figure 13 Convergence of LCP South of Prairie creek, North of the Skookumchuck Rivers. Elk (CEEL) is represented by a blue line. Black-tailed deer (ODHE) is represented by a green line. Columbian white-tailed deer (CWTD) is represented by the orange line. The only visible HCAs(habitat) is black-tailed deer (ODHE_HCA) in green. The red circle encompasses the convergence area, and the green circle identifies the area where further research should be done (ESRI et al., n.d.; Stewart, 2019; WHCWG, 2010; WSDOT, 2016).

5) Owl Creek

- AADT: 71,000
- Milepost: 35.81
- Jan 1st, 2014-Dec 31st, 2017, WVCs per 100,000 AADT associated with the location: 14.08

Figure 14 Owl Creek southbound on southside substrate facing creek (north), interior (Stewart, 2019).

Less than 0.33 miles away from the Owl Creek structure all three focal ungulate species LCPs converge and cross I-5. Owl Creek could be an excellent structure for wildlife if it was not for the commercial business there. The business has semi-trucks constantly driving on a gravel road that runs through the structure day and night. Moreover, the human presence at this location is constant, and litter and pollution are prevalent. This location has an active perennial creek that runs through it, but the waterway is in need of restoration. WSDOT cameras have caught different species utilizing this structure, but the Columbian black-tailed deer (*Odocoileus hemionus columbianus)* are the most frequently captured species at this structure. Overall, this location could benefit from fencing and other infrastructure to keep wildlife off the Interstate. Finally, this structure could be beneficial for connecting the ecology of the landscape, and passing local wildlife, if not for the commercial activity. Unfortunately, unless the current commercial usage is halted or limited, this location will only be attractive to bold wildlife that are acclimated and adapted to human presence and loud mechanical noises (Fig. 15) (Stewart, 2019).

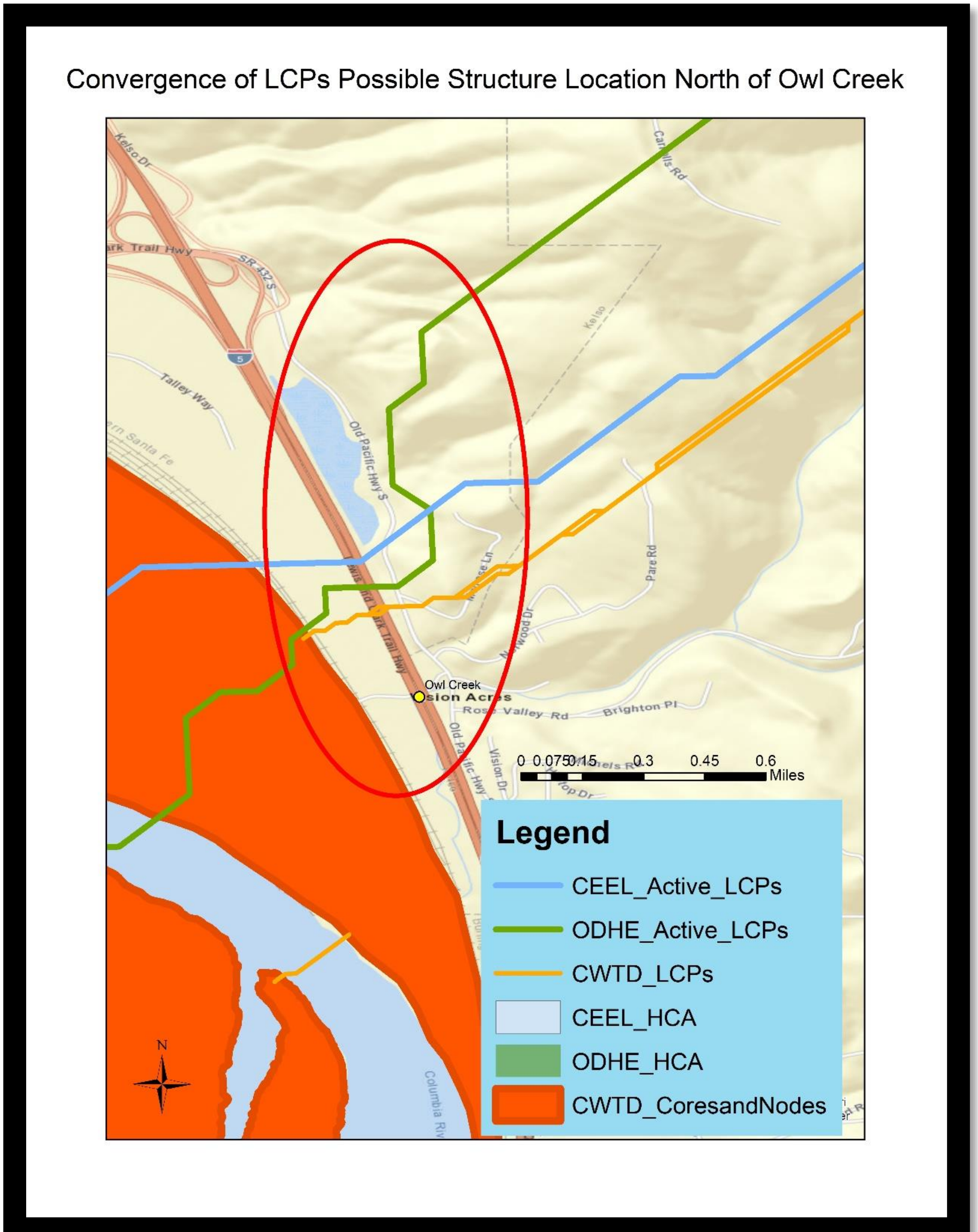

Figure 15 Convergence of ungulate LCPs north of Owl creek., Elk (CEEL) is represented by a blue line. Black-tailed deer (ODHE) is represented by a green line. Columbian white-tailed deer (CWTD) is represented by the orange line. The only visible HCAs(habitat) is Columbian white-tailed deer(CWTD) in orange (ESRI et al., n.d.; Stewart, 2019; WHCWG, 2010; WSDOT, 2016).

Methods

This paper analyzed and summarized previous ungulate connectivity mapping research in the region. Admittedly, these were the only maps that encompassed I-5 in S.W. Washington with enough detail to be analyzed. (WHCWG, 2010; WSDOT, 2016). These maps were compared to one another and analyzed with ungulate PAS rankings to show where corridors may exist (Kintsch & Cramer, 2011). In addition, these maps were compared to State land-use (2010) and National land cover (2011) maps to help identify areas where monitoring, investment, enhancements and research may be most advantageous (Homer et al., 2015; MRLC, 2011; State Land Use 2010 ECY, 2010). Another tactic this report utilized to locate structures with ecological importance, was to average PAS rankings for six species guilds from previous assessments. PAS average rankings can aid agency planners and conservationists by identifying a structures overall potential for enhancement in two ways. First, structures with high PAS averages have traits that are attractive to many different species' guilds simultaneously. Thus, maximizing the overall benefit of a project for as many species as possible, while minimizing the costs associated with numerous species-specific projects. Second, structures identified with low averages (C and Fs), may have obstacles for numerous species, thus, highlighting structures in need of improvements (Kintsch & Cramer, 2011; Stewart, 2019). This paper relies on data provided by WSDOT for a graduate thesis researching the permeability of I-5 in S.W. Washington. Stewart (2019) summarized wildlife-vehicle conflicts (WVC[3]) data (Jan 1st, 2014 – Dec 31st, 2017) by normalizing the data to better represent the probability of hitting an animal by evaluating the WVC

[3] An aggregated dataset of combined carcass removals and collision reports.

data per 100,000 annual average daily traffic (AADT), this paper continues using WVC per 100,000 AADT (Stewart, 2019).

Results

Average PAS Rankings and WVC Mapping

Combining PAS rankings for each guild at each surveyed location and then averaging the totals, resulted in a new GIS map (Fig.16) (Kintsch & Cramer, 2011; Stewart, 2019)**.** Additionally, WVC data from a previous study was added to the GIS layer file to illustrate WVCs per 100,000 AADT associated with each location (Fig. 16). Interestingly, both the Newaukum and Skookumchuck structures have high numbers of WVCs, and have an average PAS ranking of A. Also, there appears to be a trend showing that WVC per 100,000 AADT numbers decline as one approaches the larger city centers in the north (Tumwater) and south (Longview). Applying averages of PAS rankings to each location resulted in 6 A ranked structures, 13 C ranked structures, and only 1 F ranked structure. Importantly, averages may represent an overall snapshot of the potential of a structure to accommodate as many species as possible, when appropriate enhancements and retrofits are made.

Locations that averaged an A PAS ranking: Skookumchuck River; Newaukum River; Lacamas Creek[4]; Cowlitz River; Lewis River; East Fork Lewis River.

[4] Previous camera monitoring showed high numbers of black-tailed deer using this structure (Stewart 2019).

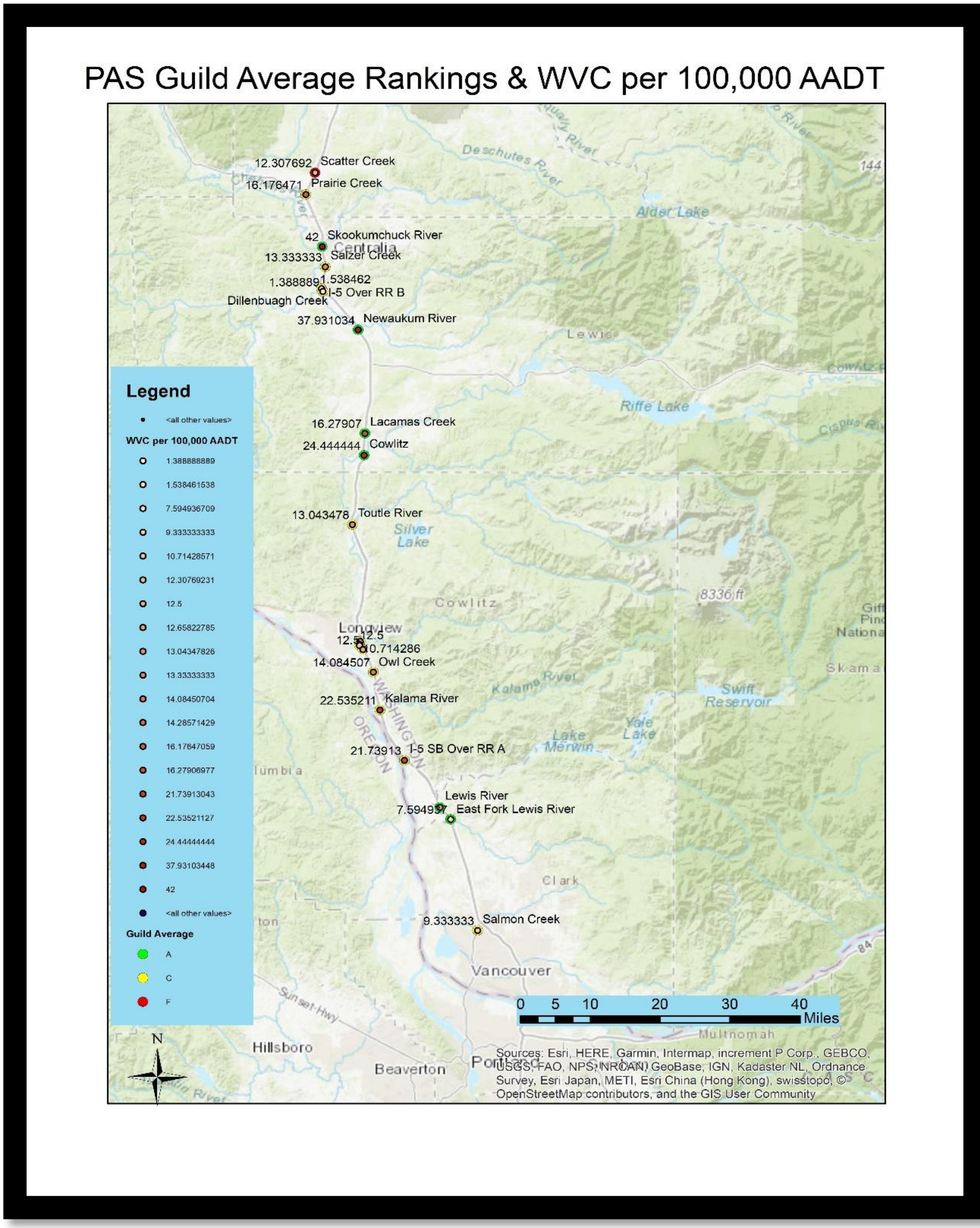

Figure 16 Wildlife-vehicle conflicts (WVC) per 100,000 AADT associated with +/- 0.5 miles on either side of each structure are represented with inside dots yellow (low), orange (medium) red (high). Average PAS guild rankings are represented by the outside border color of each point. Green equals an A (best crossing, may still need some retrofitting/enhancements), Yellow equals a C (good crossing, but is need of major retrofit or enchantment for permeability), Red equals F (not permeable not able to retrofit or enhance at this time (Kintsch & Cramer, 2011; Stewart, 2019; WSDOT, 2018a).

Location Land use and Land Cover Visualization

This paper utilized simple visualizations of landcover/use, to prioritize locations with the most “naturalness”, intact forest, habitat, working lands and public lands. The Skookumchuck River location had the highest amount of WVCs per 100,000 AADT during the period analyzed in previous research and has an average PAS guild ranking of A (Kintsch & Cramer, 2011; Stewart, 2019). Furthermore, the area is surrounded by development, with only mall patches of forest, and city parks within the area (Fig. 17). The Newaukum River was shown to have the second highest amount of WVCs of locations surveyed in previous research and was assigned an average PAS ranking of A (Kintsch & Cramer, 2011; Stewart, 2019). Interestingly, the location has far less development around it than the Skookumchuck location, with mostly agricultural land in the nearby vicinity. However, there are small patches of forest and undeveloped patches of land close to this structure as well (Fig. 18).

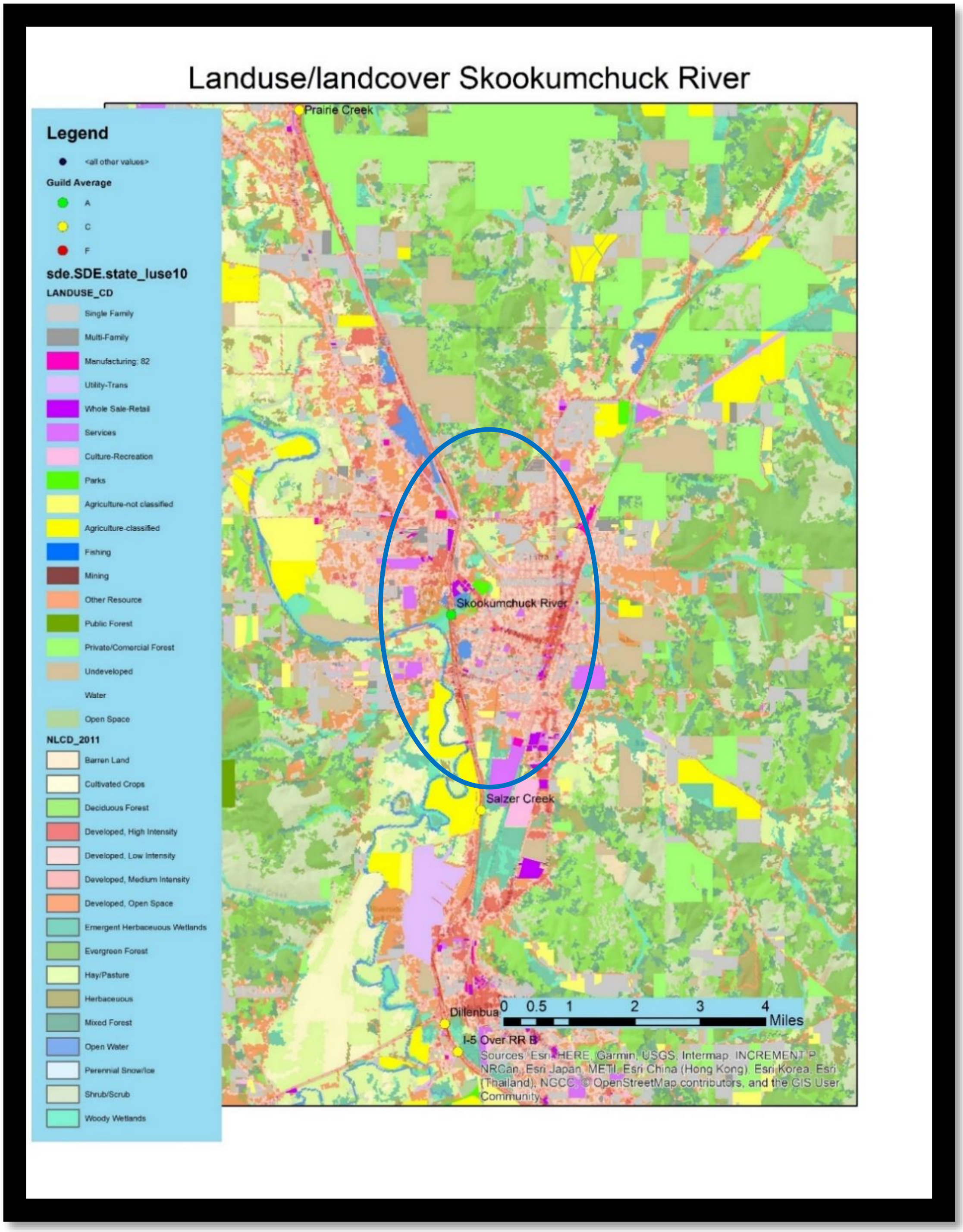

Figure 17 Land cover and Land use map of the area around the Skookumchuck crossing structure on I-5. In addition, PAS average ranks for structures have been included. Shades of green (forests, public lands) are the best general landcover/use, Yellow and white (agriculture, open land, cultivated crops) better than urban areas, Shades of red/purple and gray are developed (commercial, homes, industrial) the redder the more urban. Shades of blue represent wetlands and open water (woody wetlands, herbaceous wetlands) (Kintsch & Cramer, 2011; MRLC, 2011; State Land Use 2010 ECY, 2010).

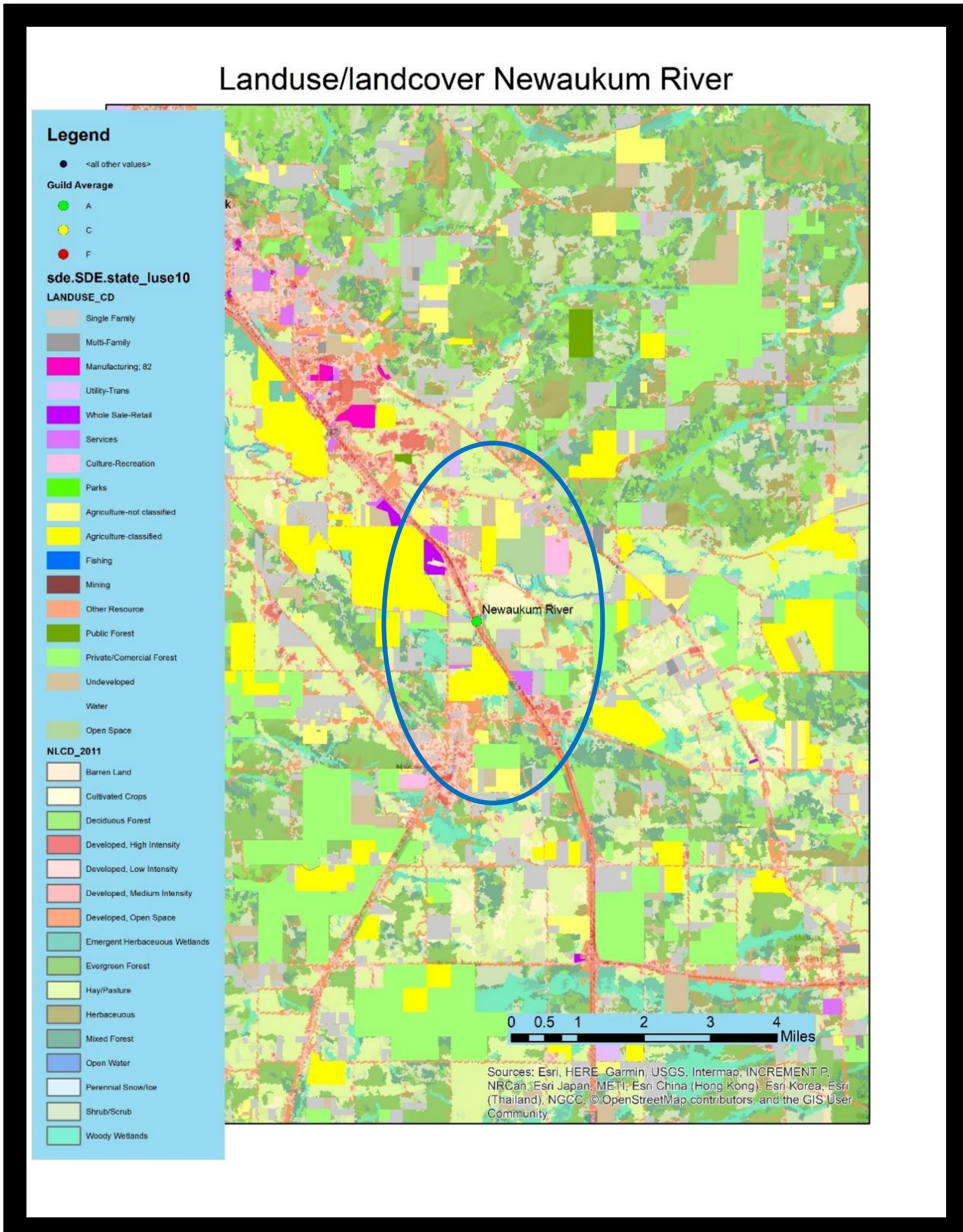

Figure 18 Land cover and land use for the area around the Newaukum River crossing structure on I-5. In addition, PAS guild average rankings have been included. Shades of green (forests, public lands) are the best general landcover/use, Yellow and white (agriculture, open land, cultivated crops) better than urban areas, Shades of red/purple and gray are developed (commercial, homes, industrial) the redder the more urban Shades of blue represent wetlands and open water (woody wetlands, herbaceous wetlands) (Kintsch & Cramer, 2011; MRLC, 2011; State Land Use 2010 ECY, 2010).

The Toutle River area is a ~9.0 mile stretch of I-5 extending north from the structure and it has been identified as the most likely area for a wildlife crossing structure by previous research (Stewart, 2019). Furthermore, the some of the mileposts with the highest amounts of WVC not associated with structures were found 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 133.59 WVC/100,000 AADT" (Stewart, 2019). Importantly, this area has a culvert (Hill Creek) that is centrally located within the identified area. However, it has not been evaluated by previous research or monitored, this paper recommends further evaluation of the Hill Creek culvert. Regardless, this area possesses the largest tract of "natural" landscape and is the only location near publicly protected land. There is very little development in the area and what exists is not as dense as other locations evaluated for this paper (Fig. 19).

The Owl Creek location has also been identified as an important location due to a convergence of ungulate LCPs found just to the north (0.33 miles) of the structures (Fig. 20) (Stewart, 2019;WHCWG, 2010; WSDOT, 2016). There are some intact "natural" areas to the west, but development is equally present at this location. To the west there is good woody wetland habitat, bordered by the river. Nevertheless, the constant commercial use and human presence at this structure means that regardless of surrounding landcover/use only the most human adapted species will find this route across I-5 attractive.

South of Prairie Creek was also identified by previous research for future research and monitoring, because Black-tailed deer have LCPs in the north, Columbian white-tailed deer have LCPs in the middle and elk have LCPs in the south, the location was chosen based on its centrality to the identified LCPs structures (Fig.21) (Stewart, 2019;WHCWG, 2010; WSDOT, 2016). The 15-mile section of road encompasses four structures and is associated with 193.21 WVC per 100,000 AADT. The Prairie Creek location has a fair amount of development to the south, and to the north. However, there is decent “naturalness” in the vicinity, although not abundant, it does stand out as having natural landscape type features to the west, while development and active agricultural fields are present to the east of the structure

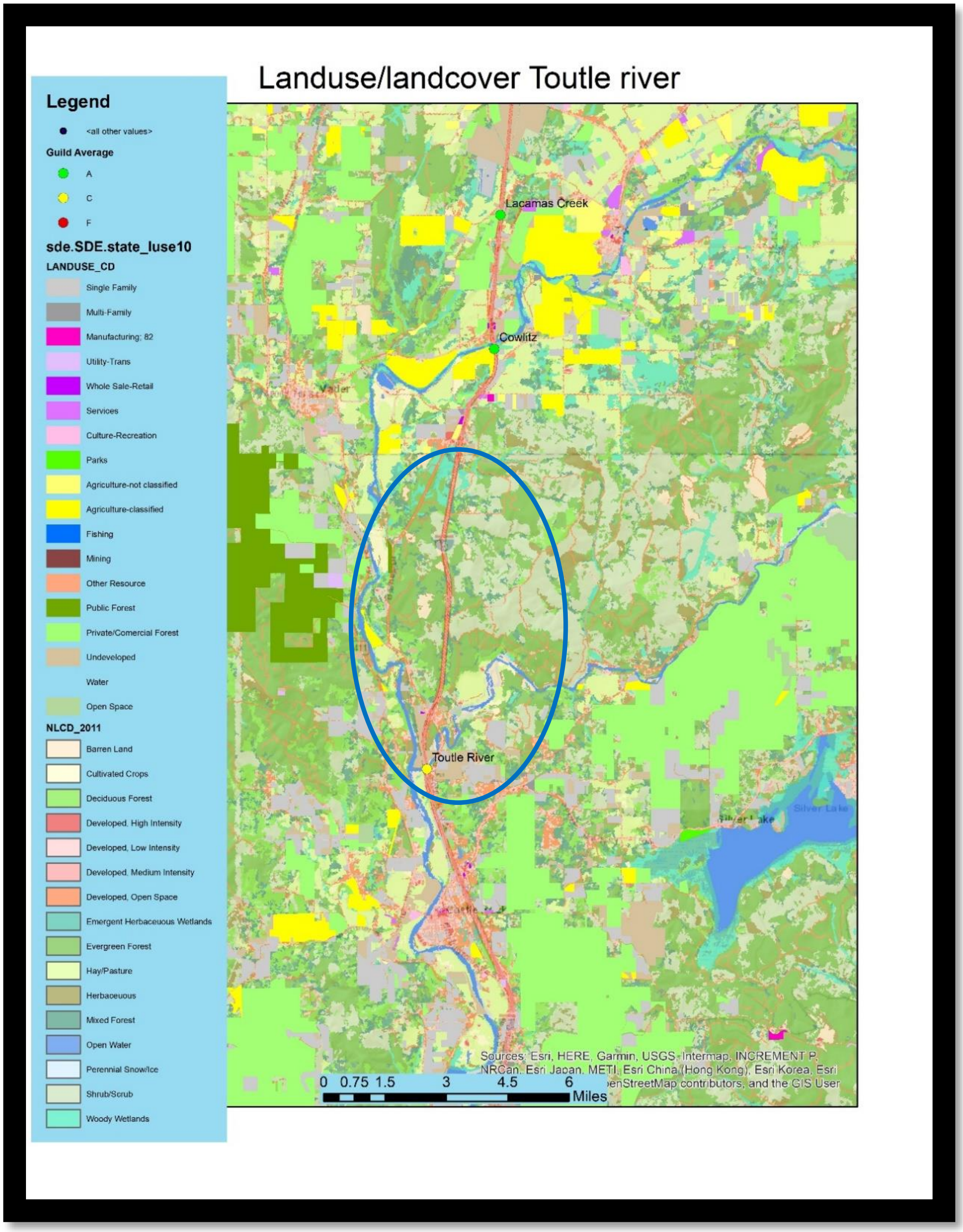

Figure 19 Land cover and land use for the area around the Toutle River crossing structure on I-5. In addition, PAS guild average rankings have been included. Shades of green (forests, public lands) are the best general landcover/use, Yellow and white (agriculture, open land, cultivated crops) better than urban areas, Shades of red/purple and gray are developed (commercial, homes, industrial) the redder the more urban. Shades of blue represent wetlands and open water (woody wetlands, herbaceous wetlands) (Kintsch & Cramer, 2011; MRLC, 2011; State Land Use 2010 ECY, 2010).

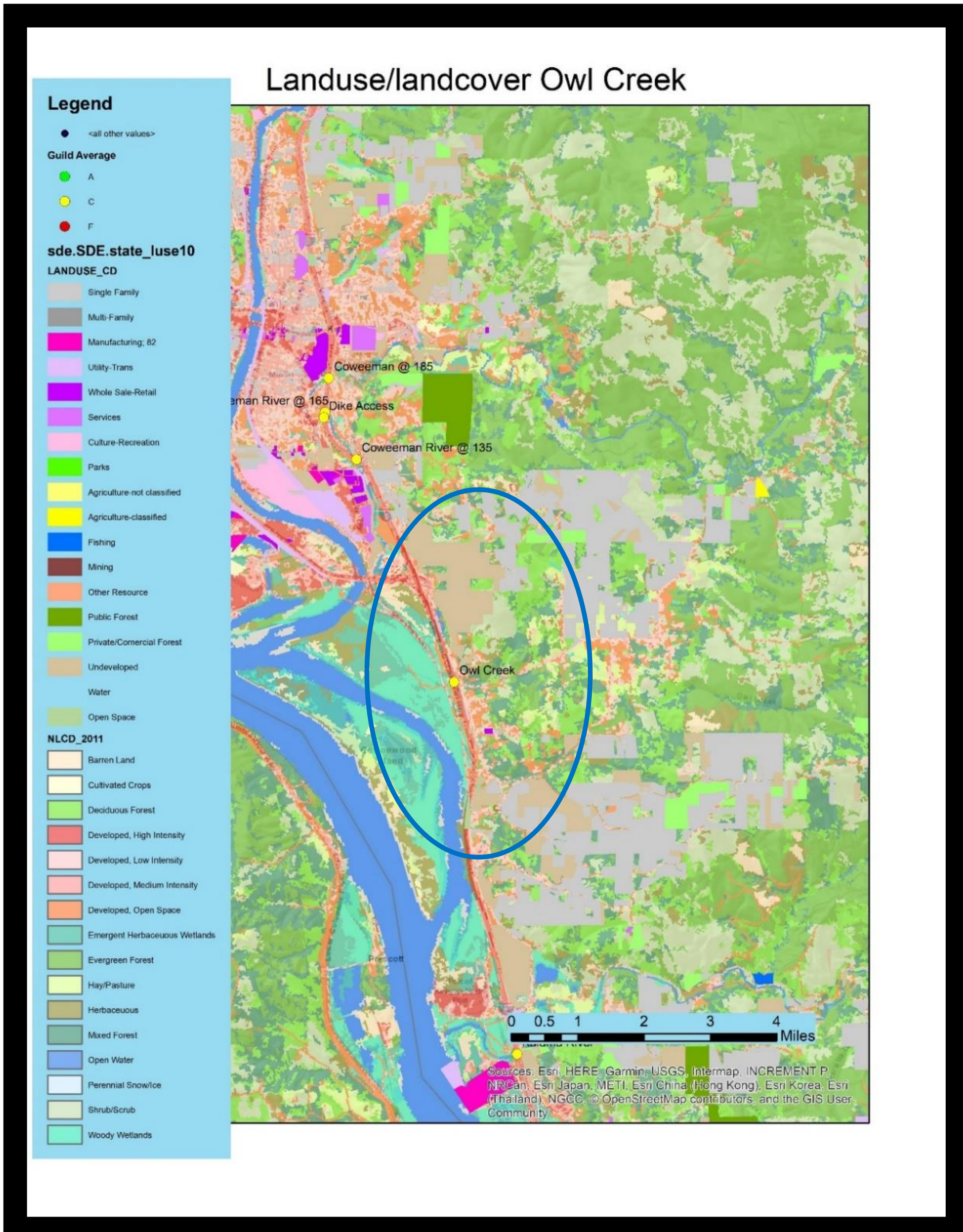

Figure 20 Land cover and land use for the area around the Owl Creek crossing structure on I-5. In addition, PAS guild average rankings have been included. Shades of green (forests, public lands) are the best general landcover/use, Yellow and white (agriculture, open land, cultivated crops) better than urban areas, Shades of red/purple and gray are developed (commercial, homes, industrial) the redder the more urban. Shades of blue represent wetlands and open water (woody wetlands, herbaceous wetlands) (Kintsch & Cramer, 2011; MRLC, 2011; State Land Use 2010 ECY, 2010).

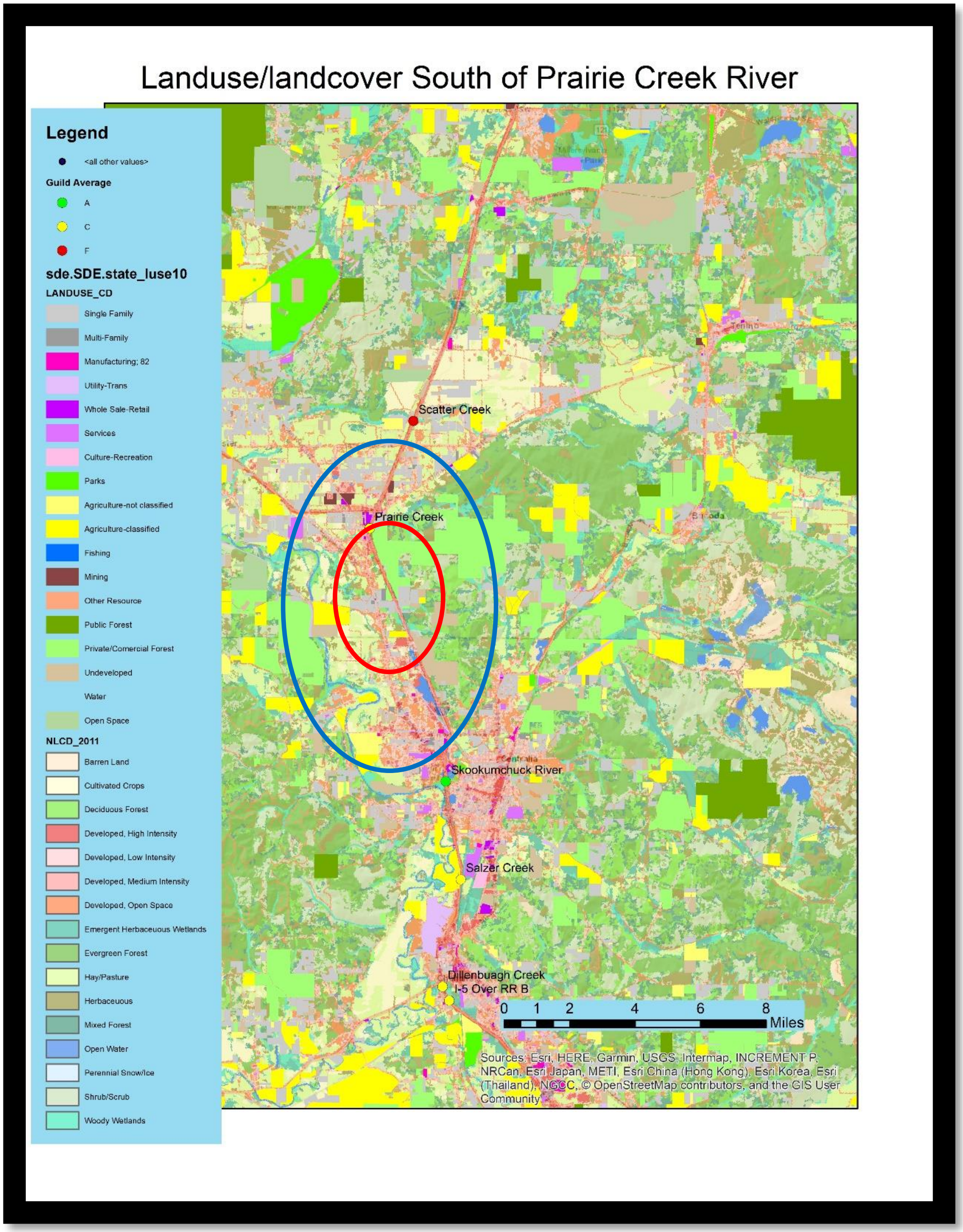

Figure 21 Land cover and land use for the area around the South of the Prairie Creek crossing structure on I-5. In addition, PAS guild average rankings have been included. Shades of green (forests, public lands) are the best general landcover/use, Yellow and white (agriculture, open land, cultivated crops) better than urban areas, Shades of red/purple and gray are developed (commercial, homes, industrial) the redder the more urban. Shades of blue represent wetlands and open water (woody wetlands, herbaceous wetlands) (Kintsch & Cramer, 2011; MRLC, 2011; State Land Use 2010 ECY, 2010).

Conclusion & Recommendations

Of the five locations evaluated for this paper, three stand out as being high priorities for conservation and connectivity efforts. Importantly, all the locations evaluated in this report are significant to overall landscape connectivity. Thus, all locations should be monitored, and allocated investments to improve reginal connectivity. General enhancements, like wildlife fencing and corridor restoration would be beneficial at every crossing structure on I-5.

Top Three priority locations in order of importance

- **Area North of the Toutle river and the Toutle river crossing.**

  Area has the most “natural” land and public land around it, has LCP convergence and has a location with higher than average WVCs per 100,000 AADT associated with it.

- **Area South of Prairie creek and North of the Skookumchuck**

  Area has a fair amount of “natural” area on either side of it, and it is a central location for three different ungulate LCPs.

- **Newaukum River location**

  Area has some “natural” patches and is on a riparian corridor but is heavily surrounded by agriculture. In addition, this location was found to have the second highest number of WVCs associated with a large structure.

Stewart (2019) summarized a list of general enhancements from prior research that could be employed at any given structure. However, they are not site specific and have to be investigated by WSDOT biologist/engineers before design or implementation.

"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, Patton, & VerCauteren, 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, Dole, Sauvajot, Riley, & Valone, 2005). Remove or fill areas that may be seen as predator perches by prey species (Little, Harcour, & Clevenger, 2002)." (Kintsch & Cramer, 2011; Stewart, 2019).

Stewart (2019) made site-specific recommendations for the three prioritized structures evaluated in this paper. Importantly, both the Toutle River area and Prairie Creek area are long stretches of road, 9 and 15 miles in length respectively. Site specific recommendations will not be applicable to these areas, only to the structures themselves. Adding long tracks of fencing, and enhancing the structures closest to these areas, may act to funnel wildlife to existing structures that have been enhanced and restored to be safer and more attractive to local species. Another possible solution is to add wildlife only crossing structures somewhere in these areas. Lastly, because each structure is ecologically important and the Skookumchuck River is associated with the Prairie Creek area, site specific enhancements are being proposed for all of the locations evaluated by this paper (Stewart, 2019).

Recommendations[5]

1. **North of the Toutle river**

The entire stretch of Interstate between the Toutle and the Cowlitz Rivers should be monitored for wildlife activity, and general enhancements like fencing, restoration, and limiting human usage should be employed. Overall, adding fencing and enhancing structures could greatly increase permeability and decrease WVCs associated with the locations. Many of the general recommendations apply to this location's associated structure. Finally, this may be the best location to evaluate installing a wildlife only over/underpass. Next steps for this area 1) employ camera monitoring 2) engage in more

[5] All locations and recommendations should be evaluated by WSDOT staff before implementation.

robust analysis of data associated with the structure; 3) start collecting information as to what counties, landowners and cities should be approached and consulted as to the possibility of a wildlife only structure. Also, future development plans should be scrutinized and analyzed in order to protect this area moving into the future. Unlike many of the areas on I-5, this section has mostly "natural" surroundings and should be conserved in perpetuity, for wildlife and the people of Washington State. Ultimately, this area appears to be the only feasible location for a wildlife only structure and should be monitored, researched, and conserved with that in mind.

2. South of Prairie Creek (North of the Skookumchuck River)

This location is between two structures the Skookumchuck River crossing to the South and the Prairie Creek crossing to the North. Many of the general recommendations for enhancements apply to both structures. In contrast to the area north of the Toutle River, this area has far denser development associated with it, this may mean a wildlife only structure would not be feasible at this location. Enhancing these areas with better structures at Prairie Creek and the Skookumchuck River, installing wildlife fencing along both sides of the freeway, may decrease WVCs, and help wildlife navigate I-5 more effectively. Engaging stakeholders and landowners in the area could act as a catalyst for a community supported effort developed in good faith. This type of effort acknowledges the concerns, well-being, lively hoods and opinions of the community in order to develop plans that are wanted and that will garner long term support. Overall, conserving land

and halting development at this location could maintain the opportunities for future structures or the enhancement of existing ones, while conserving land that may be important linkages for local wildlife. Lastly, both structures and some of the surrounding area should be monitored for wildlife usage.

3. Newaukum River

This is a single location structure with a higher than average amount of WVCs associated with it. Additionally, this area was shown to have an average PAS ranking of A, illustrating that the structure may have the potential to facilitate connectivity under I-5 for numerous species if enhancements/retrofits are made. Many of the general recommendations summarized in earlier research are applicable at this location (Stewart, 2019). Site specific recommendations:

> "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." (Stewart, 2019).

Enhancing structures associated with high numbers of WVCs with fencing should decrease overall incidents in the area and increase overall safety for wildlife and motorists. This location is a key riparian corridor within the Chehalis Basin, which is important for climate change adaptation for a multitude of local species and critical habitat for others. Conservation at this location should include getting landowner participation, easements and possible acquisition of flood prone areas along the riparian corridor. This is an excellent location for camera monitoring studies to be initiated Increasing buffers along waterways and improving the structure may help facilitate movement for many species. Furthermore, restoring and conserving the entire corridor in combination with enhancing structures at roadways could create a single connected corridor from the Coast to the Cascades. Lastly, this area sits on the outskirts of areas that are currently developing, it may be time to scrutinize development plans and halt new development when it conflicts with the health of this, or any functioning riparian corridor.

4. Owl Creek

General enhancement recommendations are applicable at the Owl Creek structure. Owl Creek is located near the convergence of ungulate LCPs and could be an excellent location for a wildlife crossing. Unfortunately, the location is near development and is highly used by semi-trucks, reflected in the Stewart (2019) recommendation quote:

> "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." (Stewart, 2019).

Advocating for fencing and other wildlife infrastructure in general will benefit wildlife and motorists. However, the key to this location is to remove or halt the commercial use of this underpass. While the location is utilized in this way, one can only expect the most human adapted generalist to consistently use this location as a crossing structure, even if significant enhancements are made.

5. Skookumchuck River

This structure is in an urbanized area, and it boasts the highest number of WVCs per 100,000 AADT on I-5 in S.W. Washington associated with a large structure. Moreover, the area between the Skookumchuck River and the Newaukum River structures had a high volume of WVC per 100,000 AADT. Due to the high number of WVCs at both the structure and the area around the structure, fencing is strongly recommended at this location and for as many miles as possible to the north and to the south. It may be advantageous to use wildlife fencing to connect both structures, funneling wildlife to one structure and/or the other. The general recommendations are also applicable to this structure, site specific recommendations are taken from the Stewart (2019) research:

"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).” (Stewart, 2019). Conservation value may be in the riparian corridor itself, maintaining or converting the small “natural” patches could be key for helping some species adapt to climate change, and may preserve key ecological processes within the Chehalis basin.

Next Steps

The Pacific Northwest Landscape Conservation Design and the Washington Habitat Connectivity Working Group are currently mapping connectivity for several focal species in S.W. Washington. The results of this effort should be utilized to help validate the recommendations and findings of this paper. Whatever results are produced, the maps will help to illustrate the potential and current permeability of the landscape including corridors that intersect with I-5. In the meantime, efforts should be made to begin the work of approaching landowners, agencies and stakeholder groups with the goal of communicating and facilitating conversations about increasing permeability across I-5 in S.W. Washington. Lastly, the areas and structures identified in this report should be actively monitored with cameras, more structures should be assessed, and efforts should continue to quantify WVC data.

Combing Terrestrial Connectivity Efforts with Riparian and Aquatic Restoration Projects

Currently, Washington State is working on repairing and restoring culverts to allow fish passage. Furthermore, areas in the Chehalis Basin will be subject to an aquatic habitat restoration program, via a plan attached to the possible building of a water retention facility in Pe Ell, Washington. Many of the structures that prohibit terrestrial wildlife connectivity are located on riparian corridors. Corridors that may be critical for many terrestrial species to adapt to a changing climate. Implementing habitat restoration for aquatic species should include terrestrial considerations (i.e. wildlife fencing, more permeable structures, buffers, restored riparian vegetation, improved canopy). By including terrestrial conservation/restoration efforts with aquatic efforts, entire ecological processes may be restored and preserved.

Conclusion

I-5 in S.W. Washington has many structures and culverts where wildlife could cross under. However, human presence, development and lack of quality habitat or "natural" areas makes the likelihood of many species utilizing them as such low. Regardless, more camera monitoring should be conducted at all prioritized locations to gain a better understanding of which species are present and attempting to use these structures to navigate I-5. Overall, the Toutle River area stands out on I-5 as the most likely for conserving ecological connectivity or building a wildlife only structure. It is recommended the area North of Toutle River and the Toutle River structure be enhanced for wildlife (i.e. fencing, restoration, retrofits etc..). Additionally, it is advised that the land paralleling the 9 mile stretch of I-5, be conserved and preserved as it is one of the few places on the I-5 that has an abundance of "natural" areas associated with known wildlife ungulate LCPs. Similar recommendations have been made for the area South of Prairie Creek, although it does not have the natural landscape found at the Toutle River or the tight convergence of known ungulate least-cost paths. Due to a higher than average number of WVCs and a lightly developed surrounding, recommendations for enhancements have been made for the Newaukum River as well. Lastly, although Owl Creek and the Skookumchuck River were not considered to be one of the top three locations for conservation or enhancement prioritization, recommendations were made regardless.

Ultimately, opportunities for conservation and connectivity along I-5 are limited due existing development. Furthermore, the I-5 corridor is always being developed, so it is urgent that conservation and connectivity plans are developed, put into place, and implemented soon. As opportunities disappear, acquisitions and conservation of lands surrounding the prioritized structures/location areas become paramount to facilitating landscape permeability and enhancing wildlife's ability to adapt to a changing climate. Additionally, I-5 runs over numerous riparian corridors which are key corridors for both ecological processes and providing migrating routes and/or climate refugia for local wildlife. Another added benefit to installing fencing and providing wildlife structure permeability (via wildlife infrastructure) is the reduction in wildlife-vehicle conflicts, improving safety for local wildlife and motorists simultaneously. Lastly, improving connectivity across I-5 is possible and achievable, but needs to be done quickly due to climate change and the lack of intact landscape along the I-5 corridor. Agencies, non-profits, stakeholders and landowners, will need to collaborate and communicate in order to pursue those avenues that present the greatest potential of increasing permeability for local wildlife, while being practical and engaging the communities where they must exist.

References

Bissonette, J. A., & Hammer, M. (2000). *Effectiveness of earthen ramps in reducing big game highway mortality in Utah: Final Report* (pp. 1–29) [Research unit report series 2000]. Retrieved from Utah Cooperative Fish and Wildlife website: http://www.azdot.gov/highways/epg/epg_Common/pdf/technical/wildlife_connectivity/Widlife_connectivity/description_of_widlife_escape_measures.pdf

Capon, S. J., Chambers, L. E., Mac Nally, R., Naiman, R. J., Davies, P., Marshall, N., … Williams, S. E. (2013). Riparian ecosystems in the 21st century: hotspots for climate change adaptations. *Ecosystems*, *16*, 359–381.

Clevenger, A. P., & Waltho, N. (2004). Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation*, (121), 453–464. https://doi.org/10.1016/j.biocon.2004.04.025

Ehinger, W., Garvey-Darda, P., Gersib, R., Halupka, K., McQueary, P., Meyer, W., … Wagner, P. (2006). *Interstate 90 Snoqualmie pass east mitigation development team: recommendation package.* [Recommendation]. U.S. Department of transportation, Federal Highway Administration, and Washington State Department of Transportation.

ESRI. (2018). *ArcMap Desktop. Geographical Information Systems GIS.*

ESRI, Garmin, USGS, Intermap, INCREMENT P, NRCAN, … GIS User community. (n.d.). *Open Street Map*.

Forman, R. T. T. (2003). *Road Ecology: Science and Solutions*. Island Press.

Forman, R. T. T., & Alexander, L. E. (1998). ROADS AND THEIR MAJOR ECOLOGICAL EFFECTS. *Annual Review of Ecology and Systematics*, *29*(1), 207–231. https://doi.org/10.1146/annurev.ecolsys.29.1.207

Fremier, A. K., Kiparsky, M., Gmur, S., Aycrigg, J., Craig, K. K., & Svancara, L. K. (2013). A riparian conservation netwrok for ecological resilience. *Biological Conservation*, *191*, 39–37.

Gardali, T., Holmes, A. L., Small, S. L., Nur, N., Geupel, G. R., & Golet, G. H. (2006). Abundance patterns in restored and remnant riparian forests on the Sacremento River, California, USA. *Restoration Ecology*, *14*, 391–403.

Golet, G. H., Gardali, T., Howell, C. A., Hunt, J., Custer, R. ., & Et, al. (2006). Wildlife Response to Riparian Restoration on the Sacramento River. *Estuary & Watershed Science*, *6*. https://doi.org/10.1111/j.1526-100X.2006.00147.x

Hartmann, M. (2003). *Evaluation of wildlife crossing structures:their use and effectiveness*.

Homer, G., Dewitz, J. A., Yang, L., Jin, S., Danielson, P., Coulstan, J., … Megown, K. (2015). Completion of the 2011 national land cover database for the conterminous United States-representing a decade of land cover change information. *Photogrammetric Enginnering and Remote Sensing*, *81*(5), 345–354.

Huijser, M. P., Fairbank, E. R., Camel-Means, W., Graham, J., watson, V., Pat Basting, & Becker, D. (2016). Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife-vehicle collisions and providing safe crossing opportunities for large mammals. *Biological Conservation*, (197), 61–68.

IPCC. (2013). *Intergovernmental Panel on Climate Change (IPCC),IPCC Fifth Assessment Report, Working Group I Report* (No. 5). Retrieved from http://www.ipcc.ch/report/ar5/wg1/#.UqI6miTHRow

Jackson, S. D. (2000). Overview of transportation impacts on wildlife movement. Wildife and Highways: seeking solutions to an ecological and socio-economic dilemma. *The Wildlife Society*.

Kintsch, J., & Cramer, P. (2011). *Permeability of Existing Structures for Terrestrial Wildlife: A Passage Assessment System* (No. WA-RD 777.1). Washington State Department of Transportation, Office of Research & Library Services.

Kintsch, J., Jacobsen, S., & Cramer, P. (2015). *The Wildlife Crossing Guilds Decision Framework: A Behavior-based Approach to Designing Effective Wildlife Crossing Structures*. Retrieved from Retrieved from http://www.icoet.net/ICOET_2015/program-proceedings.asp

Krosby, M., Theobald, D. M., Norheim, R., & McRae, B. H. (2018). Identifying riparian climate corridors to inform climate adaptation planning. *PLOS ONE*, *13*(11), e0205156. https://doi.org/10.1371/journal.pone.0205156

Little, S. J., Harcour, A. ., & Clevenger, A. P. (2002). Do wildlife passages act as prey-traps? *Biological Conservation*, (107), 135–145.

McCollister, M. F., & van Manen, F. T. (2010). Effectiveness of Wildlife Underpasses and Fencing to Reduce Wildlife–Vehicle Collisions. *Journal of Wildlife Management*, *74*(8), 1722–1731. https://doi.org/10.2193/2009-535

MRLC. (2011). *National land cover databse 2011 (NLCD 2011)* [GIS]. Multi-Resolution Land Characteristics Consortium (MRLC) (.

Ng, S., Dole, J., Sauvajot, R., Riley, S., & Valone, T. (2005). Use of highway undercrossings by wildlife in southern California. *Biological Conservation*, (121), 453–507.

Romin, L.A., Bissonette, J.A (1996) *Deer: Vehicle Collisions: Status of State Monitoring Activities and Mitigation Efforts*. Wildlife Society Bulletin. 24 (2) pg.276-283 http://www.jstor.org/stable/3783118

Seamans, T., Patton, Z. J., & VerCauteren, T. W. (n.d.). *Electrobraid fencing for use as a deer barrier*. Retrieved from ICOET website: http://www.itre.ncsu.edu/cte/icoet

Seavey, N. E., Gardali, T., Golet, G. H., Griggs, F. T., Howell, C. A., Kelsey, R., … Weigand, J. F. (2009). Why climate change makes riparian restoration more important than ever: recommendations for practice and research. *Ecological Restoration*, *27*, 330–338.

Sgrò, C. M., Lowe, A. J., & Hoffmann, A. A. (2011). Building evolutionary resilience for conserving biodiversity under climate change. *Evolutionary Applications*, *4*(2), 326–337. https://doi.org/10.1111/j.1752-4571.2010.00157.x

Shilling, F., Collins, A., Louderback, A., Farman, P., Guarnieri, M., Longcore, T., … Knapp, H. (2018). *Wildlife-Crossing mitigation effectiveness with traffic noise and light. A research report from the National Center for Sustainable Transportation.* (p. 14) [Research]. UCDAVIS, Road Ecology Center: National Center for Sustainable Transportation.

Snover, A. ., Mauger, G. ., Whitely Binder, L. C., Krosby, M., & Tohver, I. (2013). *Climate Chnage Impacts and adaptation in Washington State: technical Summaries for Decision makers* [State of knowledge report prepared for the Washington state Department of Ecology]. Retrieved from Cliamet Impacts Group website: http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

Spellerberg, I. (1998). Ecological effects of roads and traffic: a literature review. *Global Ecology & Biogeography Letters*, *7*(5), 317–333. https://doi.org/10.1046/j.1466-822x.1998.00308.x

State Land Use 2010 ECY [GIS Arcmap]. (2010). In *State Land USE*. Retrieved from https://fortress.wa.gov/ecy/gispublic/DataDownload/ECY_CAD_Landuse2010.htm

Stewart, B. C. (2019). *Assessing the permeability of large underpasses and viaducts on I-5 in Southwest Washington for wildlife, with an emphasis on ungulates.* Evergreen State College, Olympia, Washington.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., … Williams, S. E. (2004). Extinction risk from climate change. *Nature*, *427*(6970), 145. https://doi.org/10.1038/nature02121

Washington Wildlife Habitat Connectivity Working Group (WHCWG. (2010). *Washington connected landscape project: Statewide analysis*. Retrieved from Washington Departments of Fish and Wildlife, and Transportation website: http://waconnected.org/statewide-analysis/

Washington Wildlife Habitat Connectivity Working Group (WHCWG. (2011). *Washington Connected Landscapes Project: ClimateGradient Corridors Report*. Retrieved from Washington Departments of Fish and Wildlife, and Transportation website: http://www.waconnected.org

WSDOT. (2016). *Columbian White-tailed deer (odocoileus virginianus leucurus) Habitat connectivty analysis.* (p. 34). Olympia, Washington: Washington State Department of Transportation.

WSDOT. (2018a). *Collision & Collison Data_retrevied from Beist & Hats*. Olympia, Washington: Washington State Department of Transportation.

WSDOT. (2018b). *Reducing the risk of wildlife collisions*. Retrieved from Washington State Department of Transportation website: www.wsdot.wa.gov/environment/protecting/wildlife-collisions

Yinhai Wang, Yunteng Lao, Yao-Jan Wu, & Joanathan Corey. (2010). *Identifying High Risk Locations of Animal-Vehicle Collisions on Washington State Highways* (Final No. WA-RD 752.1 (TNW 2010-04); p. 93). Olympia, Washington: Washington State Department of Transportation.

List of Figures

List of Tables