# ROADS AND RAPTORS

# A SPATIAL ANALYSIS OF REPORTED RAPTOR COLLISIONS ON THE WASHINGTON STATE HIGHWAY SYSTEM

by

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ABSTRACT

Roads and Raptors:
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Human activity impacts animals in many negative ways. As our infrastructure demands grow, habitat loss and fragmentation are inevitable. When available habitat shrinks and ecosystems become less connected, animals are faced with complex challenges. One of the single most devastating anthropogenic disturbances in modern times has been the expansion of road networks. Vehicle strikes kill millions of animals each year worldwide, and roads also act as a barrier for flying species such as bats and birds. Birds experience high rates of mortality due to vehicle collisions. Raptors (birds of prey) are highly susceptible to vehicle collisions due to their hunting and feeding behaviors. My research examined locations of raptors hit on the Washington State Highway System from 2015-2020. Using the Washington Department of Transportation's Wildlife Carcass Removal Database, I created a series of maps in ArcGIS Pro, and used a kernel density function to identify hotspots on major highways in the state. Four hotspot locations were found for reported raptor collisions. Two of these locations were on Interstate 5, and the other two were found on Interstate 90. My research led me to explore the realm of community science efforts in roadkill data due to some limitations I experienced with the wildlife carcass removal database. I created a survey in ArcGIS's Survey 123 platform, making a data collection tool to expand efforts around raptor collisions in the state. My spatial analysis results may help strengthen information and spread awareness of raptor vehicle collisions in the future. This could lead to mitigation efforts in specific spots on Washington State Highways where raptors are being killed in large quantities due to vehicle collisions.

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# Introduction

"Roads appear as major conspicuous objects in aerial views and photographs, and their ecological effects spread through the landscape. Few environmental scientists, from population ecologists to stream or landscape ecologists, recognize the sleeping giant, road ecology. This major frontier and its applications to planning, conservation, management, design, and policy are great challenges for science and society."

-Richard T.T Forman & Lauren E. Alexander, *Roads and Their Major Ecological Effects* (1998)

Clad in orange, glowing like a highlighter, I make my way down the side of the highway. Pressed up against the guardrail, feeling like I could get blown off my feet as semi-trucks barrel past me, my heart beats faster. Between the off-putting smell, the excessive amount of litter, and the distorted cloud of constant noise, all I want is an escape from this environment. This is no place for animals, crossing the highway like a game of chicken. No bright orange color draped around their bodies, no crosswalks, no bright flashing lights, no crossing guards to help them get across safely.

Humans have carved up the land, laying down ribbons of roadways, disconnecting the natural landscape, pushing wildlife into smaller and smaller patches of intact habitat. The need to study, understand, and mitigate risks associated with roads reaches all corners of the world. Currently, 750 million vehicles operate on these roads, and their numbers are increasing (van der Ree et al 2011). This linear infrastructure disconnects habitat for wildlife and increasing the interface between animals and roads. Roads pose enormous risks for animals as road networks span over 31 million miles connecting human environments across the globe (van der Ree et al 2011).

Even though humans understand that roads are and historically have been a significant impediment to animals, the branch of road ecology science is relatively new and small. The term "road ecology" was first used in 1981; it was translated from German to English for the seminal book, *Road Ecology: Science and Solutions*, published in 2003 by Richard T.T. Forman and coauthors (van der Ree et al. 2011). Transportation planners must understand numerous variables associated with roads, and as outlined in Forman et al. (2003, pp. 99), the objectives are to:

- Minimize cost
- Maximize motorist safety
- Enhance visual quality while maintaining ecological benefits
- Reduce erosion and sediment flow
- Control non-native species
- Enhance biodiversity
- Enhance wildlife density and reduce the road barrier effect to improve animal crossing of roads
- Reduce wildlife density and increases the road barrier effect to reduce roadkills and wildlife-vehicle crashes
- Accomplish a multiple-use array of societal goals

This list consists of highly lofty objectives which cover a lot of ground and reflect the complicated nature of the roads. As Forman et al. (2003) state and van Ree restates in 2011, scientists and transportation planners must work together for the future of roads and wildlife (van Ree et al. 2011). Many transportation agencies prioritize sustainability as an objective that helps enforce policies to ensure the safety of wildlife and humans near and on roads. In 2007, The Washington Department of Transportation (WSDOT) created a policy which was issued to protect habitats and wildlife alike as stated in WSDOT Secretary's Executive Order 103:

> Assume that road and highway programs recognize, together with other needs, the importance of protecting ecosystem health, the viability of aquatic and terrestrial wildlife species, and the preservation of biodiversity.

Looking forward, executive order 1031 will be vital in protecting habitat and wildlife in the state. Washington state is currently experiencing population growth; right now, Washington ranks thirteen in population numbers in the United States. Washington is experiencing a growth rate of 1.27%, ranking eighth in the US (World Population Review). This is leading to increased development and habitat loss and fragmentation are inevitable. With more than 50 percent of the land is owned by private companies and individuals, developers need to understand which habitats are being built upon and where expansion occurs (Washington Department of Fish and Wildlife, 2009). Each region that gets developed supports many species as Washington state is home to numerous different ecoregions.

My research aimed to gather baseline data to understand better where raptors are being killed on Washington State Highways. I wanted to identify raptor vehicle collision hotspot locations. The questions I sought out to answer in this work include:

1. Where are raptors being hit and killed due to vehicle collisions on Washington State Highways?

2. What are the emerging temporal and spatial trends in the data? Are there hotspots that appear? Are there certain times of year in which more raptor collisions are reported?

3. What is the methodology in capturing raptor data within the wildlife carcasses removal database? Are there gaps in the data? How can this data source be strengthened?

To answer these questions, I created a series of maps in both ArcGIS Pro and ArcGIS Maps. I also used a kernel density function to identify hotspots based on collision locations. Additionally, I looked to create a way to collect informed data across the state using the ArcGIS Survey 123 Platform. I analyzed how a community science effort could further strengthen the records of raptors collected.

This thesis consists of five sections. The first is a literature review to situate my research in the broader context of road ecology and provide background information. The literature review aims to connect the realms of raptor ecology, habitat loss, and fragmentation, wildlife-vehicle collisions, mitigation efforts surrounding animal collisions, and educate the reader on current gaps in this area of research. The methods section explains the process of gathering, cleaning, and exporting the raptor collision data from 2015-2020. This section also details map creation and hotspot analysis in Arc GIS Pro and Arc GIS Maps. The results and discussion sections explore the findings and patterns in the data. The results section includes an array of tables, graphs, and maps to display where raptors are being hit on the Washington state highway system. The discussion section elaborates on trends and hotspots found in the spatial analysis. This section also delves into gaps in the current research of road ecology and raptor road relations. Lastly, the discussion section looks to the future and what work could be done to support more findings in the interface of birds and collisions utilizing community science data collection methods. The final section of the paper concludes the findings in the results of this work. This field of work lends itself to more significant decisions that will need to be looked at in the future by transportation planners and ecologists alike.

# Literature Review

***Introduction***

Humans are ecosystem engineers. We alter the landscape to best suit our needs; as human beings redesign the environment; wildlife needs are pushed to the side. People have addressed the desire for connectivity by making roads. In the United States, nearly 20% of the land is directly affected by public roads (Husby 2016). The infrastructure humans have created lessened intact habitats for animals. More roads mean less space for wildlife. The interface of edge habitat and roads has led to many vehicle animal collisions.

Animal collisions are not only dangerous to wildlife but to humans as well. Copious numbers of animals are struck and killed by motor vehicles each year. As more roads are constructed, there is an increase in the number of drivers on the roads. In California alone, an estimated 8.4 large animals are killed per day, and State Farm Insurance has reported upwards of 23,000 claims per year for accidents involving deer in that state (Nguyen et al. 2020).

The presence of roads affects animal behavior near and far. The visible effects of roads such as animal carcasses only tell a portion of the story. Animals changing their behavior to avoid roads account for more of the total disturbance that roads create to animal movements and behavior (Forman & Alexander 1998; Hovick et al. 2014).

Humans have tried to negate these animal collisions in hotspot areas (areas where many animals are hit). Wildlife crossing structures have been constructed and are being monitored for wildlife use. Wildlife crossing structures do not specifically address the needs of flying animals, birds in particular. In the United States alone, it is estimated that between 80-340 million birds are involved in car collisions each year (Loss et al. 2014).

This literature review will examine raptor ecology and wildlife-vehicle collisions with a focus on avian species. It will also address the role of habitat fragmentation and habitat loss. Lastly, it will examine road ecology mitigation efforts.

***Raptor Ecology***

Raptors (birds of prey) hold an important niche within their environments (Burfield 2008). Occupying a high trophic level as top predators and scavengers, raptors provide a suite of ecosystem services in their environments (Donázar et al. 2016; HawkWatch International; Meunier et al. 2000; McClure et al. 2018). Raptors control small mammal populations, acting as a system of checks and balances (Government of Alberta 2002). Vultures will be categorized as raptors throughout the length of this paper, as most avian resources include vultures as diurnal raptors (McClure et al. 2019). Raptors that scavenge, such as eagles and vultures, help keep the ecosystem clean and assist in decomposition.

Birds of prey are also important indicator species, meaning we can tell how well the ecosystem functions by the fitness of raptors (Donázar et al. 2016; McClure et al. 2018). The high trophic level that predatory species occupy makes them sensitive to changes in the ecosystem (Kovacs et al. 2008). By analyzing the patterns within raptor populations, we can better understand how an ecosystem is faring as a whole. When conservation plans are situated around raptors, the plans have positive results as raptors are widespread, easy to observe, susceptible to changes in their surroundings, and popular within society. (Burfield 2008; Donázar et al. 2016; Kovacs et al. 2008). Conservation policies that start at a very high trophic level with predatory birds can encapsulate the surrounding flora and fauna as well. Animals that occupy higher trophic levels are not as plentiful in an ecosystem because they consume a plethora of resources; thus, each individual is essential for a stable population.

Raptors are long-lived, require ample space for their habitat, and are highly affected by anthropogenic disturbances (Mcclure et al. 2018). One study in Southern California found that short-eared owls nesting in areas experiencing high development rates had caused a dramatic decline in their population, at least a 55% loss in numbers of these nocturnal raptors due to urbanization (Bloom & McCravy 1996). This is just one example that speaks volumes for raptors failing to adapt in an area of rapid growth.

Raptors can adjust if suitable measures are put into place, even in the case of the Northern Spotted Owl, which has precise habitat requirements. Northern Spotted Owls are typically found in old-growth forests; however, when replanted forests consider the needs of spotted owls, the owls can be successful if the outcome of the newly planted forest provided the owl with the form and fit that they seek in old-growth environments (Petty 1996; Horton 1996).

Even though raptors can adapt to changes in the environment, there is less space available for them; worldwide, raptors are in decline, as McClure and colleagues write (2018).

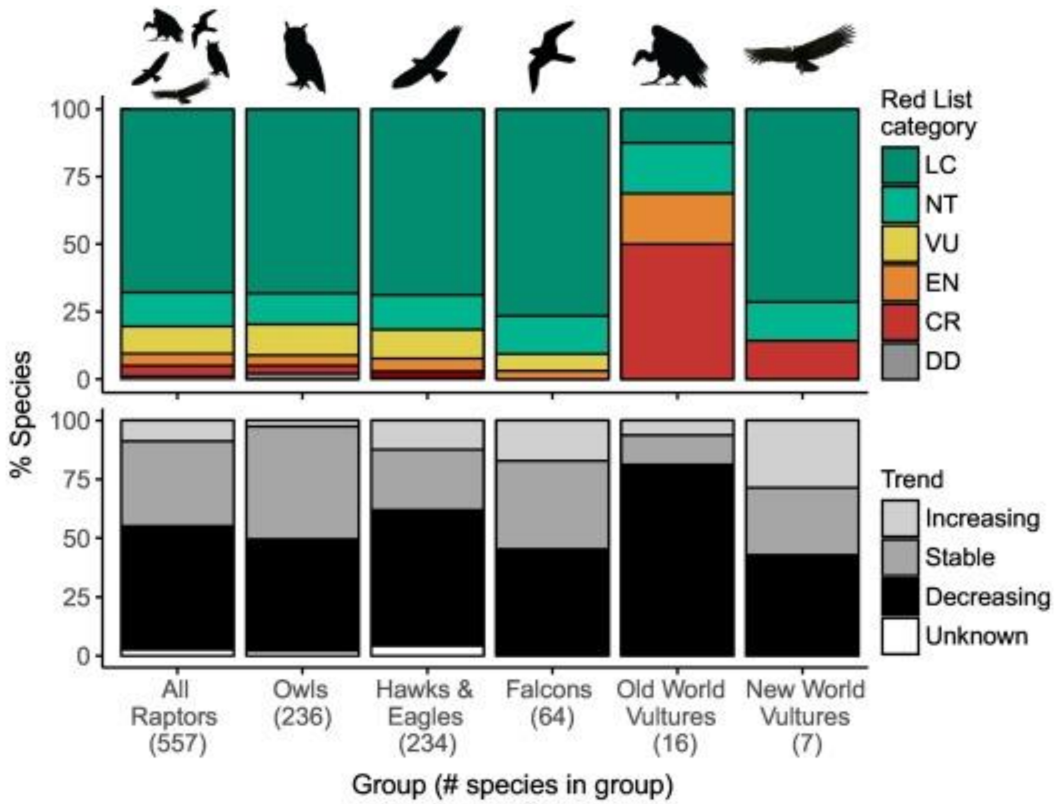



*Figure 1. Status of the world's raptor populations. Above, by Red List Categories LC-Least Concern, NT-Near Threatened, VU-Vulnerable, EN-Endangered, CR-Critically Endangered, DD-Data Deficient; below, by population trend. Figure 1 in McClure et al. 2018.*

Most owl populations worldwide are either stable or decreasing, with hawk and eagle populations experiencing a similar trend (**Figure 1,** McClure et al. 2018). 18% of raptors are threatened with extinction, and 52% of raptors have declining populations (McClure et al. 2018). Declining raptor populations are chiefly due to habitat being transformed into agricultural land and forested lands being logged (**Figure 2**, McClure et al. 2018). As landscapes change to agricultural fields and actively logged forests, this creates patches of unusable habitat for raptors. The land cover changes and become fragmented.

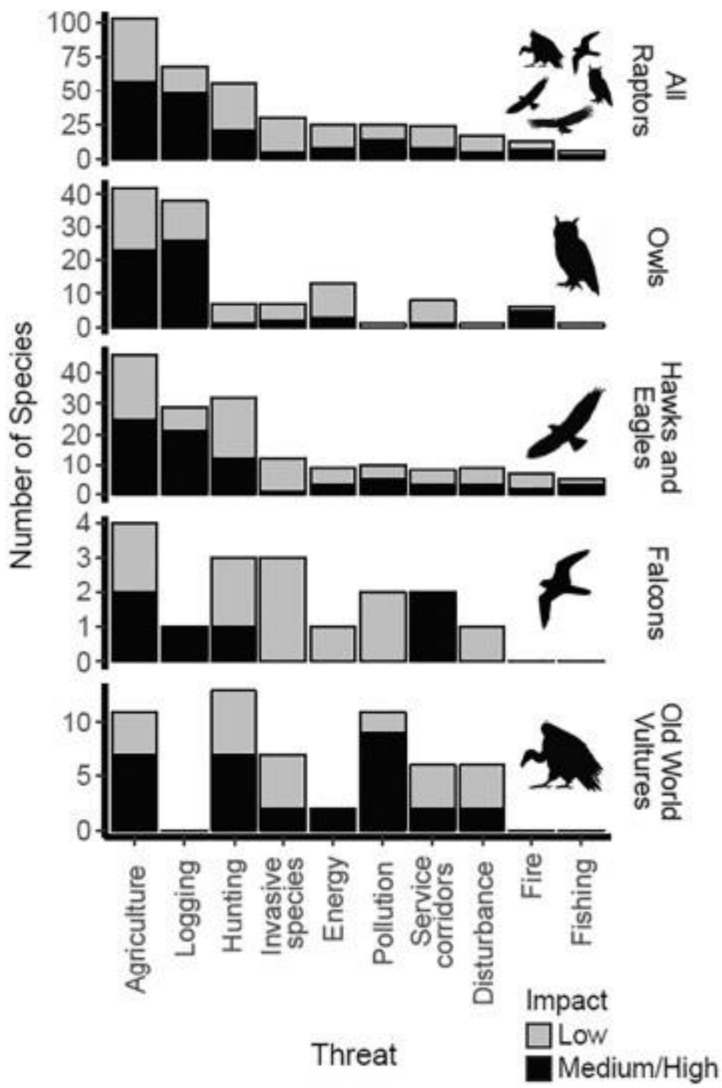



*Figure 2. Threats to raptors by group. Figure 6 in McClure et al. 2018.*

A study in an area that has been converted to agricultural land in France examined the relationship of raptors uses the sides of roads for hunting purposes. Meunier et al. researched diurnal birds of prey and their relationship to roadsides; there is a lack of research that looks at this association. Diurnal raptors were more present at the roadsides in the wintertime than any other season to hunt small mammals along roads. This study concluded that more research should be conducted to better understand how raptors use roadsides in highly converted farmlands because there is high prey availability alongside roads and in medians (Meunier et al. 2000).

### ***Habitat Loss and Fragmentation***

It is crucial to define habitat loss, and habitat fragmentation, in any comprehensive treatment of the topic. Roads play a significant role in creating smaller disconnected habitats and decreasing the size of intact landscapes. Landscapes, in general, are variable; they differ in land cover, size, and distribution (Collinge 2009: Fahrig 1997). Humans and wildlife view landscapes and space through entirely different lenses because our interactions with the land are much different than wildlife and the environment (Lindenmayer & Fischer 2006). This has led to humans significantly altering the land in ways we see fit, while animals must adapt to these changes.

Habitat loss and fragmentation are complex principles to separate because many studies have not been able to discern the effects of habitat loss from those of habitat fragmentation (Collinge 2009). For the purposes of this research, we will utilize the definitions outlined in *Ecology of Fragmented Landscapes*. Author Sharon Collinge defines habitat loss as “anytime a piece of land is converted from its current state to some other land use or land cover type.” Whereas habitat fragmentation “denotes a particular spatial process of land conversion.” (pp. 3). The process of habitat fragmentation is illustrated in (**Figure 3**, Fahrig 2003); over time, the intact habitat is broken up into smaller, spatially separate parcels of land.

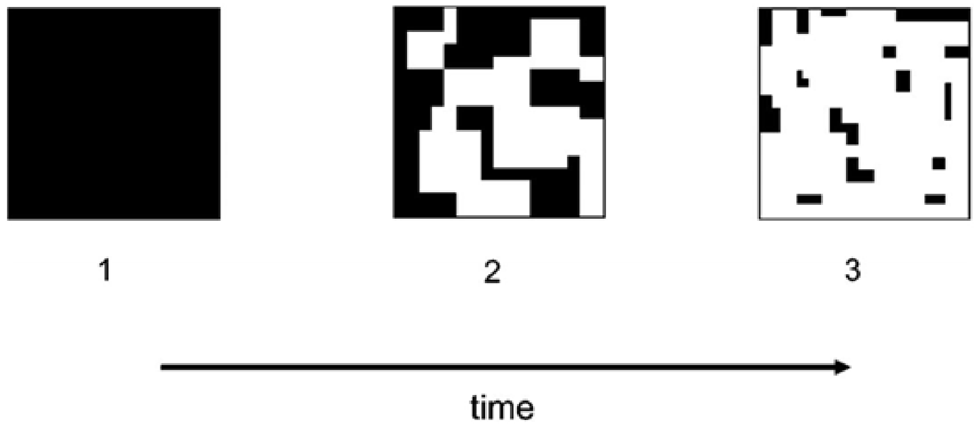



*Figure 3. The spatial separation of habitats becoming less connected through the process of habitat fragmentation. Figure 1 in Fahrig 2003.*

Although natural effects can lead to habitat loss and fragmentation, anthropogenic urbanization and the transformation of landscapes into agricultural fields have a much more devastating impact on the environment (Collinge 2009: Lindenmayer & Fischer 2006). Habitats can recover from specific temporary loss and fragmentation in cases of logging and wildlife fires. It is unlikely that habitats will bounce back from the pressures of urbanized development and industrial, agricultural use (Lindenmayer & Fischer 2006).

The process of habitat fragmentation has adverse effects on wildlife, including raptors. As intact areas decrease in size, the richness of species decreases and negatively affects biological variety (Hinam & Clair 2008; Lindenmayer & Fischer 2006; Tigas et al. 2002; Wilcove et al. 1986). Fragmented areas may, in some cases, be too small to sustain populations of species (Tigas et al. 2002). The process of habitat fragmentation can be connected to the extinction of species over time (Patten et al. 2005). Birds are affected by the changes in habitat size and shape.

Birds in altered landscapes face several challenges during the breeding season. Species may experience shorter breeding seasons and lay fewer eggs which are lighter in weight (Hinam

& Clair 2008). As it is taxing to move between smaller parcels, birds experience decreased numbers of chicks that tend to be smaller; this is influenced by the food limitations that come with less available space (Hinam & Clair 2008: Lindenmayer & Fischer 2006). These changes add up quickly and can substantially impact the livelihood of birds in fragmented habitats well into the future. The breeding season effects of habitat loss and fragmentation are just one season in the lives of wildlife. Animals also require different size parcels of land for dispersing, foraging, and migrating (Collinge 2009: Lindenmayer & Fischer 2006). An area that requires further research is understanding how individuals are affected by habitat fragmentation, as habitat loss and fragmentation are usually studied at the population level (Hinam & Clair 2008).

As habitats are fragmented, there is less habitat connectivity for animals. When areas are developed and used for human purposes, the land becomes more fragmented. Humans connect developed land through roads. For the persistence of endangered species, habitat restoration needs to be prioritized (Fahrig 1997). Roads have an enormous impact on wildlife communities. One way to connect dispersed pieces of habitat is by wildlife corridors; channels of intact land help to increase connectivity (Collinge 2009; Tigas et al. 2002). As corridors aid in creating safe passage for animals, little is known about how individual animals actually use the corridors to move between fragments (Tigas et al. 2002). Where natural corridors no longer exist, humans can help recreate connected landscapes over or under roads in many ways. I will be covering the creation of habitat connectivity in the mitigation section of the literature review.

***Animal Collisions***

When habitats are fragmented, they create enormous risks for many animal species. Birds are highly affected by habitat fragmentation and loss, as there is less connectivity between parcels of habitat and less space available. As more roads are built and road experience higher volumes of traffic, animals face lower levels of habitat connectivity, increased genetic bottlenecks, fewer areas to claim as their territories, an increase in traffic noise pollution, and more chances to be struck by oncoming traffic (Beckman & Hilty 2010; Boves & Belthoff 2012; Foresman 2004; Husby 2016; Johnson 2005; Loss et al. 2014; Spellerberg 1998; Stewart 2019). Creating new roads destroys habitat, often forested areas become open spaces, which can affect the assemblage of species that reside in these newly transformed landscapes. (Benitez- Lopez et al. 2010; Hovick et al. 2014). The number of animals killed by automobile collisions continues to grow worldwide (Gunson & Teireira 2015; Newton 1979; Seiler & Heldin 2006).

While the problems roads create for animals are well known, challenges remain with quantifying these issues and explicitly determining how automobiles affect wildlife (Spellerberg 1998). The majority of the research surrounding animals and vehicles tends to focus on large hooved mammals due to the effects of ungulates on human lives and the property damage they can cause (Blackwell et al. 2016). A large portion of the story goes untold when just relying on roadkill numbers; many interactions and behaviors go unseen when looking at roadkill mortality events (Clevenger et al. 2003).

There are a number of different survey techniques that can be utilized when exploring roadkill data. **Table 1** (Smith & van der Ree. 2015) displays a variety of survey methods that compare studies on road’s effects on wildlife.

Some trends have been observed in many studies covering wildlife-vehicle collisions (WVC). Common spots on roads are known as hotspots that experience many WVC (Clevenger et al. 2003; Gunson & Teireira 2015; Husby 2016; Taylor 2021). Other factors such as the speed limit also play a prominent role in where WVC occurs (Foreman et al. 2003; Husby 2017). In their foundational book, Road Ecology: Science and Solutions, Foreman and colleagues state that vehicles driving faster than 40 mph have a more considerable negative impact on songbirds and rabbits than vehicles driving slower than 40 mph (pp.120). Birds may not have the sense that cars pose a significant threat; as DeVault et al. conclude, birds have not evolved to sense vehicles as threats. Fast-moving vehicles have not been around long enough for birds to be able to recognize them as predators. The high speeds may overwhelm a bird's system, so they cannot react in a timely manner (2014). Road density also is a factor that influences WVC (Clevenger et al. 2003).

*Table 1. Survey methods used in studies of road effects on wildlife. For each method type, there are a number of factors involved that explore how effective the survey method is. These survey types are varied and range in scale and effort. It is important to recognize that different methods can be useful depending on the size and scope of a road ecology study. Retrieved from Smith & van der Ree. 2015.*

| **Method** | **Data Type** | **Animal Handling** | **Spatial Extent** | **Resolution/scale** | **Complexity** | **Effort** | **Cost** |
|---|---|---|---|---|---|---|---|
| Roadkill surveys | Point | No | Small-large | Fine | Low | Moderate | Low |
| Animal tracks | Point, line | No | Small-large | Fine | Low | Moderate | Low-moderate |
| Camera traps | Point | No | Small-medium | Medium | Low | Low | Low |
| Wildlife census: observational | Point, line, area | No | Small-medium | Medium | Low | Moderate | Low |
| Wildlife census: interventional | Point | Yes | Small | Medium | Moderate | High | High |
| Animal tracking | Point, line, area | Yes | Small-medium | Medium | High | Low-high | Low-high |
| Genetics | Point | Yes/no | Small-large | Medium | High | Moderate | Moderate |
| Landscape/ GIS models | Point, line, area | No | Large | Coarse | High | Low | Low |

Traffic volume has been cited as having a significant role in WVC by Clevenger et al. 2003 and in other studies: Meunier et al. found that traffic volume was not a factor when raptors hunted near roadsides. In a hotspot analysis study conducted by Eberhardt et al., they found a negative relationship between traffic volume and amphibian vehicle collisions. In contrast, they found a positive relationship between bird collisions and traffic volume (2013).

According to a review that analyzed 49 different studies, mammals and birds had smaller population sizes close to roads. Mammals were shown to be affected by the presence of roads up to 5 km away from roads, whereas in general birds could tolerate being closer to roads and were only affected when they were 1 km or less away from the road. In comparison with other groups of birds, raptors were found in greater numbers close to roads (Benitez-Lopez et al. 2010).

Roadkill estimates usually undervalue the total number of species killed due to WVC (Delgado et al. 2019; Jacobson 2005). There are a number of reasons why roadkill counts are often smaller than the actual amount of roadkill; some surveys do not continue year-round; they are only funded for specific projects, or animals take roadkill before it is recorded. Eberhardt et al.'s 2013 study found that 63% of carcasses were gone in a 24-hour window between their initial roadkill study and their follow-up survey occurring one day later. Guinard et al. conducted a roadkill survey in southwest France. They compared how long carcasses remained on the landscape during different seasons; they found that carcasses were picked up or eaten more quickly during the spring. They attributed this to more scavenger presence during this time of year. Guinard et al. also found that larger owls stayed on the landscape longer than smaller songbirds (2015).

Lee et al. (2021) further explored ways to account for the low number of found carcasses by assigning a correction factor that can be used in roadkill studies. For their study on Highway 3 in Alberta, Canada, they applied a correction factor of 2.8 for the detection of ungulates. This correction factor does not carry over to smaller animals because smaller species do not persist on the landscape for the same length of time and are generally more difficult to find. Guinard et al.'s study in France found that they underestimated the percent of owls by 10% and 30% for songbirds (2015, pp. 100). The survey method also plays a prominent role in detecting roadkill; more animals are seen if the survey method is done on foot compared to conducting surveys by car or bicycle (Erritzoe et al. 2003). Guinard et al.'s study in 2015 was conducted by car as well as on foot. The surveys conducted by moving vehicles underestimated bird carcasses by 33% (pp.100).

Smaller species make up about 60% of the total kills from WVC; this includes both small mammals and birds (Seiler & Helldin 2006). Vehicle collisions account for a sizable portion of bird deaths: **Table 2** (Erickson et al. 2005) shows that 80 million birds die each year due to collisions with automobiles just in the United States, which account for 8.5% of anthropogenic bird deaths.

*Table 2. Estimate of yearly bird mortality events in the United States. Retrieved from Erickson et al. 2005.*

| Mortality Source | Estimated Annual Mortality | % Composition |
|---|---|---|
| Buildings | 550 million | 58.2 % |
| Power lines | 130 million | 13.7 % |
| Cats | 100 million | 10.6 % |
| **Automobiles** | **80 million** | **8.5 %** |
| Pesticides | 67 million | 7.1 % |
| Communication Towers | 4.5 million | 0.5 % |
| Wind Turbines | 28,500 | <0.01 % |
| Airplanes | 25,000 | <0.01 % |

It is important to understand that secondary factors cause birds to be near roadways. For example, habitat fragmentation has pushed avian species and other wildlife closer to major roads; predatory birds are drawn to open areas that roadsides provide for hunting (Meunier et al. 2000: O'Brien 2006). Certain groups of birds are attracted to roads for various resources, including nesting, hunting, and scavenging. Scavengers, including vultures and eagles, are more likely to get hit by vehicles (Foreman et al. 2003; Hartley et al. 1996; Husby 2016; Jacobson 2005; Kociolek et al. 2015; Newton 1979). Scavengers count on roads for their carrion needs and often use roads to locate carcasses since they are easily spotted from above. This is a universal trend as studies worldwide have documented scavengers being attracted to roads and consequently killed due to WVC. Birds that hunt near roads are also susceptible to being hit and killed by vehicles (Foreman et al. 2003; Jacobson 2005; Kociolek et al. 2015; Lambertucci et al. 2009). Hawks and owls prey on small rodents near roads and in the median strip of vegetation on highways. Owls are especially vulnerable while hunting near roads since they are known to fly especially low. Meunier et al. (2000) detail the importance of roadsides for raptors to hunt, especially in agricultural areas. As more birds reside near roads, the chance of them getting struck by moving vehicles surges.

In a synthesis of studies by Kociolek et al. (2011), the authors found that birds are likely to hit struck by water, at lower elevations, and in open areas as opposed to forested habitats. Birds were also 92% more likely to be hit on raised roads when compared to flat roads (Clevenger et al. 2003). They also found that birds were more likely to be killed on sections of road with open spaces rather than forested areas of road. In general, birds are more likely to get hit during breeding periods (Bujoczele et al. 2011; Foreman et al. 2003; Husby 2016 and Kociolek et al. 2015). This could be influenced by young dispersing and not being aware of the danger's roads present for wildlife.

Birds sampled after being killed due to a WVC were in good health, which went against what certain studies hypothesized, thinking that birds in poor health would be more likely to get hit (Bujoczele et al. 2011; Husby 2016; Ramsden 2007). Birds are more likely to suffer injuries from gusts created by vehicles due to their hollow bones. Orlowski & Seimbieda (2005) noted that 39% of raptors admitted to the North Carolina Raptor center from 1998-2002 suffered from injuries due to WVC. The most common affliction was broken bones in the wing region (pp. 15). Solutions to WVC are being implemented at various scales worldwide. Many of these mitigation efforts are created for large mammals; mitigation efforts will be discussed in the next section. One area for improvement with WVC mitigation efforts is studying how birds benefit from these solutions (Kociolek et al. 2015).

### *Mitigation*

Mitigation efforts for WVC range in terms of size, scale, and effectiveness. Certain projects are centered around promoting practical measures to keep animals off the road, whereas others target drivers to make them aware of wildlife in the area. In 1992 a survey published by natural resource agencies in 43 states summarizing mitigation strategies that fell into two categories: modifying deer behavior and modifying human behavior. The mitigation strategies that targeted changing deer behavior were wildlife fencing, overpasses and underpasses, hazing, habitat alteration, and, lastly, mirrors & reflectors. The mitigation strategies that targeted changing human behavior were public relations, warning signs, warning whistles, highway lighting, and lower speed limits. The survey was distributed in 43 states. The results quantified mitigation techniques used in each state and the level of success reported for each mitigation strategy. Attempts to modify deer behavior were more successful than any of the strategies to modify human behavior. Wildlife fencing and the installation of overpasses and underpasses proved to be the most successful. Wildlife fencing was 91% effective, and overpasses and underpasses were 61% effective. While warning signs were used in almost all 43 states surveyed, it was less than 10% effective in changing human driving behavior. The most effective strategy in attempting to modify human behavior was public relations. If outreach is done, drivers can know more about the potential risks of animals being on roads in certain areas; this can be done successfully, as discussed in the discussion section.

Distinct strategies have been implemented depending on the targeted species, area, and cost of the operation. Wildlife mitigation systems, helping to aid animal movement and restore corridors include vegetated overpasses, open medians, bridge underpasses, culvert underpasses, fences, and detection systems (Cramer & Leavitt 2009, pp. 56). Each mitigation effort listed has its advantages as well as its drawbacks.

One simple and effective way to make humans aware of wildlife in the area is to install wildlife signs (Gunson & Teixeira 2015). Signage increases drivers' awareness of animals in the area that could come onto the road (WSDOT). Signs used to warn drivers about animals on the site can be broken down into four different categories: standard signs, enhanced wildlife warning signs, temporal warning signs, and animal detection signs (Huijser et al. 2015, pp, 199). The two most important factors in determining the success of a sign in alerting humans and making a lasting impression on are sign location and when the sign in use, both time of day and time of year, are important (Huijser et al. 2015, pp, 202). Standard signs usually are depicted by a large picture of an animal without any text. These signs are stationary and do not have a lasting impact on drivers. Enhanced wildlife warning signs are generally more prominent than the standard signs and include text or flashing lights. The location of enhanced signs often reflects high collision zones, and drivers tend to recall these signs for more extended periods than standard signs. Temporal signage is used at specific times of the year, alerting drivers to certain events such as an animal migration. These signs have a lasting impact on drivers since they are not always in use; drivers pay more attention to them. Lastly, live detection signs are only visible when that animal is in the area. These signs are sometimes connected to radio-collared individuals and alert drivers when that animal is in the area and could come onto the road. WSDOT has one of these systems still functioning on U.S. 101 in Sequim to help alert the public of the elk presence in the area. These systems are not always reliable due to false triggers (sign flashing when elk are not actually present). It is very taxing to keep up with attaching radio collars to individual elk (WSDOT 2021).

One example of success with temporal signs as well as radar speed limit signage is a project based in Jackson Hole, Wyoming. The project is called Give Wildlife a Brake. The project's effort is centered around alerting the public to slow down and pay attention to large animals that could be present. The project has four stationary radar signs and three dynamic message signs, like the sign from WY 360 shown in **Figure 4**. These efforts have already resulted in a decrease in animals hit and killed in the area: from 2010-2014, 36 moose were struck and killed on WY 360, while in 2015, no moose were reported as killed (Jackson Hole Wildlife Foundation n.d.).


*Figure 4. An example of a temporal dynamic sign that is used in the program, Give Wildlife a Brake. Retrieved from The Jackson Hole Wildlife Foundation's website.*

Lowering traffic speeds and centering traffic on fewer, more commonly utilized roads are ways to help alleviate problems caused by WVC as well (Forman et al. 2003; Gunson & Teixeira 2015; Kociolek et al. 2015).

Wildlife crossing structures are well-known wildlife mitigation efforts engineered to assist terrestrial wildlife in crossing over or under roadways. Wildlife crossing structures have been built all over the globe. The first crossing structure built in the United States was in Utah in 1978. The crossing structure was implemented to aid in the migration of deer. In the 1980s and

1990s, a considerable effort went into creating habitat connections in the Everglades. State and federal partners helped oversee a project consisting of 23 underpasses and bridges. Their main focus was to lessen the number of Florida panthers killed due to WVC and help enhance water movement for the American alligator. (Foreman et al. 2003). As of 2009, more than 700 wildlife crossing structures exist in North America, as well as thousands of crossing structures to aid aquatic wildlife (Cramer & Leavitt 2009).

In Washington state, WSDOT works with partners such as the Washington Department of Fish and Wildlife to determine where hotspots of WVC occur. WSDOT has created a number of wildlife crossings, including the Interstate 90 project, which features a vegetated over-crossing and an undercrossing from Hyak to Easton, elk are using the overpass frequently and species as cougars have been seen on the undercrossing. A great horned owl was documented landing on the camera on the overpass on I90. Another successful project is on U.S. Highway 97; Janis bridge undercrossing was retrofitted in 2019, the vegetation was cleared from the structure, and a mile of wildlife exclusion fencing was built. This area is one of the top deer collision areas in the state, with 350 deer being hit each year over a twelve-mile stretch. Since 2019, the crossing is seeing, on average, six mule deer per day. Other faunas such as ring-necked pheasants, raccoons, and bobcats have been documented using this passage as well (Conservation Northwest 2019, WSDOT 2021).

Birds often get overlooked when it comes to crossing structures, and there have been very few papers published on crossing structures for avian species (Pell & Jones (2015). What is known about the relationship between wildlife crossing structures and birds is that even though they are not commonly built with birds in mind, birds benefit from them (Jacobson 2005; Jones & Bond 2010; Pell & Jones 2015). To increase the effectiveness of wildlife crossing structures, adding wildlife fencing to these areas and jumpouts and/or soil berms help keep animals out of the roadway. Eight-foot-tall wildlife exclusion fencing is a beneficial way to keep animals off of roads. When fencing is combined with wildlife crossing structures, it decreases the chances of animals finding a way onto the road (Huijser et al. 2010; WSDOT 2021). A great way to monitor the long-term use of wildlife crossing structures is to install wildlife cameras. Data from wildlife cameras help understand what animals are using the cross structures, what animals are being repelled from such structures, and identify wildlife movement patterns (WSDOT 2021).

Mitigation efforts that separate birds and other species from roads as early as possible in the planning and construction efforts will be most effective long term (Jacobson 2005; Jones & Bond 2010). Mitigation projects should also be widespread initiatives to account for the mobility of birds (Kociolek et al. 2011). Some measures that help separate birds from roads include removing roadkill promptly not to attract scavengers to the roadside. HawkWatch International conducted a study to better understand how eagles were using roads to scavenge on roads. They found that moving roadkill ten meters off the road significantly decreases the chances of eagles flushing into traffic when cars pass (Taylor 2021). It has been found that tall barriers on either side of a road will encourage birds to fly across the road without dipping down to the height of the road. The birds will choose to fly within their line of sight straight across the road (Delgado et al 2019; Pons 2000). Placing poles by the roads mimics the appearance of a physical barrier, so birds are not tempted to fly into roadways. (Kociolek et al. 2015; Jacobson 2005). **Table 3** highlights mitigation strategies surrounding differing communities of birds that interact with roads.

*Table 3. A visual representation of different problems roads create and solutions to fit the needs of particular groups of birds. Retrieved from Jacobson, 2005.*

| Group Impacted | Problem | Suggested Solution |
|---|---|---|
| Walking Birds | Non-flying birds incur great mortality risk. | Crossing structures with large openness ratios (underpasses) or wildlife over-crossings. |
| Water Birds | Winds over bridges can slam flying birds into vehicles. | Diversion poles on bridge decks. |
| Owls | Owls hunt at headlight height. | Diversion poles or short fences along highway medians and right-of-way. |
| Ground nesters | Mowing right-of-way kills nesters. | Mow after August 1. |
| Scavengers | Corvids or raptors are killed while foraging on roadkill, attracted scavengers reduce productivity adjacent to highways. | Reduce roadkill & remove roadkill from road. |
| Migrant landfalls | Exhausted cross-gulf migrants fly into vehicles. | Low temporary fences to encourage higher flight across roads. |
| Frugivores | Fruiting median plants attract birds across traffic | Plant non-fruiting varieties & remove fruiting varieties. |
| Winter finches | Deicing salt or sand attracts birds to road surface. | Velocity spreaders, road temperature sensors to reduce quantities, concentrate runoff appropriately, & public education program. |

Long-term monitoring efforts should be implemented to help better understand what makes a successful mitigation project. Cramer and Leavitt (2009) suggest monitoring a crossing structure for a minimum of three years after it has been built; most wildlife will not use a structure for about two years, this may vary due to animals that are not always present in the area that may only use it once or twice a year during its migration. It is an exciting time for change as much of our highway infrastructure needs to be updated in the next few decades; there is room to retrofit bridges and culverts to create wildlife corridors (Cramer & Leavitt 2009).

# Methods

The main objective of this research was to identify the relationship between locations of reported raptors collisions on Washington State Highways. Raptor collision information was extracted from the Washington Department of Transportation's (WSDOT) Wildlife Carcass Removal Database (WCRDB). Maps were created in ESRI's ArcGIS Pro application utilizing a series of GIS modeling steps.

### *Study Area & Data Sources*

The study area included Interstate and state highways within Washington State (**Figure 5**). The data used in this study came from the Washington Department of Transportation's Wildlife Carcass Removal Database (WCRDB). A disclaimer about the WCRDB from WSDOT:

> This data is protected under the same United States Code (Section 409 of Title 23) as the WCR data. Any collision data furnished is prohibited from use in any litigation against state, tribal or local government that involves the location(s) mentioned in the collision data.

The data in the WCRDB has been collected for almost fifty years, starting in 1973. When the database was first established, maintenance personnel collected data using a paper form, as shown in **Figure 6**. Data collection has changed and evolved alongside advances in technology. Personal digital assistants replaced the paper wildlife roadkill report form in 2010, and in 2015, iPads were implemented to collect data in the field.

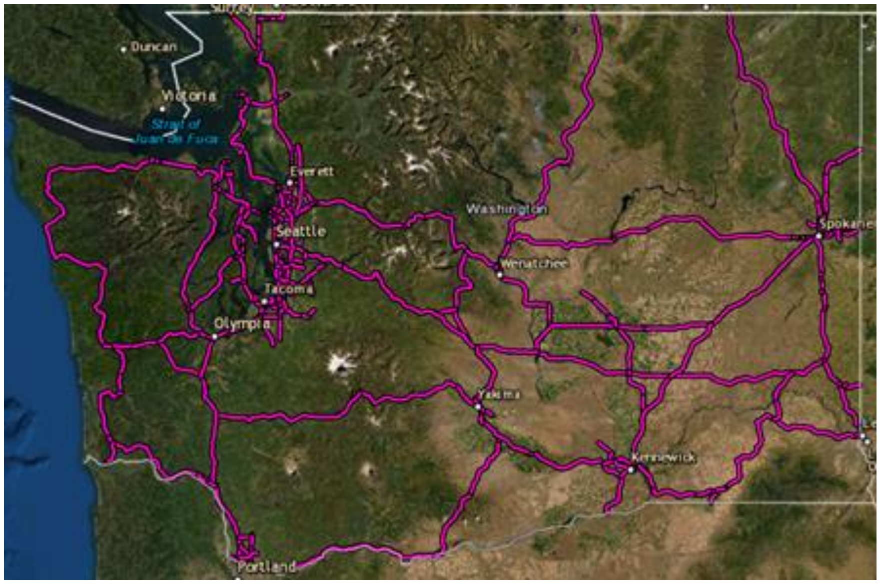
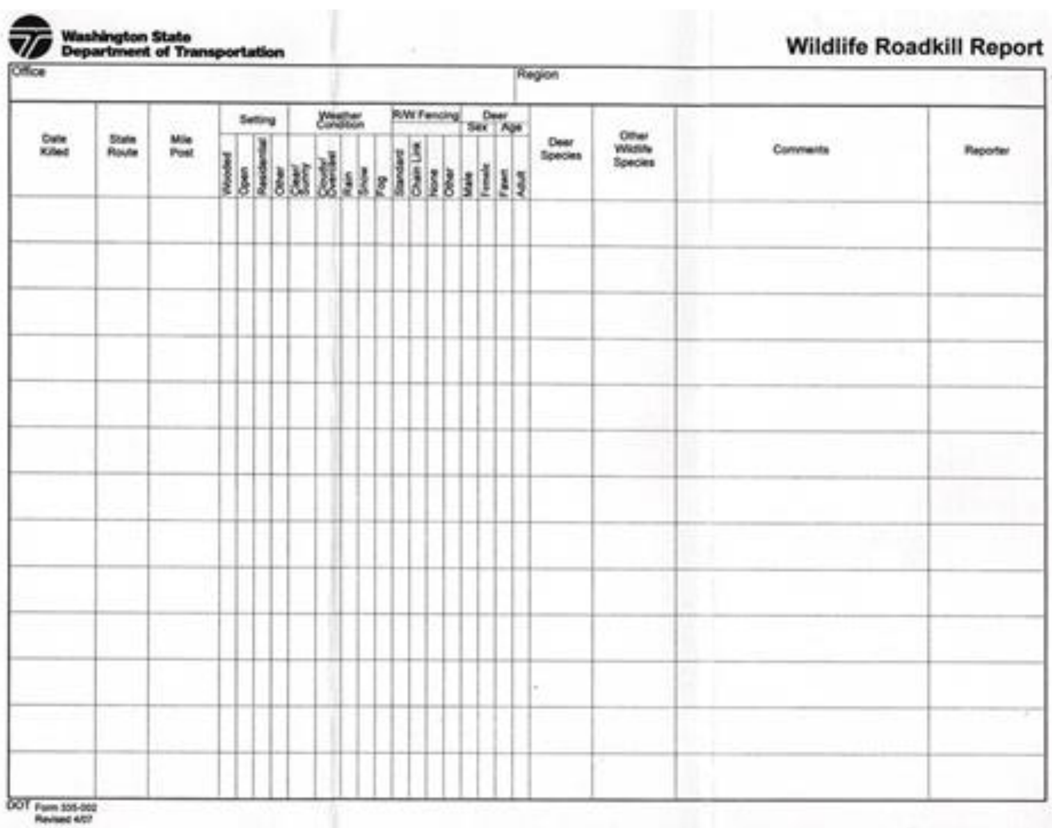



*Figure 5. A map of the study area, Washington State Highways shown in pink. Created in ArcGIS Pro.*



Washington State Department of Transportation

Wildlife Roadkill Report

Office | Region

| Date Killed | State Route | Mile Post | Setting: Wooded | Open | Residential | Other | Weather Condition: Clear/Sunny | Cloudy/Overcast | Rain | Snow | Fog | R/W Fencing: Standard | Chain Link | None | Other | Deer Sex: Male | Female | Deer Age: Fawn | Adult | Deer Species | Other Wildlife Species | Comments | Reporter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

DOT Form 335-002
Revised 4/07

*Figure 6. An example of the roadkill spreadsheets before the data was collected by iPad. Retrieved from WSDOT.*

The roadkill data is reported initially in the Highway Activity Tracker by WSDOT maintenance staff, and then digitally transferred to the WCRDB. Once uploaded in the WCRDB, a member of the habitat connectivity team processes each individual record. If there are errors within a record, the maintenance personnel who entered the record is contacted by email (if necessary). A habitat connectivity team member fixes each error manually. The most common errors include wrong location and incorrect species identification (Croston pers. comm).

In order to separate raptor data from the rest of the records in the WCRDB, I exported all accounts of bird carcasses to an Excel spreadsheet. I only exported data from 2015-2020 as it was all collected using iPads. From here, I filtered the data to display all raptor kills. This included bald eagles, golden eagles, hawks, red-tailed hawks, owls, and turkey vultures in the database. I then created a separate spreadsheet for each group of raptors. The fields collected in the WCRDB are as follows, removal date, species, region (Eastern EA, North Central NC, Olympic OL, South Central SC, Southwest SW, and Northwest NW), State Route, Milepost, Latitude & Longitude, Type of Animal, Sex-if known, Age-if known, disposal method, as well as the observers' name. **Figure 7** below displays the different regions within Washington that WSDOT uses.


*Figure 7. A map displaying the different regions of Washington, a field that is collected in the wildlife carcass removal database. Retrieved from WSDOT.*

I looked through every raptor carcass in the system to double-check its authenticity based on location (both regionally as well as the Lat/Long coordinates). I had to manually input the latitude and longitude for many raptor records in the system because only their mileposts and highway numbers were put into the records. In order to locate the specific mileposts, I utilized WSDOT's Milepost Values map image layer via the ArcGIS online platform. WSDOT's Milepost value layer is split up into 1/10 of a mile segments. WSDOT's Milepost Values layer was created on August 13, 2014, and last updated on February 2, 2020. After locating each reported raptor's location, I then looked up that specific spot in Google Maps. After finding the raptor carcass collision location in Google Maps, I was able to copy and paste the latitude and longitude into the existing raptor Excel spreadsheets.

I also looked up all raptor identifications in the Highway Activity Tracker (HATS), where the record could have an attached photo(s). The images help to reinforce a positive identification. I also wanted to check to see if I could identify owl and hawks to species by looking up their incident numbers. HATS does not have an option to identify owls or hawks (besides red-tailed hawks) to species. Posters have been created by the habitat connectivity biologist and distributed to the maintenance departments around the state in order to help make the correct identification. The owl poster is shown below in **Figure 8**. The owls displayed on the poster make up a collection of both common owls and rare owls (Northern Spotted Owl). Even though there is not an option in the pull-down menu of species, the type of owl can be included in the comments field in the HATS database.

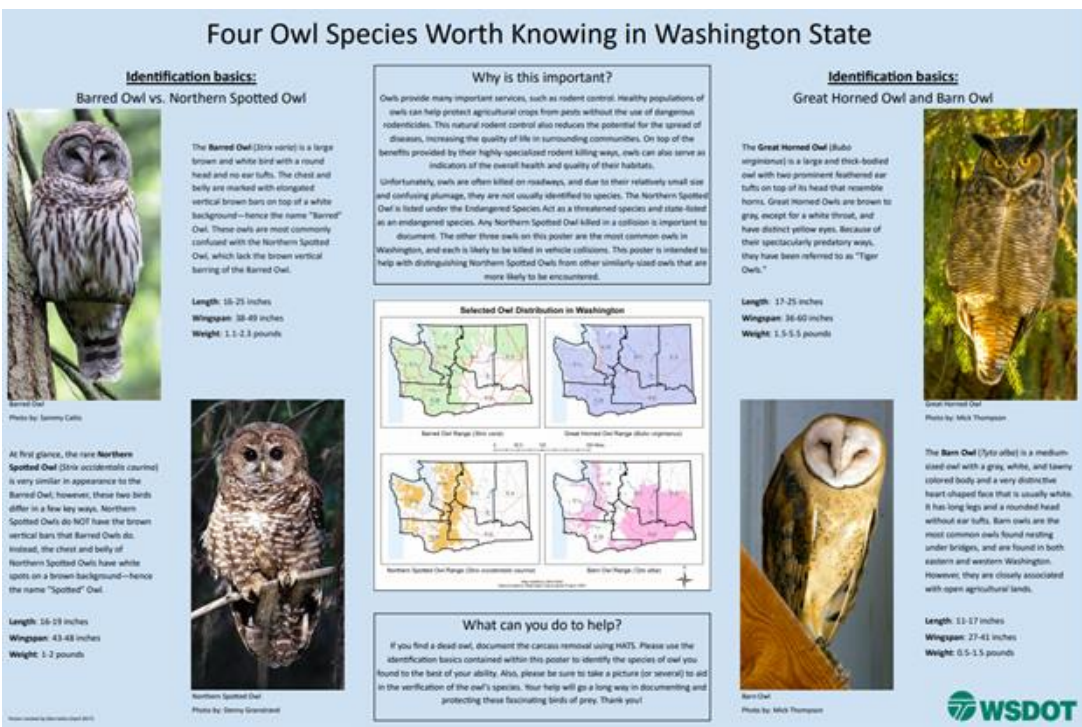



*Figure 8. Owls in Washington state, a key to help identify owl carcasses. Created by Habitat Connectivity Biologist Glen Kalisz, Retrieved from WSDOT.*

While looking up species in the HATS database, I corrected a number of misidentified raptors. Besides the records I was able to correct, many of the records did not have photos attached, and there was no way for me to confirm these raptor identifications. Using Excel, I created a spreadsheet for each group of raptors as well as a separate spreadsheet for all combined raptor records.

### ***ArcGIS Pro Applications***

I uploaded the different raptor data as CSV files into ArcGIS Pro to create a series of maps and graphs. I used an elevation raster layer from the USGS. I downloaded a highway shapefile layer from WSDOT. Maps were created using the WGS 1984 coordinate system.

### ***Kernel Density Analysis***

To determine which sections of the highway system account for the highest frequencies of reported raptor collisions, I ran a kernel density analysis in ArcGIS Maps. Kernel density tests determine "the density of point features around each output raster cell." (ArcGIS Pro). The kernel density calculation is shown in (**Figure 9,** ESRI, n.d.).

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} \left[ \frac{3}{\pi} \cdot pop_i \left( 1 - \left( \frac{dist_i}{radius} \right)^2 \right)^2 \right]$$

$$\text{For } dist_i < radius$$

*Figure 9. The expanded equation to calculate kernel density, Retrieved from ESRI, n.d.*

I made the output size of the cell 30 m (98.4252 ft) to be consistent with other spatial analyses. I also made the diameter 10,720 ft, the same extent that the Washington Department of

Transportation uses to catalog deer collision hotspots in the state. I measured the distance from the beginning to the end of each hotspot location using the ‘map an SR (state route)’ tool available in WSDOT’s GIS toolbox.

### *ArcSurvey 123 Application*

I also created a new tool for raptor carcass data collection. I designed a data entry system using the ArcGIS Survey123 platform. The survey has a more comprehensive list of raptor species; the user can select the type of raptor and then is given a drop-down menu of species within that group. This raptor list is located in **Appendix B**. The survey design is meant to be used as a collective science effort to strengthen raptor collision data on a state level. Using Survey123, I developed the schema of the application in an Excel spreadsheet.

### *Limitations*

Numerous limitations come with using the WCRDB. One inconsistency in the data is the different versions of data collection methods as the database has evolved over time. Another limitation of this dataset is precision: the location of the carcasses is not calculated using GPS data but instead relies on milepost markers, which can be imprecise especially if milepost markers are missing in certain areas.

Another drawback of the WCRDB are the taxonomic distinctions available within the database. In particular within raptors, owls cannot be broken down into types of owls, same goes for hawks with the exception of red-tailed hawks. There is a way to upload photos, but these can only be accessed by the HATS database, which is a separate system altogether, and pictures are not required.

This database does not account for animals struck by a vehicle that then leave the scene before dying. Carcasses could also be picked up and moved before WSDOT is aware of them, affecting the total number of raptors killed on Washington State Highways. The quality and quantity of entries in the WCRDB can vary from region to region and from the individual maintenance employee.

Regardless of these limitations, having a database that provides information on raptor collisions in Washington State does help to visualize where they occur. This data does not exist in any other database on such a widespread level within the state of Washington.

# Results

The total number of reported raptor carcasses from 2015-2020 is reported in **Table 4**. Owls account for 68.7% of the data. The raptor groups recorded in the WCRDB were bald eagles, golden eagles, turkey vultures, hawks, and owls. **Table 5** contains the reported raptor collisions by year and species/group. **Table 6** displays the owl carcasses by month; each month recording is a calculation of all owl carcasses reported for that month between 2015-2020. **Table 7** contains all owls from the HATS database identified to species by photo or written in comments. 154 of the 683 records contained either photographic or verbal identification. These owl records are also broken up by region in the state.

*Table 4. The total recorded raptor carcasses in the WCRDB from 2015-2020, broken up by whole number as well as percent.*

| **Type of Raptor** | **Total Carcasses Reported 2015-2020** | **% of the Total** |
|---|---|---|
| Bald Eagle | 18 | 1.8 |
| Golden Eagle | 7 | 0.7 |
| Turkey Vulture | 9 | 0.9 |
| Owl | 683 | 68.7 |
| Hawk | 278* | 27.9 |
| **Total** | 995 | 100 |

* 62 identified as Red-tailed Hawks

*Table 5. Reported raptor carcasses in the WCRDB from 2015-2020, broken up into raptor group and separated by year.*

| | Bald Eagle | Golden Eagle | Turkey Vulture | Owl | Hawk | **Grand Total** |
|---|---|---|---|---|---|---|
| 2015 | 2 | 1 | 2 | 36 | 21 | 62 |
| 2016 | 1 | 0 | 1 | 102 | 36 | 140 |
| 2017 | 8 | 2 | 0 | 128 | 49 | 187 |
| 2018 | 3 | 0 | 0 | 155 | 48 | 206 |
| 2019 | 2 | 1 | 4 | 156 | 55 | 218 |
| 2020 | 2 | 3 | 2 | 106 | 69 | 182 |
| **Total** | 18 | 7 | 9 | 683 | 278 | **995** |

*Table 6. Reported owl carcasses in the WCRDB from 2015-2020, as monthly totals.*

| **Month** | **Number of Owl Carcasses Reported** |
|---|---|
| January | 66 |
| February | 41 |
| March | 45 |
| April | 37 |
| May | 38 |
| June | 30 |
| July | 35 |
| August | 55 |
| September | 53 |
| October | 101 |
| November | 94 |
| December | 88 |

*Table 7. A display of all owl records with species written in the comments section of the WCRDB from 2015-2020, by WSDOT Region (see Figure 7).*

| Owl Species | EA | NC | NW | OL | SC | SW | **Total** |
|---|---|---|---|---|---|---|---|
| Barn Owl | 1 | 19 | 19 | 10 | 13 | 9 | 71 |
| Great Horned Owl | 11 | 9 | 3 | 3 | 10 | 9 | 45 |
| Barred Owl | 1 | 1 | 6 | 9 | 1 | 18 | 36 |
| Northern Saw-whet Owl | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| **Region Total** | 13 | 29 | 28 | 22 | 24 | 38 | **154** |

**Figure 10** illustrates raptor type by region of the state. The northwest region has the most total raptor carcasses in the state. The eastern, northwest, and south-central region each have more than one hundred reported owl carcasses. **Figure 11** depicts all reported raptor collisions by county. Skagit County has the most collisions in any particular county.

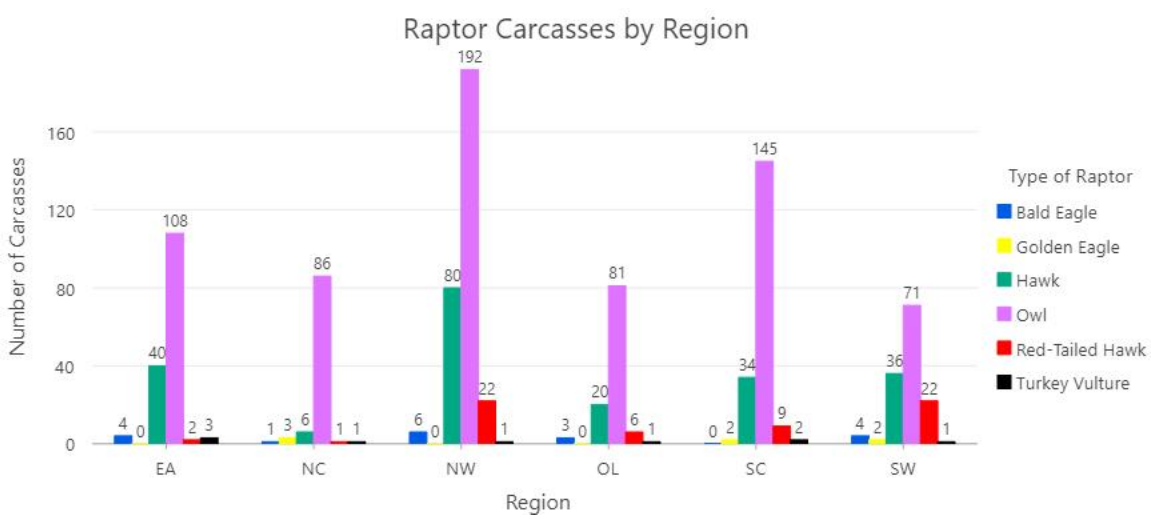



*Figure 10. Raptor types reported in each region of the state in the WCRDB from 2015-2020.*

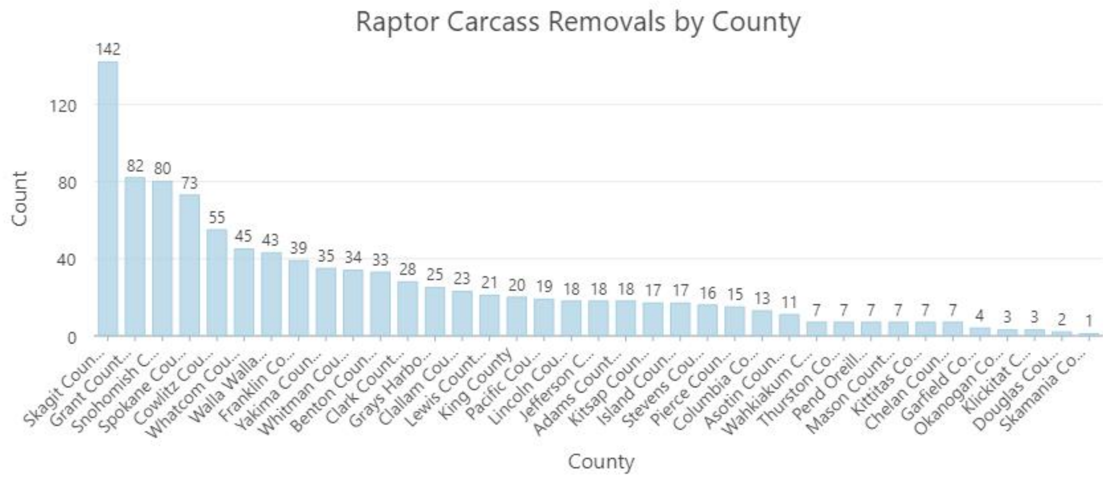



*Figure 11. A graphic display of raptor collisions by county reported in the WCRDB from 2015-2020.*

**Figures 12-14** show the locations of carcass data along highways in Washington State (all reported, owls and hawks). There is a significant discrepancy between the records with photos attached versus records without photos from the HATS database.

*See what you think of the 2 images on one page (next page) – if you like the larger images better, go ahead and increase their size again. I just think it's nice to be a little more compact if possible.*

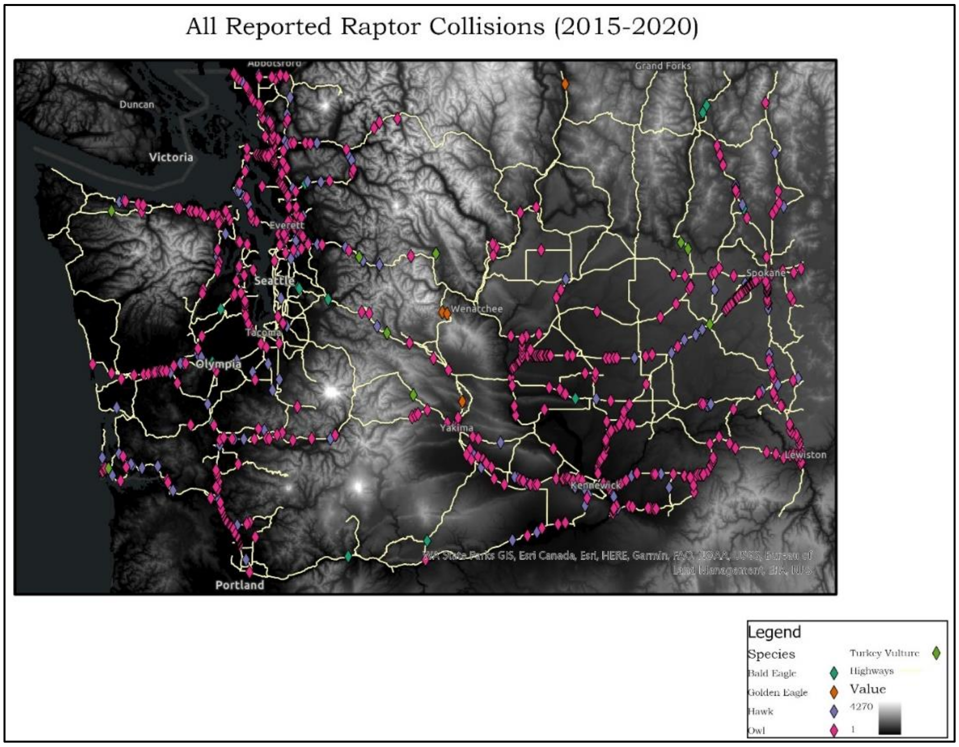



*Figure 12. All reported raptor carcasses displayed spatially from 2015-2020. Map was created in ArcGIS Pro.*

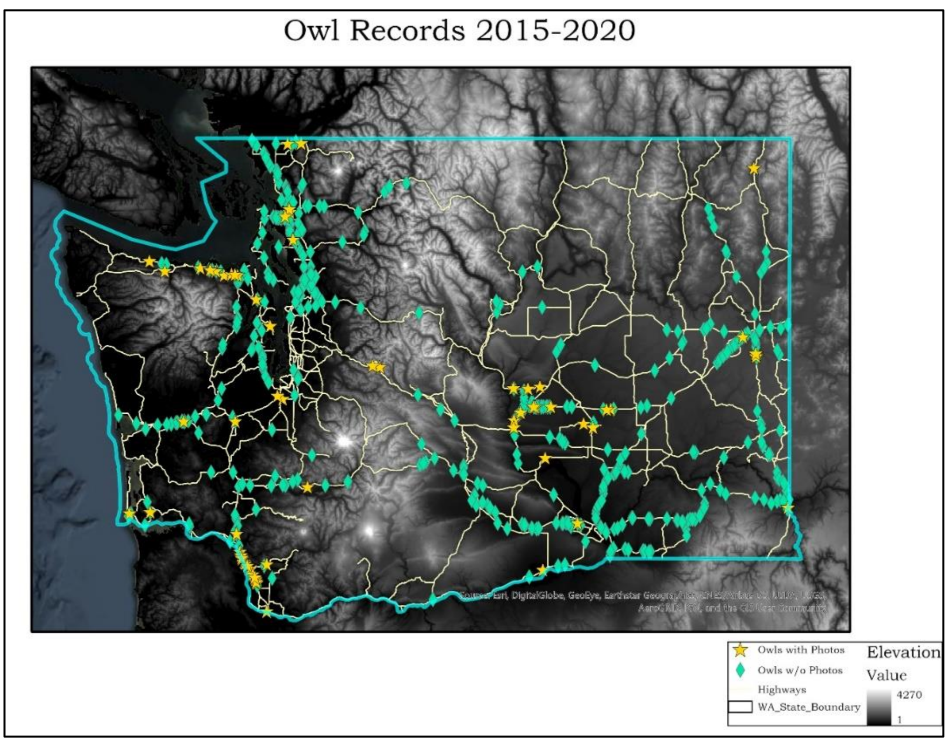



*Figure 13. A spatial display to document the locations and frequencies of owl records with and without photos attached in the HATS database. Map was created in ArcGIS Pro.*

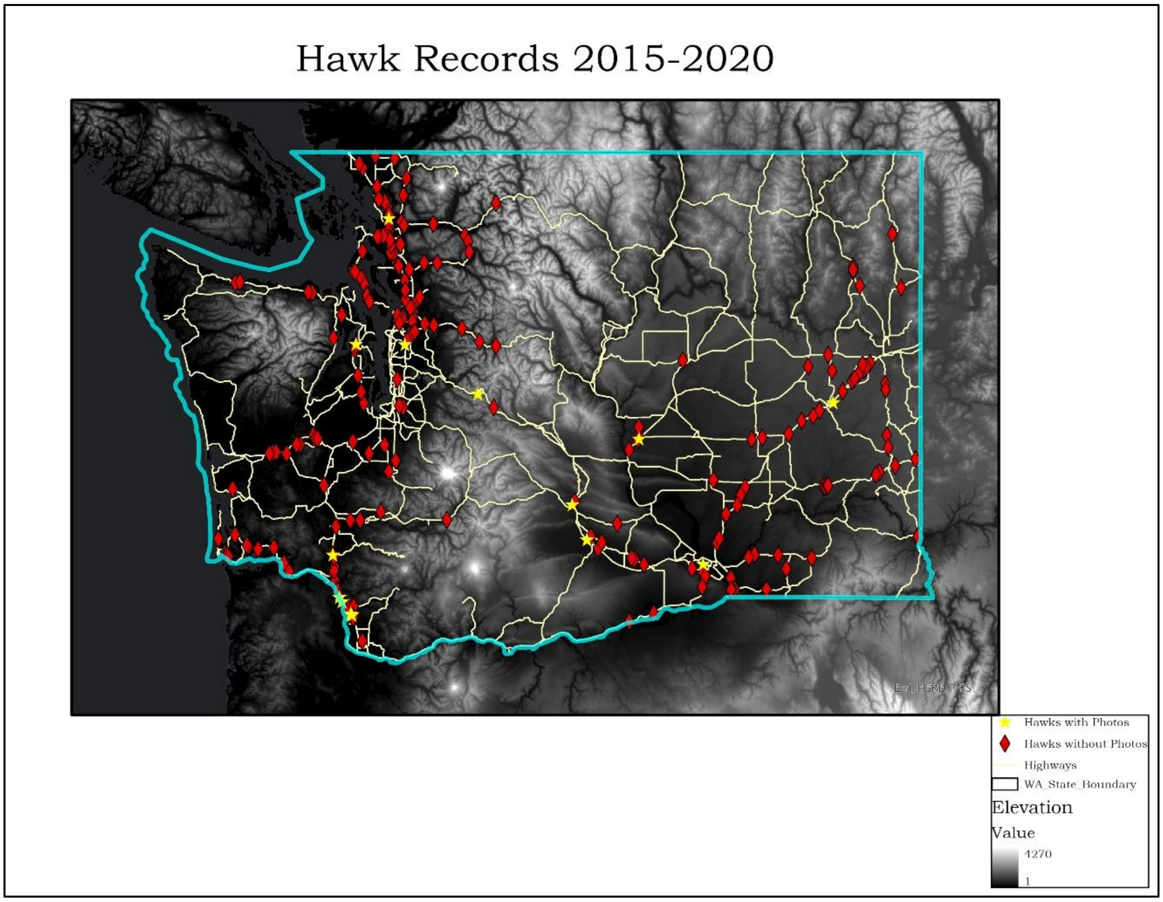



*Figure 14. A spatial display to document the locations and frequencies of hawk records with and without photos attached in the HATS database. Map was created in ArcGIS Pro.*

**Figure 15** shows the locations of hotspot areas in the state as you can see reported raptor collisions occur in specific areas in the state, they do not occur evenly across state highways. **Figures 16, 17, 18,** and **19** display the zoomed-in areas of each of the four hotspot areas for reported raptor collisions. **Figure 16** is a hotspot just north of Vancouver Washington in an area featuring hay/pastureland type as well as human development. **Figure 17** displays the second hotspot on Interstate 5, this is where the most highly concentrated area of reported raptor collisions occurs. **Figure 18** shows the first hotspot location on Interstate 90, this hotspot is in Grant county and the land type in this area is mostly used for cultivated cropland. **Figure 19**

displays the second hotspot on Interstate 90, southwest of Spokane. The reported raptor collisions in this area occur remarkably close together.

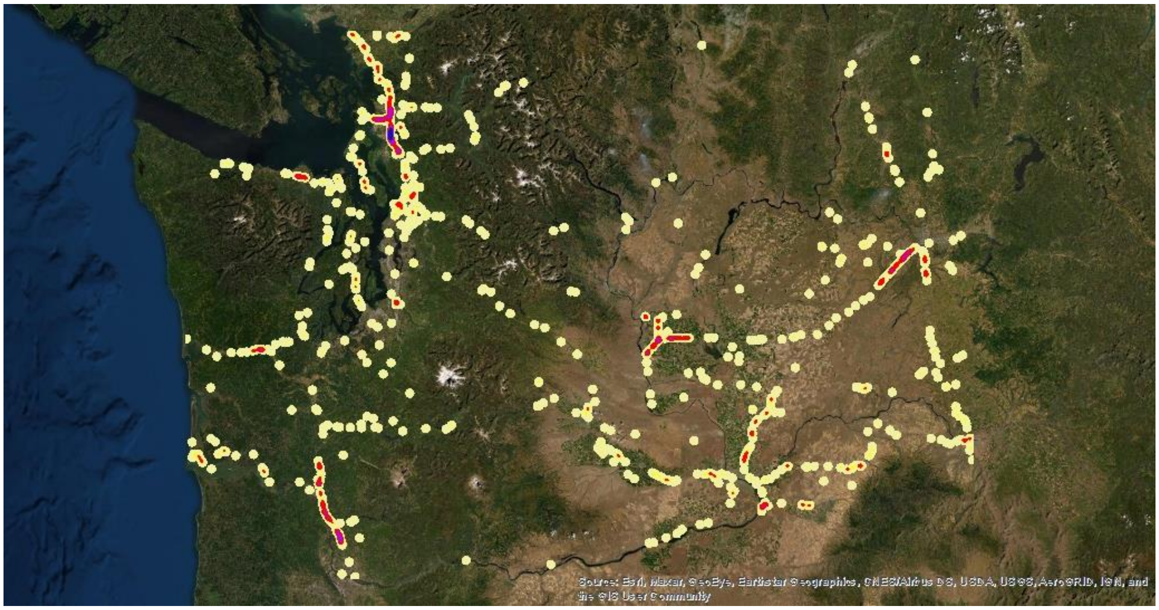


*Figure 15. Kernel Density distribution of raptor collisions in Washington. Map was created in ArcGIS Maps.*

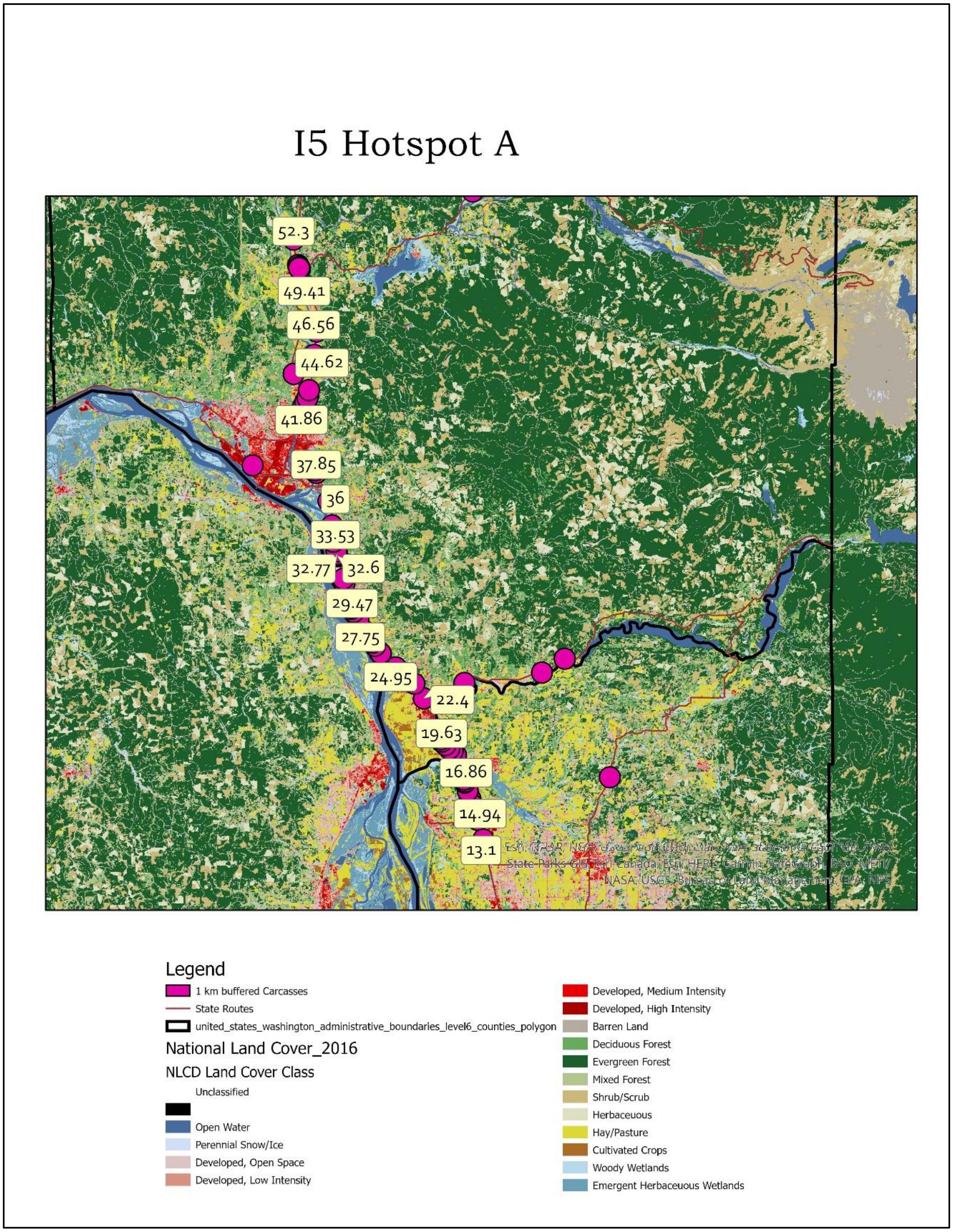



*Figure 16. A close-up view of raptor the I5 raptor hotspot A. Map was created in ArcGIS Pro.*

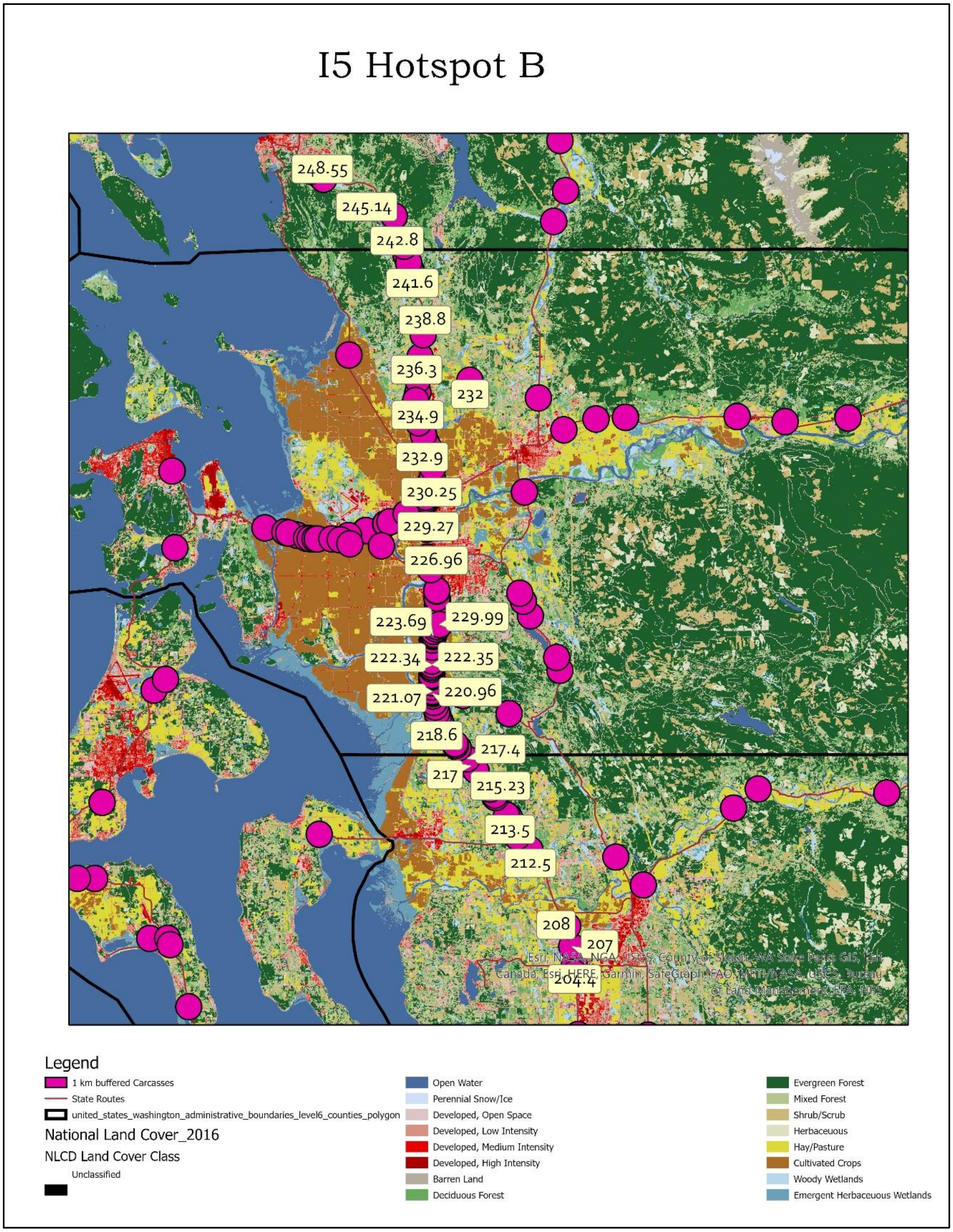



*Figure 17. A close-up view of raptor the I5 raptor hotspot B. Map was created in ArcGIS Pro.*

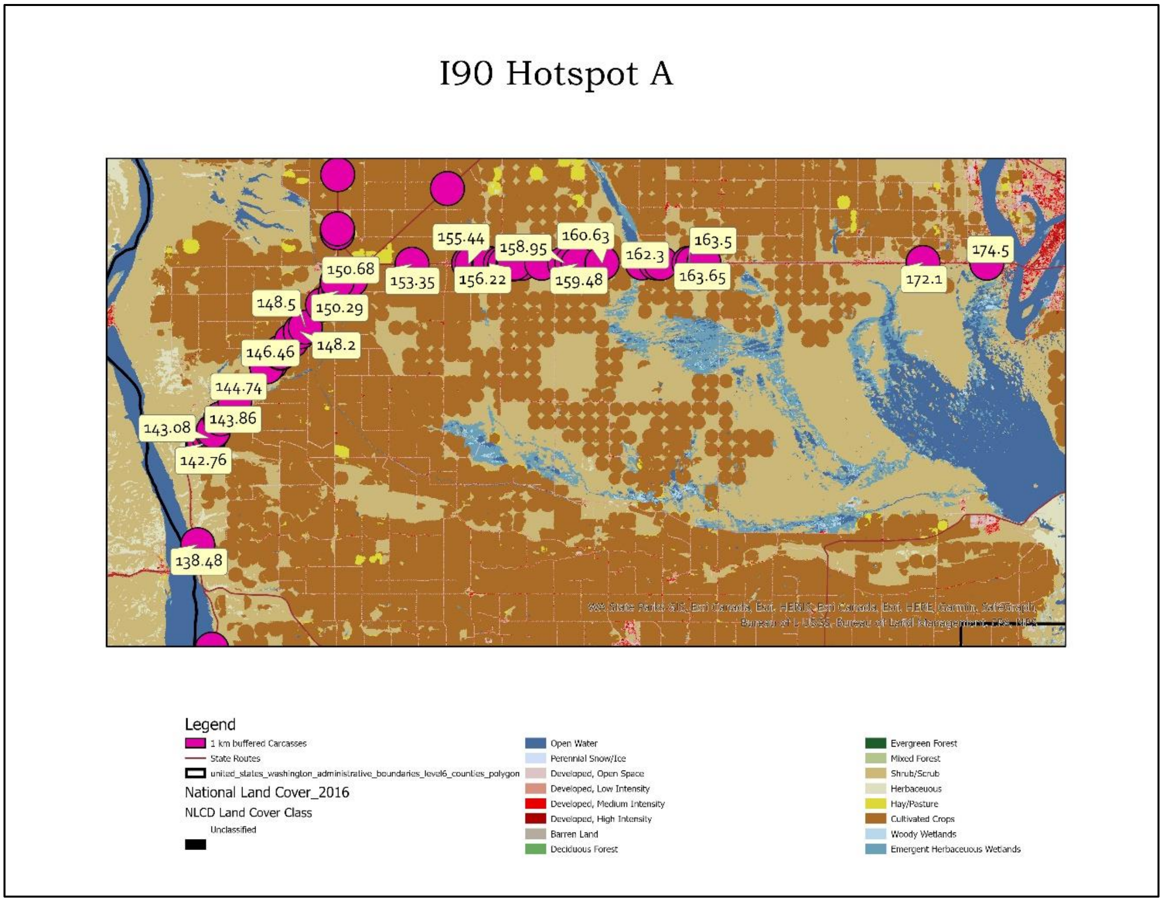



*Figure 18. A close-up view of raptor the I90 raptor hotspot A. Map was created in ArcGIS Pro.*

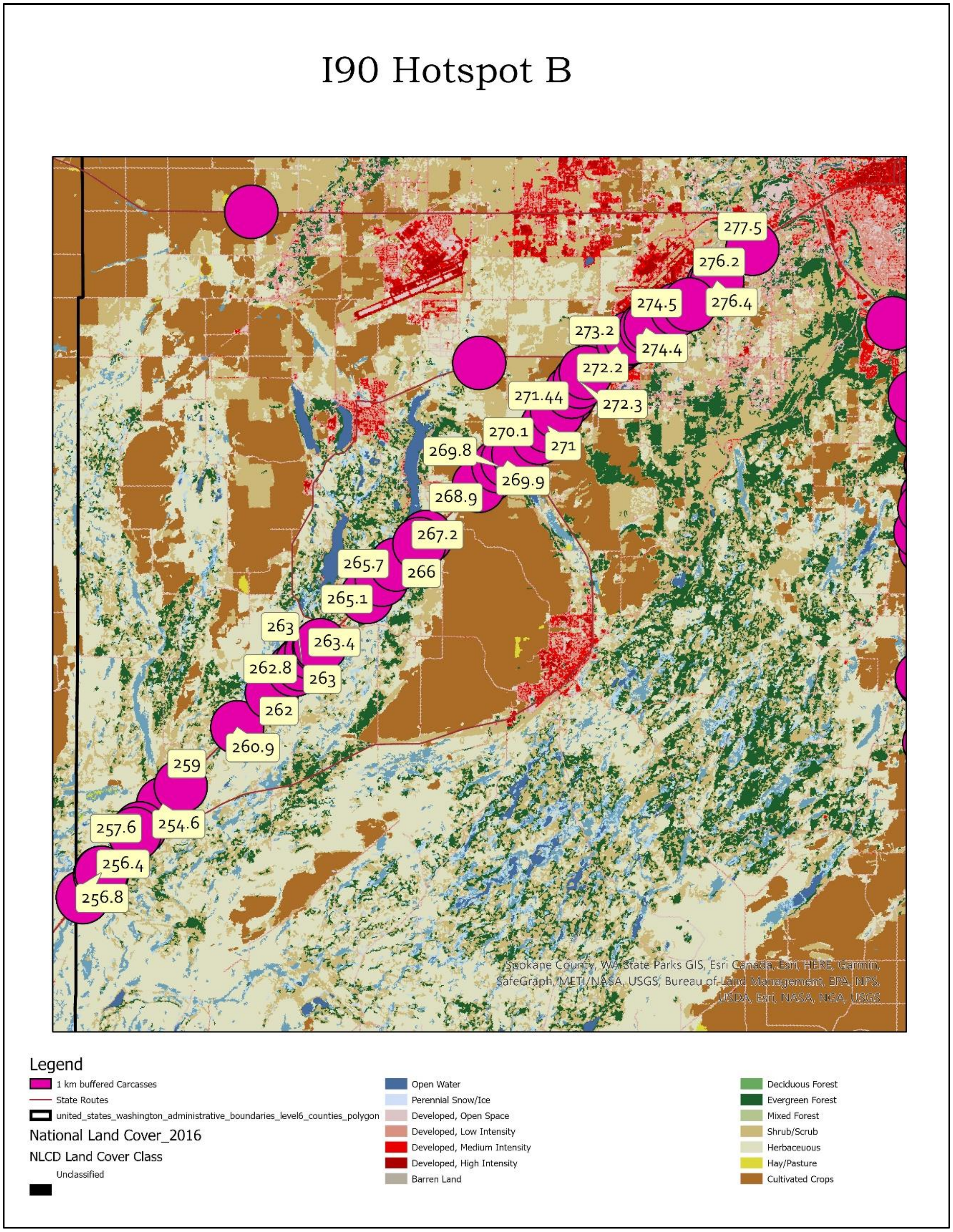



*Figure 19. A close-up view of raptor the I90 raptor hotspot B. Map was created in ArcGIS Pro.*

# Discussion

The questions I set out to answer through this research were:

1. Where are raptors being hit and killed due to vehicle collisions on Washington State Highways?

2. What are the emerging temporal and spatial trends in the data? Are there hotspots that appear? Are there certain times of year in which more raptor collisions are reported?

3. What is the methodology in capturing raptor data within the wildlife carcasses removal database? Are there gaps in the data? How can this data source be strengthened?

I was able to answer each of these questions. For question 1, the state's northwest region accounts for 30.25% of all raptor collisions in the state from January 1, 2015, to December 31, 2020. The hotspots in the state are situated in areas that experience high traffic volumes. This does not mean that there are necessarily more raptors in these areas, just that the raptors that are present are more likely to be hit and reported due to the number of vehicles on the roads.

I would have expected more scavenger presence in the overall number of raptor carcasses recorded. The literature cites that the frequency of scavengers involved in WVC is higher than other groups of birds (Foreman et al. 2003; Hartley et al. 1996; Husby 2016; Jacobson 2005; Kociolek et al. 2015; Newton 1979). In a presentation given by HawkWatch International, they reported eagle carcasses being picked up and stolen before transportation departments could pick up and document those individuals being hit and killed by vehicles. They were able to obtain this data by cameras that were monitoring other roadkill carcasses that would attract both bald and golden eagles (Taylor, 2021). Compared with different raptor types, the proportion of owls is high, which I would anticipate since they fly low and are attracted to roads during crepuscular and nocturnal times, making them difficult for drivers to see.

Large owls make up most owls recorded, with species noted in the comments field of the WCRDB. Large owls would likely be found more frequently since they are easier to spot than smaller owl species. I was surprised that two saw-whets were identified (both accounts had photos attached) due to their small stature. Their carcasses could have easily been carried away in the grill of a vehicle or blown off the road completely. A 10-year study conducted in Cape May, New Jersey, found 250 raptor carcasses over a 145 km route. Twelve different species of hawks and owls were found (6 species of owls, six species of hawks). Owls comprised 88% of the data, with saw-whets making up 52% of the total owl carcasses. Loos and Kerlinger (1993) reported that 87% of saw-whets and 72% of eastern screech owls were hit between November and January. They hypothesized that many of the owls hit during this period were dispersing and were last year's young—this study is unique due to the small owls (saw-whets and eastern screech owls) making up most of their data (Loos and Kerlinger 1993). The most common owl cited in the literature for being involved in WVC is the barn owl (Boves & Belthoff 2012; Guinard et al. 2012; Meunier et al. 2000; Ramsden 2007). Boves and Belthoff (2012) found barn owls to be the most common species hit between July 2004 and June 2006 on I-84 in Idaho. Of 63 species they encountered, barn owls accounted for 32% of all roadkill mortality events. I also found barn owls to be the most prominent owl in the reports; **Table 7** shows that 71 out of the 154 owls with species listed were identified as barn owls.

To answer question 2, regarding temporal trends, I found similar chronological patterns as Loos and Kerlinger (1993) within the owl data; 51% of owls were hit between October and January, as shown in **Table 6**. Over the five years of data collection, 101 owls were hit and killed in the month of October, which contrasts with Loos and Kerlinger (1993) as they do not cite October as a month that their study saw significant raptor records.

Increased traffic volume is known to play a role in raptor collisions. A fifteen-year study from the Barn Owl Trust in Britain found a positive correlation between traffic volume and the number of barn owls being struck (Ramsden 2007). This becomes an important factor on major roads; The Barn Owl Trust calculated that Barn owls are three times more likely to be involved in a WVC on main roads than to be seen alive. On smaller roads in Britain, they found that Barn Owls were fifty-seven times more likely to be found alive rather than dead (Ramsden 2007). Washington state has experienced a significant increase in the annual vehicle miles traveled per year. **Figure 20** (2016 WSDOT) shows the increase from 1990 to 2016 in both urban and rural traffic volumes; this information came from the 2016 Annual Traffic Report published by WSDOT. **Appendix A** displays this information in a table format displaying the changes in percent from year to year.

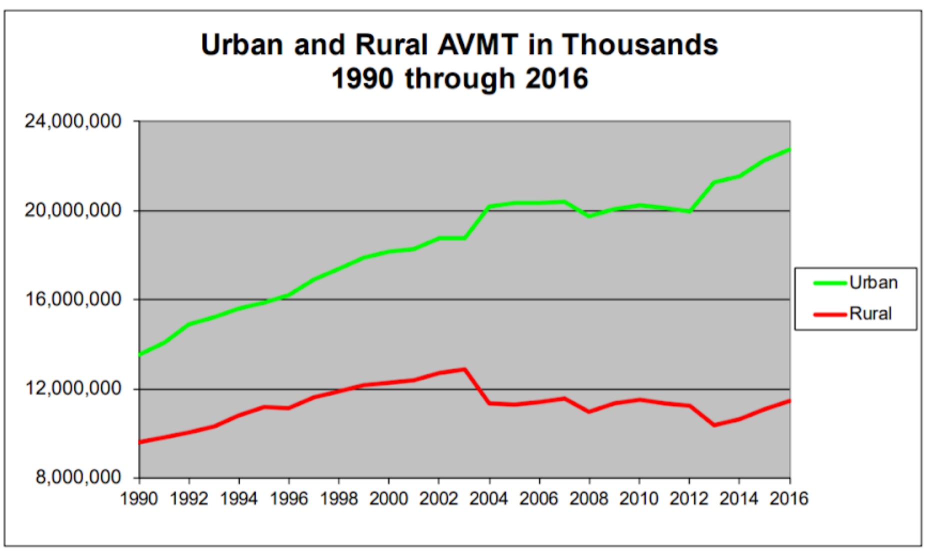



*Figure 20. The amount of vehicle miles traveled (AVMT) in Washington state from 1990-2016. Data is separated by rural and urban miles. Graph is taken from 2016 Annual Traffic Report, Washington Department of Transportation, pp.55.*

***Hotspots in Washington***

To answer question 2 with regards to spatial trends, I found that four major hotspot areas emerged for raptor collisions in the state. 239 out of the total 995 strikes occurred on Interstate 5, comprising 24% of the data. 78 of the reported raptor collisions were between mileposts 13-76. The land cover in this area is hay/pastureland as well as developed land. These mileposts span across three different counties: Clark County, Cowlitz County, and Lewis County. 151 of the raptor collisions on Interstate 5 took place between mileposts 167-274. The land cover in this area is developed, hay/pastureland, and cultivated cropland. These mileposts span across four different counties, starting in King County, crossing Snohomish and Skagit county, and ending in Whatcom County.

Skagit county had the most raptor collisions of any individual county in the state. The Skagit Valley is home to very fertile soil, and many farming practices occur here. The Skagit area hosts a rich estuarine environment as well. Due to the area's wealth of resources, it attracts many bird species. The Skagit is an important migration area for many avian species, including raptors, shorebirds, swans, and snow geese (Audubon n.d.; Birds of Winter 2018). One specific location known as the Skagit River Delta is a winter migration hotspot for over 50,000 snow geese, and 262 individual species of birds have been identified via Ebird here (Birds of Winter 2018).

125 reported raptor collisions from 2015-2020 occurred on Interstate 90. This makes up 12.5% of the total data. 49 of these strikes took place between mileposts 138-175. The main landcover in this area is cultivated cropland and lies entirely within Grant county. The other hotpot on I90 is between mileposts 220-298; 56 strikes were reported here. The landcover types

in this area are cultivated land, herbaceous land, and developed land. These mileposts are in Adams and Spokane county.

### *Gaps in Current Research*

Roads and their effects are widespread; the research in road ecology needs to reflect the size and magnitude of its subject. Systematic methods to detect roadkill mortality rates need to be implemented at a larger scale. Local efforts use state, region, and community science data to understand WVC rates better. These WVC datasets, however, are usually need-based and not sustained efforts. The long-term effects of roads need to be better monitored (Beckman & Hilty 2010; Forman et al. 2003; Spellerberg 1998). Due to the lack of widespread WVC data collection efforts, the mortality rates of animals are probably more significant than what estimates currently are (Foreman et al. 2003; Jacobson 2005). The parties responsible for collecting and reporting carcasses need specialized training based on bird identification so they can recognize the different species of birds that are getting hit and killed in vehicular collisions (Ramsden 2007). There is a gap in the knowledge base surrounding the effects of birds and roads; more research and understanding need to focus on birds and roads to help mitigate the negative repercussions roads present to the avian community.

### *Future Studies*

To answer my third and final question, with regards to how can this data source be strengthened, I began to think about different ways the data could be collected and improved upon. The limitations listed in the methods section display the finite species identification options in the WCRDB when it comes to birds, in particular raptors. Along with the shortage of avian options, another challenge is the scarcity of photos captured to help strengthen raptor identification.

To create an effective roadkill carcass survey, there are four objectives to consider, as outlined in (**Figure 21**, Shilling et al. 2015).

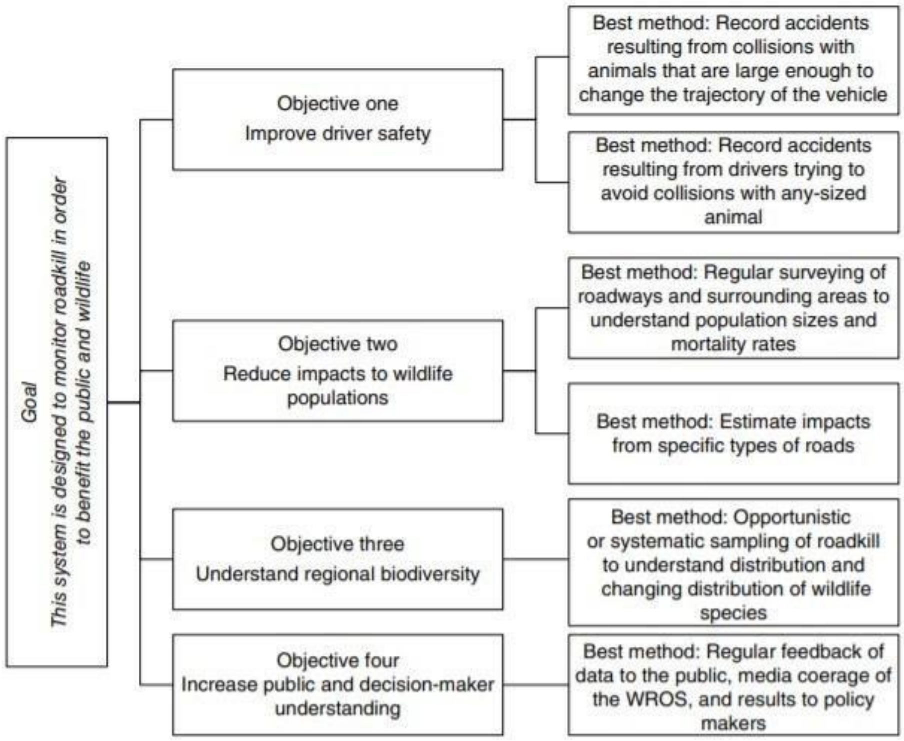



*Figure 21. A systematic way to select objectives of a WVC survey. Figure 62.1 Shilling et al. 2015.*

When creating a wildlife collision survey, it is important to decide what objective(s) are most important to the study; this will influence how data is collected. Shilling et al. 2015 also depict two different strategies for collecting data. Studies can utilize opportunistic and random observations or transect/targeted route observations. The opportunistic and random observations rely on people reporting WVC when they happen across carcasses. The latter method is based on people following specific routes actively looking for carcasses. Both methods are beneficial in collecting carcass observations.

One effort that has bolstered carcass data specific to ungulates in WSDOT'S WCRDB is the salvage data system. The salvage database is a partnership between WSDOT and the Washington Department of Fish and Wildlife. This system is a way to maintain and keep track of all deer and elk carcasses salvaged in Washington. The salvage system began in 2016 and has given the WCRDB a wealth of data since then. The salvage removal system is a form of community science because community members are helping to identify where deer and elk are hit and removed in the state. I believe a community science effort surrounding raptor carcass data would help account for raptors all over the state, not just those hit on Washington State Highways.

I created a survey using ArcGIS 123 that could be used as a data collection tool to gather information from many different sources. This would help to strengthen the raptor WVC data in the state. I chose ArcGIS Survey 123 as the application for its user-friendly features. If a roadkill survey is too complicated, the results can be erroneous (Kinyon, 2017). The survey has options to choose from thirty-three different raptor species found in the state of Washington, some more commonly found than others. The thirty-three species it accounts for are listed in **Appendix B**. The survey allows the user to take photos and provide their GPS location. It also has an option for their level of certainty that they identified the species correctly. The survey lets the user select what type of road they were on and the speed limit where they found the carcass. The survey also allows the user to estimate how long they believe the raptor has been dead. These questions would help provide more data about raptor collisions in Washington State outside those made by maintenance personnel in the HATS database. This would allow more questions to be asked and answered about the relationship between roads and raptors, especially concerning certain species and hotspot locations that do not occur on state highways.

Numerous community science efforts focus on reducing animal collisions on roads and increasing local knowledge. The more people aware of high-use areas from wildlife, the better they can prepare when driving through those areas. Two examples of successful community science projects both took place on Highway 3 in Alberta, Canada, in the Crowsnest Pass area. Road Watch was a productive community science effort that relied on individuals driving and reporting any animal they saw near the road (alive or dead) using a web-based mapping application (Lee et al. 2010; Paul 2002). This project had over 4,044 reported wildlife observations. It succeeded in its goal of engaging the public in data collection. In 2007, they surveyed to see if community members who participated in the data collection felt they had gained more knowledge about WVC. 85% of survey participants agreed that their knowledge of WVC had increased through the Road Watch project (Lee et al. 2010).

The later study conducted in a partnership with a highway maintenance department called Citizen Count ran from 2014-2017. The aim of the community science project was to collect roadkill information pre- and post-construction on a series of mitigation projects, including an underpass, wildlife exclusion fencing, and jumpout installation. The volunteers walked the same transect each week from 2014-2017. They were taught how to record data using an app called Collision Count, and over twenty volunteers participated in the project. The maintenance contractors also surveyed Highway 3 twice a day from 1997-2017(Lee & Rondeau, 2018). The combination of maintenance crews and community members working together creates a wealth of local knowledge about an area. It helps to engage the surrounding communities to be more aware of the roadkill issues, resulting in drivers being more alert to animal movements.

With an increase in data surrounding wildlife collisions, more time and energy can go into fixing WVC problems. There are numerous ways to help wildlife navigate our infrastructure and be successful in the wild. Community science efforts could help pinpoint where raptors are being hit in Washington; this could solve other challenges that wildlife face in these areas.

For the purposes of my study, I looked at all raptor vehicle collisions in the state; future studies may decide to look at the effects of roads on individual species or groups of raptors (e.g., owls). Since not all raptors occupy the same scale, looking at individual species may be beneficial in better understanding individual species' spatial ranges in union with the hotspots (Sevigny et al. 2021).

If particular species are being hit and killed by vehicles more often, this could lead to long-term changes in a population; these changes over time could impact an ecosystem (Santos et al. 2016: Seiler & Helldin 2006). It would also be interesting to study individual raptor species to see how certain species better adapt to roads over time, understand the relationship between roads and cars, and use roads to their advantage.

One other future study area that I think would be influential in understanding raptors, open agricultural land, and the relationship of the road would be to look specifically at the Skagit Valley region. As noted earlier, this area is home to fertile fields, numerous migratory birds, and an estuarine environment. Skagit county also experienced the most raptor vehicle collisions than any other county from 2015-2020. A systematic road carcass system would capture more information in the area. Getting in touch with local wildlife rehabilitators and rehabilitation centers would also help account for raptors not killed on site. This would be a way to capture data concerning injured raptors as well.

## Conclusion

Animal collisions only tell a small part of the story in the realm of road ecology. There is so much more to learn about the complex relationship between animals and roads. Raptors are a unique set of birds to study; roads are important for hunting grounds and scavenging resources. As long as raptors find the benefits of roads to overshadow the potential danger of vehicular collisions, they will continue to utilize these resources.

Road ecology is a blossoming branch of science full of opportunities. With so many local efforts to increase habitat connection for animals, the future is bright. Transportation planners should consider data from WVC to make informed planning decisions. Road ecology lends itself to collaboration between a suite of different professions. Creating and restoring habitat connectivity is vital for the well-being of animal communities. As we look forward, many roads, bridges, and other forms of infrastructure are outdated and currently being worked on or will be in the near future. The time is right to update antiquated designs to incorporate mitigation efforts for wildlife.

The trends found in my research are capable of aiding in creating mitigation efforts to help lessen raptor strikes, especially in the hotspots of collisions. The WCRDB can be strengthened when it comes to raptor and bird identification. This work is a great baseline to strengthen in the future.

Moving forward, I hope to educate people and make them aware of potential animals on roads, whether they are fly, walk, slither, or hop across the street. Educating the public on road awareness can not only benefit wildlife but drivers as well. Community science is a powerful tool that can help in collecting data and increasing awareness of WVC. I also hope people who read this work will become more aware of the challenges that animals face due to anthropogenic causes and feel empowered to become involved in community science efforts.

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# Appendices

**Appendix A: Washington State Highway Amount of Vehicle Miles Traveled per year 1990-2016** The amount of vehicle miles traveled (AVMT) in Washington state from 1990-2016. The expanded data is separated by rural and urban miles and shows the percent change from year to year. Table is taken from 2016 Annual Traffic Report, Washington Department of Transportation, pp.55.

State Highway AVMT in Thousands

| Year | Rural | Urban | Total | Change |
|---|---|---|---|---|
| 1990 | 9,611,285.0 | 13,512,508.6 | 23,123,793.6 | 3.4% |
| 1991 | 9,804,824.0 | 14,089,564.0 | 23,894,389.0 | 3.3% |
| 1992 | 10,031,337.2 | 14,874,629.8 | 24,905,967.0 | 4.2% |
| 1993 | 10,317,842.4 | 15,209,742.9 | 25,527,585.3 | 2.5% |
| 1994 | 10,835,712.7 | 15,593,377.3 | 26,429,090.0 | 3.5% |
| 1995 | 11,189,929.7 | 15,894,498.4 | 27,084,428.1 | 2.5% |
| 1996 | 11,120,686.8 | 16,188,271.3 | 27,308,958.1 | 0.8% |
| 1997 | 11,624,399.2 | 16,918,735.3 | 28,543,134.5 | 4.5% |
| 1998 | 11,904,185.7 | 17,415,929.0 | 29,320,114.7 | 2.7% |
| 1999 | 12,167,551.8 | 17,916,570.0 | 30,084,121.8 | 2.6% |
| 2000 | 12,271,911.3 | 18,162,693.6 | 30,434,604.8 | 1.2% |
| 2001 | 12,398,500.7 | 18,272,192.3 | 30,670,693.0 | 0.8% |
| 2002 | 12,731,757.3 | 18,754,308.7 | 31,486,066.0 | 2.7% |
| 2003 | 12,900,328.6 | 18,763,380.8 | 31,663,709.4 | 0.6% |
| 2004 | 11,353,780.5 | 20,203,474.8 | 31,557,255.3 | -0.3% |
| 2005 | 11,292,860.6 | 20,335,811.9 | 31,628,672.5 | 0.2% |
| 2006 | 11,397,272.6 | 20,366,807.2 | 31,764,079.8 | 0.4% |
| 2007 | 11,564,241.0 | 20,405,957.1 | 31,970,198.1 | 0.6% |
| 2008 | 10,987,639.9 | 19,754,004.2 | 30,741,644.1 | -3.8% |
| 2009 | 11,362,399.0 | 20,093,110.7 | 31,455,509.6 | 2.3% |
| 2010 | 11,521,205.9 | 20,242,894.4 | 31,764,100.3 | 1.0% |
| 2011 | 11,352,596.4 | 20,102,696.1 | 31,455,292.5 | -1.0% |
| 2012 | 11,251,513.9 | 19,962,581.8 | 31,214,095.7 | -0.8% |
| 2013 | 10,371,062.5 | 21,277,756.2 | 31,648,818.7 | 1.4% |
| 2014 | 10,640,610.3 | 21,536,476.6 | 32,177,087.0 | 1.7% |
| 2015 | 11,098,178.9 | 22,237,103.2 | 33,335,282.1 | 3.6% |
| 2016 | 11,486,533.4 | 22,740,581.9 | 34,227,115.3 | 2.7% |

***Appendix B: Complete list of Raptor Species included in Arc Survey123***

| **Common Name** | **Scientific Name** | **Group** |
|---|---|---|
| Turkey Vulture | *Cathartes aura* | New World Vulture |
| Osprey | *Pandion haliaetus* | Osprey |
| White-tailed Kite | *Elanus leucurus* | Kite |
| Golden Eagle | *Aquila chrysaetos* | Eagle |
| Northern Harrier | *Circus cyaneus* | Harrier |
| Sharp-shinned Hawk | *Accipiter striatus* | Hawk |
| Cooper's Hawk | *Accipiter cooperii* | Hawk |
| Northern Goshawk | *Accipiter gentilis* | Hawk |
| Bald Eagle | *Haliaeetus leucocephalus* | Eagle |
| Red-shouldered Hawk | *Buteo lineatus* | Hawk |
| Swainson's Hawk | *Buteo swainsoni* | Hawk |
| Red-tailed Hawk | *Buteo jamaicensis* | Hawk |
| Rough-legged Hawk | *Buteo lagopus* | Hawk |
| Ferruginous Hawk | *Buteo regalis* | Hawk |
| Barn Owl | *Tyto alba* | Owl |
| Flammulated Owl | *Otus flammeolus* | Owl |
| Western Screech-Owl | *Megascops kennicottii* | Owl |
| Great Horned Owl | *Bubo virginianus* | Owl |
| Snowy Owl | *Bubo scandiacus* | Owl |
| Northern Hawk Owl | *Surnia ulula* | Owl |
| Northern Pygmy-Owl | *Glaucidium gnoma* | Owl |
| Burrowing Owl | *Athene cunicularia* | Owl |
| Northern Spotted Owl | *Strix occidentalis* | Owl |
| Barred Owl | *Strix varia* | Owl |
| Great Gray Owl | *Strix nebulosa* | Owl |
| Long-eared Owl | *Asio otus* | Owl |
| Short-eared Owl | *Asio flammeus* | Owl |
| Boreal Owl | *Aegolius funereus* | Owl |
| Northern Saw-whet Owl | *Aegolius acadicus* | Owl |
| American Kestrel | *Falco sparverius* | Falcon |
| Merlin | *Falco columbarius* | Falcon |
| Peregrine Falcon | *Falco peregrinus* | Falcon |
| Prairie Falcon | *Falco mexicanus* | Falcon |