West-Wide Study to Identify Important Highway Locations for Wildlife Crossings

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EXECUTIVE SUMMARY

Wildlife-vehicle collisions (WVCs), reduced ecological connectivity, and associated impacts to wildlife and humans are widespread problems across road networks, but mitigation measures like wildlife crossings[1] that can address those problems are often considered expensive. This effort aims to support transportation agencies, wildlife agencies and other decision-makers by identifying important road segments where cost-effective wildlife crossings can be deployed to address motorist safety, ecological connectivity and other conservation values across the eleven U.S. western conterminous states of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

Most studies identify “hotspots” for highway mitigation locations based solely on the highest rates of wildlife-vehicle collision (WVC) risk and have looked at different scales such as by state, county, tribal reservation, or an individual highway section. This study evaluates WVCs and incorporates ecological and economic values. It is one of the first to look at all western states with a consistent methodological approach and to incorporate collision risk, economic cost, and connectivity considerations to identify the sections of highway across the West that are best served by future wildlife crossings.

Specifically, this project sought to inform transportation agencies and other stakeholders about road segments (1) with high levels of WVC rates that cause wildlife mortality and threaten motorist safety, (2) located in landscapes important for ecological connectivity, (3) that relate to other conservation values such as the proximity of threatened and endangered species’ critical habitat, public lands, or privately conserved lands, and/or (4) that potentially create barriers to wildlife movement due to high traffic volume. A recent, updated, and expanded cost-benefit analysis for WVC mitigation measures, particularly wildlife crossings, is used to identify road segments where the cost of building and maintaining overpass and/or underpass structures with fencing is less than the cost of unabated WVCs long-term. While there are dozens of potential mitigation measures to choose from, we focus on wildlife crossings because they are the most effective and robust approach to reduce WVCs while also allowing for safe wildlife passage under or over the road.

In addition to examining the eleven states as a whole, we mapped and analyzed each state separately (see Appendix A). Additionally, we developed an accompanying interactive web map **(http://largelandscapes.org/west-wide-mapping)** to allow users to examine the results of the analyses at various scales.

Based on our analyses using state crash data and recently updated WVC cost estimates, it is estimated that WVCs with large animals in the West cost $1.6 billion per year, at minimum. This is a conservative estimate as the number of large wild mammal-vehicle crashes are typically

[1] Throughout the document, we use the term ‘wildlife crossings.’ In this Study, that term always implies the inclusion of necessary components that make the crossings effective at both allowing wildlife movement and reducing collisions: 1) the crossing structures themselves; 2) wildlife fencing of sufficient length that funnels wildlife to the structures and that may include dig barriers or aprons; 3) escape opportunities from the right-of-way such as jump-outs; 4) measures at fence-ends and access points to deter wildlife from entering the roadway at those locations.

only a fraction of the number of carcasses that are removed. The $1.6 billion per year is an estimate of the cost of doing nothing and letting WVCs continue to occur. These costs can be significantly reduced by implementing wildlife crossings. As remediating barriers to wildlife movement across the West will be a significant undertaking, our study helps prioritize locations for wildlife crossings.

We strove to identify highway locations where safety concerns and ecological connectivity values overlap. We analyzed tens of thousands of road segments across the West to identify those that meet various considerations. We used the top 10th percentile as a threshold for WVC rates. We considered road segments in the top 50th percentile of permeability values as a threshold for identifying areas important for overall ecological connectivity. This approach reduced the 9,299 segments or 2,005 miles (mi) that experience the highest WVC rates, and the 356,741 segments or 73,031 mi intersecting landscapes important for ecological connectivity, to 3,509 road segments or 777 mi across the West that, if mitigated with wildlife crossings and fencing, could address *both* human and wildlife safety and ecological connectivity. We refer to those segments as ‘collision and connectivity’ or ‘CC’ road segments.

Next, we looked where those CC road segments are within one mile of a protected area (3,097 segments or 695 mi), within a quarter mile of critical habitat (400 segments or 89 mi) and determined the segments that are near both protected areas and critical habitat (358 segments or 81 mi). We found that across the western states, 42 percent of the CC road segments are directly adjacent to protected areas, leaving 58 percent of the CC road segments directly adjacent to non-protected areas. There is a small number of locations (7 percent, 230 segments, totaling 53 mi) directly adjacent to federally designated critical habitat.

We found stretches of road where a barrier effect may be occurring due to high traffic volume and, as a result, are important areas to consider for installation of mitigation measures for connectivity purposes. We found many (9,616, totaling 2,121 mi) road segments with high connectivity and high traffic volume that should be examined more closely for potential barrier effect issues. This helps highlight those regions where road sections may have ecological problems but where there are not human safety concerns – areas that are often overlooked for implementation of wildlife crossings and fencing.

We examined which of the CC road segments have WVC costs that meet or surpass the costs to construct and maintain wildlife crossings and associated fencing for their 75-year service life. Across the western U.S., 1,523 segments (338 mi) of the CC road segments identified meet the economic threshold for wildlife crossings using underpasses, and 830 of these segments (182 mi) meet the economic threshold where wildlife crossings using both under- and overpasses are cost-effective, based on the model used.

This study and its accompanying website can be used by federal and state transportation and natural resource agencies and other stakeholders to consider important road segments where wildlife crossings can be deployed to address ecological connectivity, conservation, and economic values, in addition to the standard focus on human safety. Due to the broad-scale scope of the research, all critical connections for wildlife may not be reflected in our maps and suggested locations. Finer-scale data and local knowledge may more accurately pinpoint suitable locations and capture local context not considered in this study. This work is intended to supplement current state and ecological studies. Additional information and finer scale studies are needed to more accurately identify and prioritize specific locations for crossings.

This is an especially opportune time; there is increased momentum and action in the West and nation with the advancement of state and federal connectivity-focused policies and the wildlife crossing funding opportunities in the Infrastructure Investment and Jobs Act (IIJA)/Bipartisan Infrastructure Law (BIL). Managers can use this information to coordinate across jurisdictions to develop collaborative strategies to reduce WVCs and improve conservation outcomes across larger landscapes throughout the West.

1. INTRODUCTION

1.1. Background

The United States has the largest road system in the world, with over 4 million miles of highways (USDOT 2019) that support over 3.3 trillion vehicle miles in travel annually (USDOT 2022). Federal, state, and local agencies continually invest in its development, reconstruction, improvement, and maintenance given the road system's centrality to the nation's socioeconomic well-being.

Roads have a profound effect on wildlife (Forman et al. 2003; Fahrig and Rytwinski 2009; van der Ree et al. 2015) whether directly, for example via wildlife-vehicle collisions (WVCs), or through the disturbance of wildlife behavior due to increases in artificial light, noise, fumes, and other human-induced factors. Roads and their traffic can also have indirect effects through such impacts as increased forest fragmentation (Torres et al. 2016) or the introduction of exotic species (Lazaro-Lobo and Ervin 2019).

Two of the adverse effects of roads are direct mortality of wildlife caused by accidents with vehicles (Seiler and Bhardwaj 2020; Oddone Aquino and Nkomo 2021) and the decrease in habitat connectivity caused by a highway itself or in conjunction with the volume of traffic (McGregor et al. 2008; Shepard et al. 2008; Ascensão et al. 2016). Numerous methods have been developed and studies conducted to identify where WVCs are highest and which environmental and road design factors are most influential in problematic road segments (Gunson et al. 2011; Bil et al. 2013; Santos et al. 2017). These studies help transportation agencies select priority sites for investing in highway mitigation measures that address high crash rates with large wildlife and improve habitat connectivity.

The selection and prioritization of road segments for wildlife mitigation measures is an important task that transportation agencies are responsible for as part of their highway management (Lee et al. 2023). In the past several years, transportation and wildlife agencies have worked more closely together to address motorist safety, wildlife conservation, and ecological connectivity (e.g., Cramer et al. 2022a). This has led to an emphasis on selecting sites that, in addition to improving motorist safety, also conserve wildlife of all sizes and maintain and restore ecological connectivity.

1.1.1. Project Objectives: Safety, Connectivity, and Cost-Effective Measures

While WVCs, reduced ecological connectivity, and associated impacts to wildlife and humans are a widespread problem across road networks, mitigation measures are often considered by transportation agencies to be expensive. Understanding where WVCs occur most frequently (for human safety), where wildlife need to move across roadways (for ecological connectivity), and where mitigation will be cost-effective is essential for transportation planning and responsible allocation of public and private resources. Spatially explicit data on WVCs, ecological connectivity, and cost-effective mitigation measures can be used to inform strategic planning and public-private partnership development, and to allow consideration of biodiversity issues in transportation projects.

This *West-Wide Study to Identify Important Highway Locations for Wildlife Crossings* evaluates the eleven U.S. western conterminous states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) using a common methodology across the region to identify and prioritize road segments where mitigation measures may be needed most to address motorist safety and ecological connectivity, and where the measures will be most cost-effective when addressing collisions with large wildlife.

The Study was developed to inform transportation agencies and other stakeholders about road segments that (1) have high levels of WVC rates that cause wildlife mortality and threaten motorist safety; (2) are located in landscapes important for ecological connectivity; (3) relate to other conservation values such as the proximity of threatened and endangered species' critical habitat, public lands, or privately conserved lands; and/or (4) potentially create barriers to wildlife movement due to high traffic volume. A recent, updated, and expanded cost-benefit analysis for wildlife mitigation measures, including wildlife crossings (Huijser et al. 2022a) was used to identify the road segments in the western U.S. where economic benefits of overpass and/or underpass structures with fencing are greater than the costs, and where economic investments can be considered wise based on cost-benefit alone. While there are dozens of potential mitigation measures from which to choose (Huijser et al. 2021), we only examined wildlife crossings (overpasses and/or underpasses in combination with wildlife fences, escape opportunities like jump-outs, and measures at fence-ends and access points[2]) because they are the most effective and robust approach to reduce WVCs while also allowing for connectivity for wildlife under or over a road (Huijser et al. 2009; Rytwinski et al. 2016).

This report and associated interactive web map (**http://largelandscapes.org/west-wide-mapping**) identify road segments where the implementation of wildlife crossings would be most beneficial and cost-effective for human safety and ecological connectivity and allow users to examine the results of the Study in detail West-wide and for each state (see Appendix).

The West-wide and associated state by state analyses identify road segments:

1. with high rates of WVCs,
2. that cross areas with high ecological connectivity,
3. where other wildlife conservation values are present, including designated critical habitat for threatened and endangered species, or proximity to public lands and/or private lands with conservation easements,
4. with high traffic volume that may restrict wildlife movement,
5. with high rates of return for economic investment in wildlife crossings (and fences), and
6. that contain combinations of these factors.

[2] Throughout the document, we use the term 'wildlife crossings.' In this Study, that term always implies the inclusion of necessary components that make the crossings effective at both allowing wildlife movement and reducing collisions: 1) the crossing structures themselves; 2) wildlife fencing of sufficient length that funnels wildlife to the structures and that may include dig barriers or aprons; 3) escape opportunities from the right-of-way such as jump-outs; 4) measures at fence-ends and access points to deter wildlife from entering the roadway at those locations.

1.2. Special Considerations of this Study

Most studies identifying “hotspots” for highway mitigation locations are based primarily on WVC risk and conducted at a scale of a state, county, tribal reservation, or individual highway section. This study incorporates several types of new information into analyses of the eleven states in the study area. We review preceding studies that have taken place in the West, as many provide excellent examples of high-quality analyses and different types of spatial information to determine key road segments for mitigation to reduce WVCs and to safeguard natural resources. This Study uses a novel approach, including a unique regional ecological connectivity analysis, and incorporation of new economic data on the costs and benefits of WVC mitigation measures. We focus on wildlife crossings as the primary mitigation measures, due to their proven effectiveness at both reducing collisions and providing for safe wildlife movement. We combine collision data common to WVC analyses with that of annual average daily traffic (AADT) information to identify potential barriers to wildlife movement, designated critical habitat to indicate areas important for threatened or endangered species, and public lands or private lands with conservation easements to highlight locations where wildlife habitat and crossing structure benefits may be safeguarded. The findings of this Study and associated geographic information system (GIS) data are intended to complement existing studies and inform highway mitigation prioritization efforts at regional, state, and local scales across the West.

1.2.1. Western States Analyses and Efforts

Increased momentum and action exist in the West and nationally to address wildlife, transportation, and habitat connectivity needs. The Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL) since it was enacted at the end of 2021, created unprecedented funding opportunities for projects that reduce wildlife-vehicle collisions and improve habitat connectivity. The Wildlife Crossings Pilot Program—a $350 million competitive grant program—is the first-ever dedicated pot of federal funding to complete these projects. In addition to this dedicated funding, projects that improve habitat connectivity and reduce wildlife-vehicle collisions are eligible for a wide range of federal transportation programs under the BIL. This expanded eligibility means billions of additional federal dollars are potentially available for these projects.

Many western state transportation and wildlife agencies have carried out analyses to identify priority areas and road segments for wildlife mitigation measures. Some states have identified and prioritized locations based primarily on concerns for human safety by focusing on WVC locations, while other states have included wildlife conservation concerns by examining ecological connectivity and other factors. Some states have analyzed connectivity separately from transportation concerns (and sometimes identifying areas where linkages or corridors are impacted by roadways). Table 1 includes the most recent studies and reports on wildlife-vehicle conflict and/or connectivity at a statewide scale, for each state. Additional studies have focused on specific regions within a state, and those studies are not included in Table 1. Examples include county- and reservation-wide assessments in Teton County, Wyoming (Huijser et al.

2018), Pima County, Arizona (Arizona Game and Fish Department 2012), and the Blackfeet Nation, Montana (Fairbank et al. 2019).

In addition to the analyses shown in Table 1, some states have taken other important steps to address wildlife crossing needs (Cramer et al. 2022b). Examples of these steps are a) holding wildlife and transportation summits, b) signing memoranda of understanding or agreement (MOU or MOA) between the state transportation and wildlife agencies related to working together on wildlife and transportation issues, c) establishing statewide stakeholder partnerships that include agencies, and d) creating public interactive mapping websites related to wildlife and transportation priority locations. Information on what Western states have done, and greater detail on state analyses, are available (Paul 2023).

Table 1. Existing statewide wildlife-vehicle conflict and/or connectivity studies.

State	Document name
Arizona	- Arizona Statewide Wildlife-Vehicle Conflict Study (Williams et al. 2021) - Arizona's Wildlife Linkages Assessment (Arizona Wildlife Linkages Workgroup. 2006)
California	- Large Mammal-Vehicle Collision Hot Spot Analyses (Huijser and Begley 2019) - California Wildlife Barriers 2020 (CDFW 2020) - Statewide Terrestrial Connectivity Map (CDFW 2019) - California Essential Habitat Connectivity Project (Spencer et al. 2010)
Colorado	- Western Slope Colorado Wildlife Prioritization Study (Kintsch et al. 2019) - Eastern Slope and Plains Wildlife Prioritization Study (Kintsch et al. 2022)
Idaho	- Methodology for Prioritizing Appropriate Mitigation Actions to Reduce Wildlife-Vehicle Collisions on Idaho Highways (Cramer et al. 2014)
Montana	- Montana Wildlife and Transportation Partnership (MWTP) Planning Tool Summary Report (MWTP Data and Information Working Group 2023)
Nevada	- Prioritization of Wildlife-Vehicle Conflict in Nevada (Cramer and McGinty 2018) - Wildlife Connectivity Plan (in development as of 5/23)
New Mexico	- New Mexico Wildlife Corridors Action Plan (Cramer et al. 2022a)
Oregon	- Oregon Wildlife Connectivity Implementation Plan (ODFW 2023) - Oregon Wildlife Corridor Action Plan (in development as of 5/23, ODFW and ODOT) - Oregon Connectivity Assessment and Mapping Project (OCAMP) (ODFW 2022)
Utah	- Identification of Wildlife-Vehicle Conflict Priority Hotspots in Utah (Cramer et al. 2019) - Wildlife Connectivity across Utah's Highways (West 2007)
Washington	- Washington Connected Landscapes Project: Statewide Analysis (Washington Wildlife Habitat Connectivity Working Group 2010)
Wyoming	- Framework for Prioritizing Projects to Reduce Negative Road-Wildlife Interactions (Wyoming's Wildlife and Roadways Initiative Implementation Team 2019) - Planning-Support for Mitigation of Wildlife-Vehicle Collisions and Highway Impacts on Migration Routes in Wyoming (Riginos et al. 2016)

1.2.2. Rationale for Focusing on Wildlife Crossings for Mitigation

There is a wide variety of mitigation measures that have been employed to reduce collisions with large animals. A recent literature review (Huijser et al. 2021) evaluated 24 different wildlife mitigation measures for their effectiveness at reducing WVCs with large animals and reducing the barrier effect of roads and traffic (see Section 1.2.4 for explanation of barrier effect).

The mitigation strategies were organized into three categories: a) measures aimed at influencing driver behavior, b) measures aimed at changing animal behavior or population size, and c) measures aimed at separating wildlife from a road. The ten mitigation measures that achieved at least a 50 percent reduction in WVCs are below (Table 2). Of these, wildlife overpasses or underpasses with wildlife fencing are the only measures that are highly effective in reducing collisions that also maintain or improve ecological connectivity (Figure 1).

Therefore, this Study focuses on wildlife crossings combined with wildlife fencing as measures that reduce WVCs by 80-100 percent and maintain habitat connectivity by providing safe passage for a variety of species. Depending on the design of a wildlife crossing structure, including its size, location, type, the cover or habitat it offers, and fencing, it may both reduce direct road mortality for larger wildlife and also provide safe crossing opportunities for a variety of taxa, including smaller mammal species, reptiles, amphibians, and invertebrates (Huijser et al. 2022b). While wildlife crossings often are considered an expensive mitigation option, they are the only mitigation package that addresses the objectives of collision reduction and maintaining or improving connectivity for wildlife, and they can be cost-effective (Huijser et al. 2009; Lee et al. 2012; Huijser et al. 2022a) over the course of their service life, which is commonly 75 years. “Inexpensive” measures that do not address the two objectives are not in fact alternatives, at least not without changing the objectives.

Throughout the document, we use the term ‘wildlife crossings.’ In this Study, that term always implies the inclusion of necessary components that make the crossings effective at both allowing wildlife movement and reducing collisions: 1) the crossing structures themselves; 2) wildlife fencing of sufficient length that funnels wildlife to the structures and that may include dig barriers or aprons; 3) escape opportunities from the right-of-way such as jump-outs; 4) measures at fence-ends and access points to deter wildlife from entering the roadway at those locations. Jump-outs are egress ramps at a break in the fencing that allow animals trapped on the highway side of the fence to safely get to the other side, and aprons are extensions of fencing underground from the bottom of the fence, to serve as dig barriers for species such as bears or canids (Figure 2).

Table 2. Summary of ten wildlife mitigation measures that may achieve a minimum of fifty percent reduction in vehicle collisions with large mammals and their effectiveness in reducing the barrier effect of roads and traffic (Huijser et al. 2021).

Mitigation measure	% effectiveness in reducing collisions with large mammals	% effectiveness in reducing the barrier effect of roads and traffic
Measures aimed at influencing driver behavior		
Seasonal wildlife warning sign	9 – 50%	0%
Roadside animal detection system	33 – 97%	0%
Seasonal road closure	100% during closure	Reduces barrier effect of traffic, not the road, during closure
Increase visibility for driver	57 – 68%	0%, may increase barrier effect for some species
Reduce speed with traffic calming measures	Unknown – 59%	Unknown
Measures aimed at influencing animal behavior or population size		
Wildlife culling	49 – 84%	0%
Wildlife relocation	30 – 94%	0%
Measures that seek to separate animals from the road and traffic		
Wildlife barrier – fences, boulders, walls	80 – 100%	0%, increases barrier effect
Underpass or overpass, without fencing	Varies greatly based on structural design and location	Reduces barrier effect
Underpass or overpass, with fencing	80 – 100%	Reduces barrier effect

Figure 1. Examples of a wildlife underpass with fencing and nearby jump-out, and of a wildlife overpass, both along US Hwy 93, Flathead Indian Reservation, Montana, USA

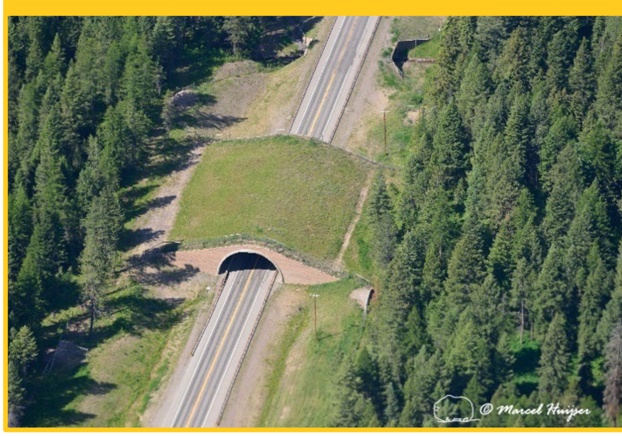

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Figure 2. Examples of a wildlife jump-out along US Hwy 93, Flathead Indian Reservation, Montana, USA and wildlife fence and dig barrier (or apron), TransCanada Highway, Banff National Park, Alberta, Canada

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1.2.3. Ecological Connectivity

This Study includes connectivity considerations as an important step beyond simply prioritizing WVC hotspot locations. Ecological connectivity is the unimpeded movement of species to meet daily and seasonal needs, dispersal, and genetic exchange. These movements may result in range shifts in response to climate change (Hilty et al. 2019). Since ecological connectivity sustains these movement types, it plays an essential role in maintaining food webs, promoting genetic diversity, allowing recolonizations, and supporting interactions within and among species, such as pollination, seed dispersal (Nunez et al. 2023), and herbivory (Hilty et al. 2019). Habitat fragmentation is recognized as one of the greatest threats to biodiversity (e.g., Noss 1983; Forman et al. 2003) and roads are a significant cause of fragmentation. Ideally, all roads would be designed for permeability (a measure of a landscape's relative potential for wildlife movement) by all types of wildlife and to maintain movement. Fortunately, wildlife mitigation measures such as wildlife crossings paired with fences are highly effective at decreasing the barrier effect of roads (Van Der Ree et al. 2015; Rytwinski et al. 2016).

Spatial modeling is an effective approach to help prioritize where to effectively spend limited resources to mitigate the detrimental effects of roads on ecological connectivity. Numerous studies have mapped and modelled connectivity at regional levels using various approaches. These include modelling naturalness-based corridors (Belote et al. 2016) and ecological flow (Dickson et al. 2017) among protected areas; mapping and prioritizing landscape connectivity of natural ecosystems (Theobald et al. 2012); modeling omnidirectional connectivity at various spatial scales and considering different sensitivities of species to human modification (Belote et al. 2022); focal species-based connectivity assessments (Beier et al. 2006), and plotting species' movement routes that may link current climate conditions to analogous climate conditions in the future (Littlefield et al. 2017). For this Study, we conducted a new permeability analysis to (1) model connectivity among areas with low human modification (rather than modelling connectivity solely among protected areas), (2) take advantage of a higher-resolution (90-meter grid) and updated human modification map (Theobald et al. 2020), and (3) simultaneously take into account multiple scales to avoid having different maps for species with different dispersal capabilities.

1.2.4. Addressing the Barrier Effect

An objective of this Study is to identify road segments with high traffic volumes that may limit wildlife movement and decrease landscape connectivity. High traffic volumes have been shown to increase WVCs; however, when traffic becomes sufficiently high, roadways can become an obstacle to wildlife movement, a phenomenon known as “the barrier effect” (Seiler 2005). Roads are barriers to wildlife movement for numerous species such as grizzly bears (Waller and Servheen 2005), caribou (Dyer et al. 2002), salamanders (Marsh et al. 2005), voles and mice (Grilo et al. 2018) and eastern chipmunks (Ford and Fahrig 2008).

Traffic volume, measured as average annual daily traffic (AADT), has been identified by many studies as an influential factor in analyzing WVC rates and risk (van Langevelde and Jaarsma 2005; Forrest and St. Clair 2009). As traffic volumes increase, a higher number of collisions may occur and then drop off once a sufficiently high traffic volume is reached because certain species avoid the road (Rost and Bailey 1979; Seiler 2005; Ascensão et al. 2019). Riginos and others (2022) identified AADT rates of 15,000 for Wyoming highways where WVCs begin to drop off, indicating a barrier effect noticeable in statewide WVC data.

Species-specific studies at finer scales have demonstrated that even lower traffic volumes can create hesitancy or pose high risk to individual animals crossing the road. For example, it became increasingly unsafe for mule deer to cross highways in Wyoming when hourly traffic exceeded 60 vehicles per hour (roughly 2,000 AADT) (Riginos et al. 2018). Another study determined that a two-lane highway poses a barrier to grizzly bears when traffic volume exceeds 100 vehicles per hour in Montana (Waller and Servheen 2005).

For this Study, we highlight road segments with high traffic volumes that would benefit from wildlife crossings to overcome the barrier effect. We use the conservative barrier effect estimate of 15,000 AADT and greater (Riginos et al. 2022), as our analysis did not focus on specific, sensitive species such as grizzly bears.

1.2.5. New Costs of Wildlife Collisions and Other Economic Data

The economic costs of collisions with deer and other large wildlife were recently updated from an initial 2009 study on the costs and benefits of WVC mitigation measures (Huijser et al. 2009). The updated and expanded 2022 estimates of costs and benefits have been incorporated into this Study (Huijser et al. 2022).

There are several key findings from the recent study by Huijser and others (2022). WVCs have become increasingly expensive. In fact, the direct cost per average collision with large wildlife – accounting for vehicle repairs, human injuries, human fatalities – has more than doubled for deer (2.12), elk (2.6) and moose (2.69) between 2007 and 2020. Passive use or non-use values are the values placed on the existence of a given animal species or population as well as the bequest value of knowing that future generations of society will also benefit from preserving the species (Duffield and Neher 2019). When passive use value for each species is included in the cost estimate, then the costs per average collision between 2007 and 2020 has nearly tripled for deer (2.88), increased more than four-fold for elk (4.19) and increased more than 3.5

times for moose (3.59). Conversely, over the same period, the rate of increase in the cost of mitigation measures was far less.

The incorporation of updated cost-benefit factors highlights more road sections where mitigation measures are now justified economically, at least based on the model used. This broadens the number of locations where the construction and maintenance of mitigation measures such as wildlife crossings are a sound use of public funds. However, since the model is limited by the input parameters, it is by no means complete. Including additional parameters, especially those related to the conservation value of individual species and entire ecosystems, would reduce the thresholds above which the costs of doing nothing exceeds the costs of implementing effective mitigation measures. In other words, our identification and prioritization of road sections where mitigation measures are economically justifiable are conservative, and there are likely many more road sections where investment in mitigation measures is an economically wise decision.

2. METHODOLOGY

This Study focuses on the eleven states in the western conterminous United States. These states were selected in reference to the Department of Interior's Secretarial Order 3362 (USDOI 2018) which addresses conserving, enhancing, restoring, or improving the condition of priority big game winter range and migration corridor habitat across these states. The combination of large wildlife species, which are most often identified in WVCs, along with the need for connectivity has brought attention to areas where roads adversely impact wildlife movement in addition to vehicular-caused mortality. This Study supports this federal initiative by addressing ecological connectivity at a broader scale.

2.1. Safety and Economics

Using public WVC data acquired from each state, we identified and mapped WVC hotspots and used cost-benefit analyses to identify road segments where the benefits of implementing wildlife crossing infrastructure outweigh the monetary costs incurred by WVCs.

Many differences exist in WVC data collection methods used among the states. These differences include types of roads on which data are collected as well as the intensity and consistency of WVC reporting effort. These differences also include other types of parameters that may or may not be recorded depending on the state, such as the species name, whether it is a wild or domestic animal, and spatially accurate information of the incident (e.g., GPS location versus highway mile marker).

Such differences make it challenging to compare WVC data between different states and also between different regions of the same state. For this reason, we developed a process to standardize the available data to the degree possible, described in Section 2.1.1 and 2.2.2. All spatial mapping was conducted using ESRI ArcGIS Desktop 10.8 (ESRI 2021). The WVC spatial locations were projected onto a single map using WGS 1984 Web Mercator Auxiliary Sphere.

2.1.1. Road Segments

States define road segments and the functional classes of their highways differently, complicating the creation of a consistent road network for the WVC analysis at a regional level. To make road segments as consistent as possible across the West, we used the 2021 TIGER/Line geodatabase, which is plotted and mapped the same way nationwide. These data are available from the U.S. government and uses the same labels and structures across all states.

To develop the road segments for each state, the TIGER/Line primary and secondary road network was dissolved together to create a single polyline in ArcGIS. Based on the dissolved shapefile, points were plotted along the road network (polyline) every 0.1- 0.2 mile (mi) (0.16-0.32 kilometer (km)) with an average of 0.2-mile road segment lengths across the states. The differences in road segment lengths were the result of large-scale geographic projections of the polylines onto the base map. A summary of the road segments and their lengths per state analyzed is in Table 3.

Table 3. Summary statistics for road segment analysis units.

State	# of analysis segments	Total road length (mi)	Segment lengths (mi)			
			Min.	Max.	Mean	Std. Dev.
Arizona	36,880	10,088	0.05	0.32	**0.27**	0.04
California	149,785	29,072	0.05	0.24	**0.19**	0.03
Colorado	45,922	14,052	0.05	0.37	**0.31**	0.05
Idaho	58,218	8,003	0.05	0.18	**0.14**	0.02
Montana	60,907	12,379	0.05	0.27	**0.20**	0.03
Nevada	22,157	8,474	0.05	0.47	**0.38**	0.07
New Mexico	97,565	16,381	0.05	0.19	**0.17**	0.02
Oregon	81,011	11,729	0.05	0.18	**0.15**	0.02
Utah	50,323	9,050	0.05	0.22	**0.18**	0.02
Washington	71,509	12,358	0.05	0.23	**0.17**	0.03
Wyoming	39,836	10,584	0.05	0.33	**0.27**	0.04
West-Wide					**0.22**	

2.1.2. Wildlife-Vehicle Collisions

Studies examining WVC data may use crash data, carcass removal data, or both. In general, the reporting efforts are more consistent over a region such as a state or across states for crash data than for carcass removal data (Huijser and Begley 2019). Crash data are collected by law enforcement personnel (e.g., highway patrol) when they are called to report a crash. These are usually crashes with substantial vehicle damage and human injuries or fatalities. Due to greater consistency across states, only wildlife-vehicle crash data were analyzed in this Study. However, crash data are likely only a fraction of the carcass removal data and severely underestimate the total number of collisions with large wild mammals (Donaldson 2017).

All eleven western states were contacted to acquire the most recent reported WVC crash data. Only WVC datapoints located within 164 feet (ft) (50 meters (m)) of the TIGER/Line road network data were included. Tribal lands and national parks were included; however, collisions tend to be highly underreported for reservations or national parks because data from these areas may not be included in databases maintained by the state transportation departments. Before initiating data analyses, all records of domestic animals (e.g., cows, horses, sheep, etc.) were removed. A summary of all reported WVCs acquired from each state is reported in Table 4.

Table 4. Wildlife-vehicle collision reported crash data acquired for each of the eleven western states.

State	Years of data	Year range	Total WVC		Large mammal WVC near TL roads		Species identifiers for cost analysis
			Count	WVC/ year	Count	WVC/ year	
Arizona	11	2010-2020	17,212	1,565	14,063	1278	Wild game, wild non-game
California	10	2005-2014	6,908	691	6,892	689	Deer
Colorado	6	2013-2018	19,357	3,226	18,559	3093	Deer, elk, moose, pronghorn, bear
Idaho	12	2009-2020	14,693	1,224	12,635	1053	Wild animal
Montana	13	2008-2020	33,468	2,574	29,644	2280	Wild animal
Nevada	7	2013-2019	1,360	194	1,310	187	Deer, elk, pronghorn, bear, bighorn sheep
New Mexico	9	2010-2018	9,533	1,059	8,897	989	Deer, elk, pronghorn, bear, cougar
Oregon	10	2010-2019	13,391	1,339	8,105	811	Deer/elk, wild game (not deer/elk)
Utah	10	2011-2020	26,680	2,668	23,600	2360	Wild animal
Washington	11	2010-2020	20,431	1,857	15,743	1431	Deer, elk, large wild animal
Wyoming	10	2011-2020	25,447	2,545	23,766	2377	Deer, elk, moose, pronghorn

The WVC locations near the TIGER/Line roads (those located within 164 ft (50 m) from the road) were joined to the nearest road segment within each state's boundaries. The total number of WVCs for each road segment was divided by the length of the segment and the number of years of data acquired. This results in road segments with collision rates expressed in WVC per mile per year (WVC/mi/yr).

2.1.3. Economic Data Analysis

Huijser et al. (2022a) recently evaluated U.S. dollar costs of collisions with wildlife. These costs include direct costs associated with vehicle repair, human injuries and human fatalities that may result from WVCs, as well as passive use values of animals killed. The cost for each road segment was calculated using the following WVC values: $19,089 per deer, $73,196 per elk, and $110,397 per moose (Huijser et al. 2022a) (Table 5).

Table 5. Total costs associated with large wild ungulate-vehicle collisions (in 2020 US$).

Costs per collision			
Cost category	**Deer**	**Elk**	**Moose**
Direct costs			
Vehicle repair	$4,418	$7,666	$9,435
Human injuries	$6,116	$14,579	$26,811
Human fatalities	$3,480	$23,200	$46,400
Sub total	$14,014	$45,445	$82,646
Passive use value	$5,075	$27,751	$27,751
Total	**$19,089**	**$73,196**	**$110,397**

These values were multiplied with the collision rate for each species identified in the reported crash data. The economic analyses in this Study include data for deer, elk, and moose, so for each state, species involved in crashes were allocated, based on similarity in body size and weight, to the categories of deer, elk, or moose. For example, black bear, cougar, antelope, and bighorn sheep are most similar to a deer's average body size. For states that did not identify the species (i.e., Arizona, Idaho, Montana, and Utah, Table 4), all WVC data identified as a 'large wild animal' was assigned the value of a deer, which resulted in conservative cost estimates for the collisions in those states.

2.1.4. Economic Thresholds for Wildlife Crossings

The costs for each road segment were compared to the mitigation thresholds estimated by Huijser and others (2022a). Mitigation thresholds are "break-even" values, where the cost of building and maintaining the mitigation measure over its service life is equal to the cost of reduced WVCs over that same period. Mitigation costs were estimated based on the cost of real-world mitigation projects and using a 3% discount rate over an expected 75-year service life for wildlife crossings and associated fencing (Huijser et al. 2022a). The threshold costs of the WVC mitigation measures are: $40,857/mi/yr ($25,388/km/yr) for the combination of underpasses, fence with apron, and jump-outs; and $51,547/mi/yr ($32,030/km/yr) for the combination of underpasses and overpasses, fence with apron, and jump-outs. For further details on the combinations of the mitigation measures, please refer to the Huijser et al. study (2022a).

2.2. Ecological Connectivity

We modeled landscape permeability to provide information on wildlife movement areas that are important for maintaining biodiversity. Assuming that maintaining connectivity through the most natural lands available provides the best opportunities for successful movement for the greatest number of species (Theobald et al. 2012), we based our analysis on a naturalness approach (Keeley et al. 2021) using a human modification map (Theobald et al. 2020) that shows the degree of human impact on terrestrial ecosystems.

We quantified landscape resistance (i.e., the estimated difficulty of moving through a specific location in the landscape) based on the degree of human modification: areas of higher modification were assumed to pose higher resistance to species that are sensitive to human development (Dickson et al. 2017; Keeley et al. 2020). We also added a penalty for steeper slopes (Theobald et al. 2012). We computed landscape permeability, an indicator of landscape connectivity, to identify areas with general ecological integrity (Theobald 2010; Theobald et al. 2020). Specifically, we followed four steps described below.

2.2.1. Gradient-based Approach

We used a gradient-based approach to evaluate ecological integrity. We assume that general ecological integrity (Theobald 2010) is higher in areas that are relatively large, contiguous, and with low human modification. Importantly, this work is meant to complement other connectivity analyses intended to understand connectivity and corridors for specific species/populations. The study area for the analysis was the 11 western states and it used a 5 km buffer into Canada and Mexico for border states.

2.2.2. Landscape Resistance

To represent our assumption that it is more likely that species are able to move and adapt to habitat loss and fragmentation due to transportation, land use, and climate change when intact areas are connected, we generated a spatial dataset of naturalness, based on the degree of human modification in the year ~2020 (*H*, Theobald 2013; Theobald et al. 2020) and topographic slope (following Figure 1 in Theobald et al. 2012).

We calculated resistance (*R*) using *H*, a factor to represent the assumption of sensitivity to human modification (*c=1*), and a penalty for steeper slopes (*s, percent slope*), where:

$$R = H^a, a = c^b, b = 1 - \frac{\sqrt{s}}{\sqrt{90}}$$

Interstate and primary highways have higher *H* values than other types of roads (secondary, local, track), so those locations will have high resistance values. Because the focus of this analysis is on terrestrial, ground-based (crawling/walking) movement, large rivers and lakes/reservoirs are presumed to serve as barriers to terrestrial movement and permeability, using this model. Interstate and primary highways have higher human modification values than other types of roads (secondary, local, track), so those locations will have lower conductance values.

	Human Modification						
Slope %	0	0.1	0.2	0.5	0.7	0.9	1
0	0.000	0.100	0.200	0.500	0.700	0.900	1.000
1	0.000	0.127	0.237	0.538	0.727	0.910	1.000
2	0.000	0.141	0.254	0.554	0.738	0.914	1.000
5	0.000	0.172	0.292	0.589	0.761	0.923	1.000
10	0.000	0.215	0.342	0.630	0.788	0.932	1.000
30	0.000	0.296	0.427	0.693	0.828	0.946	1.000
45	0.000	0.556	0.664	0.838	0.913	0.974	1.000
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 3. Resistance values for seven values of human modification at eight different slopes.

2.2.3. Movement Model

To model permeability through the natural landscape, we applied a percolation-based approach (Theobald in prep.), which proceeds in four general steps: Step 1, Identify pixels that can be moved across (T) to be those where T=1 if C > r, otherwise T=0, where r is a random value (uniform distribution); Step 2, Using an image where pixel values are 1 if T=1, otherwise NO DATA if T=0, identify the “cluster” of pixels that are adjacent (8-neighbor); Step 3, Sum the count (number) of pixels in each unique “cluster” (aka “region” in ArcGIS); and Step 4, For each pixel, calculate the cluster size averaged across k iterations.

We applied these steps in 300 Monte Carlo iterations. We then calculated permeability at multiple scales (resolutions): 90, 180, 360, 720, 1,440, 2,880, and 5,760 m. We averaged the sum of the count (step 3) using the arithmetic mean over the 7 resolutions to obtain the final percolation metric values. The resulting layer contains the permeability value of each pixel, incorporating human modification values out to approximately 1,000 km, though the proportion of influence ranges roughly linearly from 0.25 (high proportional influence of nearby pixels) down to 0.04 (low proportional influence of distant pixels) (90 to 5,760 m). In other words, the permeability value of each pixel intersected by a highway represents the spatial context within a radius of a few kilometers. The percolation permeability approach has three advantages over other methods: 1) it is fully gradient-based at high resolutions (~30-90 m) (not approximated as in Omniscape, wall-to-wall Circuitscape, and resistant-kernels); 2) conductance values are interpreted as probabilities rather than applying transformations to the resistance values to approximate cost-weights; and, 3) the randomizations (Monte Carlo iterations) provide the basis for calculating statistical distributions of values so that the diffuse to concentrated to channelized pattern of movement can be statistically determined.

2.2.4. Metric

The resulting pixel values are interpreted as the permeability of the landscape, where each pixel value ranges from 0 to 1.0. Because the permeability values reflect the mean value at multiple resolutions, a high pixel value (approaching 1.0) effectively identifies locations that are connected with nearby natural (or unfragmented) lands. The pixel values are unitless and represent the probability that a pixel is permeable. We extracted permeability values for each road segment (average 0.2-mi segment lengths, Table 3) by finding the pixels (at 90 m resolution) that intersect a road segment and calculating the mean value of the pixels for each segment. In summary, the permeability value of each pixel on a road segment represents the spatial context within roughly a few kilometers radius.

2.2.5. Outputs

For the permeability analysis we created three spatial datasets: 1) A multi-scaled landscape permeability map for 2020 at 90m resolution (PercPerm202209_amod_90_5760) as a TIF; 2) Shapefiles with summarized permeability values for highway segments (for each 90 m pixel); and 3) Table of input datasets to the naturalness dataset (Table 6).

Table 6. The class or major type of stressor, individual stressors, and source of the datasets used in the human modification layer. Stressors and classes used in this table are based on the Direct Threats Classification v2 (http://cmp-openstandards.org), which defines a stressor as the proximate human activities or processes that have caused, are causing, or may cause impacts on biodiversity and ecosystems.

Class	Stressor*	Source	Scale (m or ratio)	Year
Urban & built-up (1)	Built-up (1.1, 1.2)	National Land Cover Dataset (NLCD; www.mrlc.gov) Low-density residential (approx. <1 unit per 2 acres; BF; Microsoft 2019)	30 m 30 m	2019 2020
Agriculture (2)	Croplands & pasturelands (2.1)	NLCD USDA Cropland Data Layer	30 m	2019 2018
	Grazing (2.3)	Active grazing allotments on BLM or USFS public lands (BLM 2019; USFS 2020a)	30 m	~2017
Energy production & mining (3)	Oil & gas production (3.1)	Oil and gas wells: FrackTracker and from NLCD impervious description Petroleum refineries (EIA)	30 m 30 m	2020 2020
	Mining & quarrying (3.2)	Surface mine footprints (Maus et al. 2020)	1 km	2018
	Renewable (3.3) & non-renewable power (1.2) generation	World Resources Institute Power plants (WRI; WRI 2019) NLCD impervious descriptor	~1:100k 30 m	2019 2019
Transportation & service corridors (4)	Roads (4.1)	US Census TIGER Roads	~1:10-25k	2019
	Railways (4.1)	US Census TIGER Railways	~1:10-25k	2019
	Powerlines and pipelines (4.2)	Powerlines, and pipelines US Energy Information Administration (EIA);	~1:10-25k	2019
	Electrical infrastructure (4.2)	Nighttime lights v2 from VIIRS; Earth Observation Group, NOAA/NCEI	375 m	2019
Biological harvesting (5)	Logging & wood harvesting (5.3)	Timber harvest (USFS 2020) Forest change using USGS LCMAP and wildfire perimeters (MTBS 2021)	30 m	2020 2019
Human intrusions (6)	Human intrusions (1.3, 5.1, 5.2, 6.1)	Human intrusion (HUE; Theobald 2008) Ski resorts (USFS 2020)	90 m 30 m	2015 2019

2.3. Collisions and Connectivity

The model applied two baseline thresholds to identify where collision and connectivity parameters overlap within the study area. We set the threshold for WVCs at the top 10th percentile of the segments, those with the highest wildlife collisions/mile/year, to highlight the potential for mitigation efforts in areas most problematic to motorist safety and where large mammal mortality and injury are at the highest rates in the West. Next, we combined the high-collision road segments with those within the upper 50th percentile of the ecological connectivity model, and we refer to those segments as 'collision and connectivity' or 'CC' road segments. We chose the top 50th percentile for connectivity values to identify highway mitigation opportunities across a wider geographic range and a diversity of habitats, which support countless species that may also be detrimentally affected by highways.

Locating road segments with high values for WVCs and for ecological connectivity provides transportation and wildlife agency planners, managers and stakeholders with locations that deserve closer attention in future planning and project development. Both values can be addressed by the development of wildlife crossings as mitigation measures in these road segments.

2.4. Collisions, Connectivity, and Conservation

2.4.1. Protected Areas and Critical Habitat

An important factor for construction of wildlife crossings is the level of land security adjacent to a prospective site. Since crossings require significant financial investment and have a service life of 75 years or more, transportation agencies seek assurance that lands next to crossings will not be degraded or developed for incongruous use. Thus, important considerations for adjacent lands are ownership and management. Ideally, the land on both sides of a wildlife crossing site and highway right-of-way is publicly held and managed by land or wildlife agencies or, if privately owned, has a conservation easement to maintain open space in perpetuity. To promote adjacent land security for prospective wildlife crossings, we examined where the CC road segments occur within one mile of protected areas (public lands or conservation easements). We also examined how many segments occur directly adjacent to a protected area.

To do so, we used the National Protected Areas Database (PAD-US) Vector Analysis, which includes land owned by federal, state, and local agencies, military lands, and lands with conservation or open space easements on either private and public lands (which is input into PAD-US from the National Conservation Easement Database) (USGS 2022). These protected areas are lands under a spectrum of ownership and use from federal to local government to private and have varying degrees of protection from very limited to multiple uses. We filtered out land managed by the Bureau of Indian Affairs because it encompasses whole reservations rather than just the protected areas within them.

Another consideration is the statutory requirements of the Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531-1544). Many species listed as threatened or endangered under the ESA have designated critical habitat. State transportation and wildlife agencies and the U.S. Fish and Wildlife Service (USFWS) are charged with determining whether a highway project adversely impacts threatened or endangered species or their critical habitat. For this reason, we examined designated critical habitat and identified CC road segments located within ¼ mile of it. For critical habitat information, we utilized federally designated and proposed critical habitat line and polygon data (USFWS 2022) for plants, animals, and fish species.

The analysis identified road segments meeting the CC thresholds and that are also within one mile of a protected area or easement, within one quarter of a mile of USFWS designated critical habitat, or within those distances of both categories. We chose these types of protected areas and designated habitats and the distance thresholds because of their relevance to some transportation department policies. For instance, the California Department of Transportation uses this type of data and distance thresholds when planning new infrastructure projects.

2.4.2. High Traffic Volume

To identify where high traffic volume may present a barrier to wildlife movement, we gathered state-level data on AADT and added the AADT data to road segments. As described in Section 1.2.4, we focused on AADT greater than 15,000 vehicles per day (high AADT) (Riginos et al. 2022).

We identified CC road segments that are characterized by high AADT and also identified road segments in the 50th percentile for connectivity characterized by high AADT but not within the top 10th percentile for WVC rates. Traffic in these road segments may be so high that wildlife do not attempt to cross, creating a barrier effect resulting in low to no WVC rates, even in important landscapes for ecological connectivity.

2.5. Collisions, Connectivity, and Costs

For the CC road segments, we calculated whether they met the mitigation measure cost-benefit threshold for implementing wildlife crossings (i.e., whether the cost of the road segment's WVCs met or exceeded the threshold cost of implementing and maintaining a wildlife crossing for 75 years). For the West-wide analysis we calculated the cost/mile/year for each road segment using the average cost of a deer collision of $19,089 (Huijser et al. 2022a) to standardize the values among CC road segments across the eleven states. Using the cost for a deer collision for all WVCs was necessary since some states only reported deer in their crash database, others identified deer, elk and moose, and other state databases did not identify a specific species. We calculated the number of road segments above the mitigation threshold of $40,857 for underpasses (with fence with apron and jump-outs) and $51,547 for underpasses and overpasses (with fence with apron and jump-outs) (see Section 2.1.4).

2.6. Study Focus

This Study emphasizes the most problematic WVC areas and combines these with road segments where habitat connectivity is of high value. As a result, the CC road segments do not necessarily reflect the needs of all threatened or endangered species, nor highlight all critical habitat severed by roads throughout these species' occupied ranges in the West. By focusing on CC road segments, not all protected areas severed by roads are addressed. The dual safety and connectivity emphasis also does not reflect all generally busy roads with high traffic volumes that are creating a barrier effect for wildlife. Instead, the Study seeks to identify the most problematic safety areas and find where ecological, conservation, and economic values can be addressed at the same time.

3. RESULTS

3.1. Safety and Economics

3.1.1. Safety

We evaluated the WVC rates by road segment across the eleven western states (Table 7). There are large differences in the percentage of roads with identified WVC rates (segments that have a measurable WVC rate, that is, one that is greater than 0) by state. The lowest is 3.6% of roads in California; yet, this is misleading because we only acquired deer-vehicle collision data, so the analysis does not include collisions with other large species across the state. The largest percentage of roads with identified WVCs is in Wyoming with 29.3% of segments.

The maximum WVC crash rates by segment range from 2.92-24.68 WVC/mi/yr (1.8-15.4 WVC/km/yr). Colorado, New Mexico, and Utah all have maximum crash rates over 24 WVC/mi/yr (14.9 WVC/km/yr).

Table 7. Wildlife-vehicle collision (WVC) rates for each state by road segment.

State	% of road segments with identified WVC rate	Crash rates by road segment (WVC/mi/yr)			
		Min.	Max.	Mean	Std. dev.
Arizona	19.5	0	12.44	**0.13**	0.38
California	3.6	0	4.58	**0.02**	0.14
Colorado	21.4	0	24.68	**0.22**	0.60
Idaho	15.2	0	7.03	**0.13**	0.37
Montana	27.3	0	8.53	**0.18**	0.41
Nevada	4.7	0	2.92	**0.02**	0.11
New Mexico	5.5	0	24.32	**0.06**	0.37
Oregon	8.2	0	5.14	**0.07**	0.26
Utah	24	0	24.11	**0.26**	0.69
Washington	11.8	0	7.06	**0.09**	0.29
Wyoming	29.3	0	11.65	**0.22**	0.51

In looking at the top 10th percentile of identified WVC road segments for each state (Table 8), Montana has the most at 1,664 road segments totaling 338 mi. In contrast there are only 105 segments, totaling 35 mi, in the top 10th percentile of identified WVC rates in Nevada.

Table 8. Based on percentiles for individual states, the estimated number of road segments and number of miles* above the top 10th percentile threshold of road segments with identified WVC rates for each state.

State	Top 10th percentile of roads with WVCs		Top 10th percentile WVC rates			
	Total road segments	Total length (mi)*	Min	Max	Mean	Std. dev.
Arizona	720	197	1.27	12.44	2.14	1.09
California	540	105	1.07	4.58	1.54	0.54
Colorado	983	301	2.05	24.69	3.1	1.40
Idaho	884	121	1.41	7.03	2.11	0.71
Montana	1,664	338	1.28	8.53	1.93	0.77
Nevada	105	35	0.76	2.92	1.04	0.37
New Mexico	535	90	2.10	24.32	3.74	2.14
Oregon	665	96	1.38	5.14	1.85	0.56
Utah	1,207	217	2.03	24.11	3.46	1.75
Washington	847	147	1.23	7.06	1.81	0.65
Wyoming	1,167	310	1.54	11.65	2.41	1.07

*Estimated number of miles based on individual states' road segment length means from Table 3.

The top 10th percentile of roads with WVCs per state across the region are mapped in Figure 4. Their distribution is spread across the West, on both north-south and east-west bound highways, and they occur on interstate, primary and secondary highways.

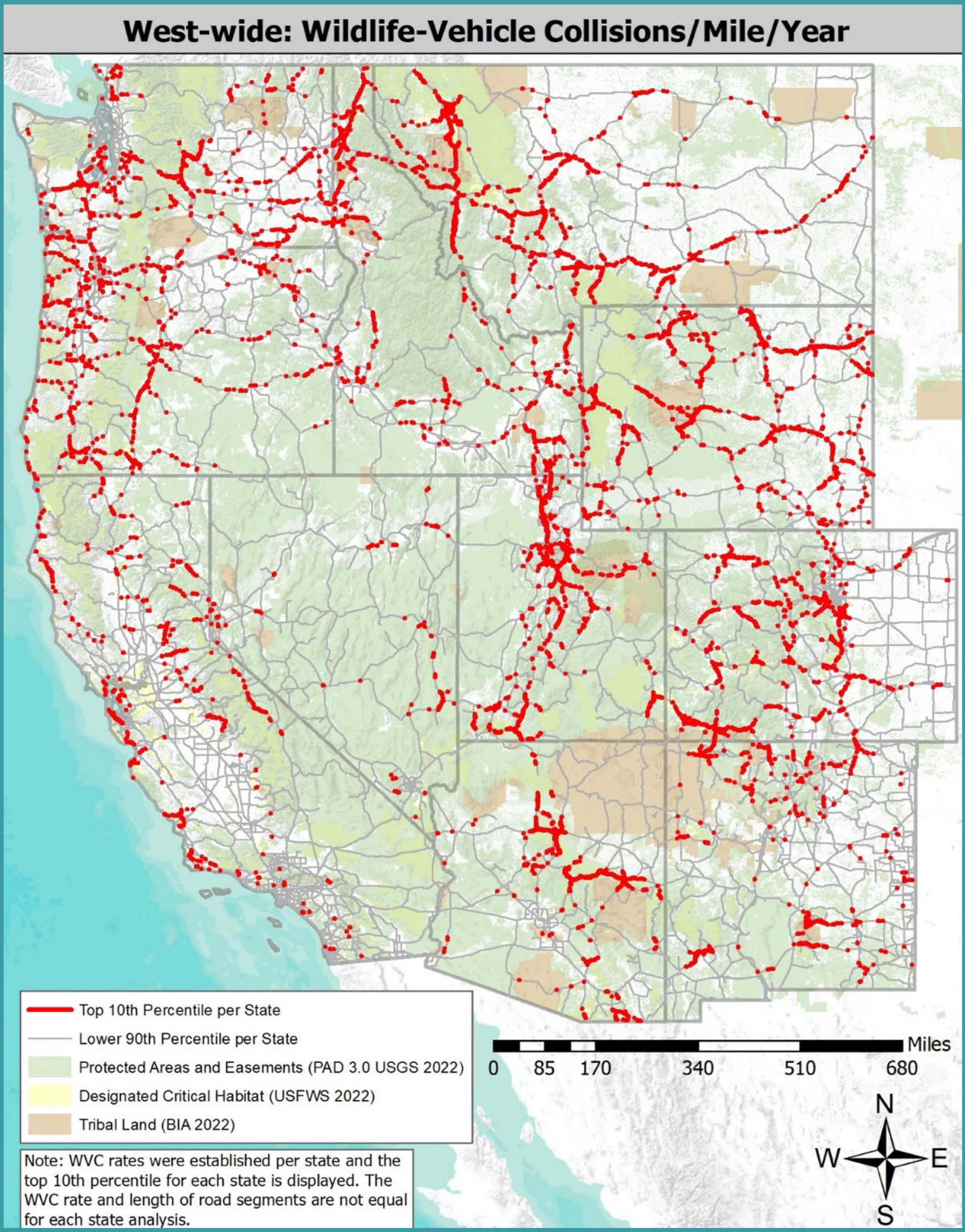

Figure 4. Top 10th percentile of roads with wildlife-vehicle collisions per state in the western U.S.

3.1.2. Economics

The economic costs of WVCs for the eleven western states were calculated using values from Huijser and others (2022a) to derive the total annual costs of WVCs for each state (Table 9). It is estimated that across the region, there is an estimated total cost of $1.6 billion per year based on WVCs (crash data only). Based upon all the roads examined in this analysis (i.e., not limited to the CC road segment categorization), there are 3,202 segments (697 mi) that meet the economic threshold for constructing underpasses (with fencing with apron and jump-outs). Road segments that meet the economic threshold for the mitigation measure combination that uses both under- and overpasses (with fencing with apron and jump-outs) totaled 4,094 or 926 mi. These locations can be seen in Figure 5.

Table 9. Economic cost summary of wildlife-vehicle collisions per road segment for each state per year.

State	Segment costs (US$/mi/yr)			Avg. cost across state (US$/yr)	Economic mitigation threshold reached across all roads			
					UFJ		UOFJ	
	Min	Max	Mean		Seg	Mi	Seg	Mi
Arizona	0	237,419	2,392	88,206,097	107	29	130	36
California	0	87,470	449	67,243,699	38	7	21	4
Colorado	0	958,457	5,550	254,889,399	711	218	1124	344
Idaho	0	134,246	2,468	143,697,736	136	19	135	19
Montana	0	162,901	3,489	212,511,197	277	56	200	41
Nevada	0	118,059	499	11,054,221	9	3	8	3
New Mexico	0	808,669	1,788	174,442,754	680	114	871	146
Oregon	0	98,199	1,317	106,666,000	87	13	52	8
Utah	0	460,151	4,919	247,531,772	436	79	693	125
Washington	0	421,369	2,111	150,943,442	358	62	295	51
Wyoming	0	423,260	5,122	204,039,048	365	97	565	150
			Total	**$1,661,225,365**	**3,202**	**697**	**4,094**	**926**

*Estimated number of miles based on individual states' road segment length means from Table 3.
UFJ = Underpasses, fence with apron, jump-outs
UOFJ = Under- and overpasses, fence with apron, jump-outs

The next steps of our analysis further narrowed the locations from Table 9 and Figure 5 to consider those road segments that are only within the top 10th percentile of the WVC rates and combined these with those that are within the top 50th percentile for permeability probability or connectivity value, referred to as the CC road segments. These will be discussed in Sections 3.2 and 3.3.

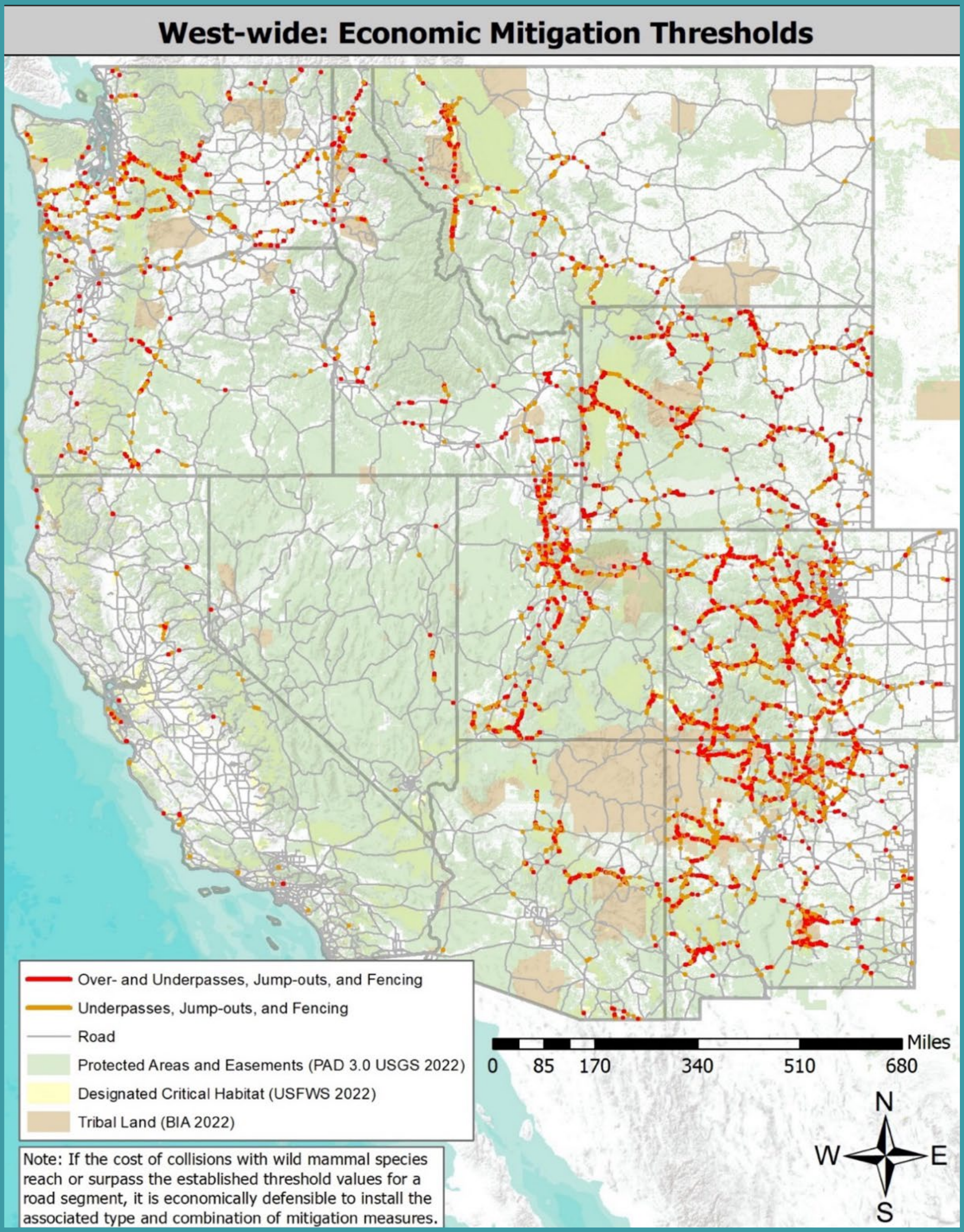

Figure 5. Road segments in the West that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs), and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs). These are all road segments, not just the CC road segments.

3.2. Ecological Connectivity

The mean probability of permeability across all states in the West-wide analysis was 0.64 (Table 10). The minimum permeability probability value was zero (not connected/permeable) and the maximum value was one (highly connected/permeable). Wyoming has the highest average permeability probability with 0.85 and California has the lowest overall permeability probability of 0.53 (Table 10). The road segments that intersect landscapes above the top 50th percentile for connectivity (i.e., permeability probability) of the West-wide analysis are mapped in Figure 6.

Table 10. Permeability probabilities (mean, minimum and maximum) for eleven western states.

State	Mean	Min	Max	St. Dev
Arizona	0.79	0.00	0.98	0.26
California	0.53	0.00	1.00	0.41
Colorado	0.66	0.00	0.98	0.31
Idaho	0.71	0.00	0.98	0.28
Montana	0.73	0.00	1.00	0.27
Nevada	0.84	0.00	1.00	0.22
New Mexico	0.82	0.00	0.98	0.20
Oregon	0.67	0.00	1.00	0.33
Utah	0.82	0.00	1.00	0.22
Washington	0.47	0.00	0.97	0.35
Wyoming	0.85	0.03	1.00	0.17
West-wide	**0.64**	**0.00**	**1.00**	**0.35**

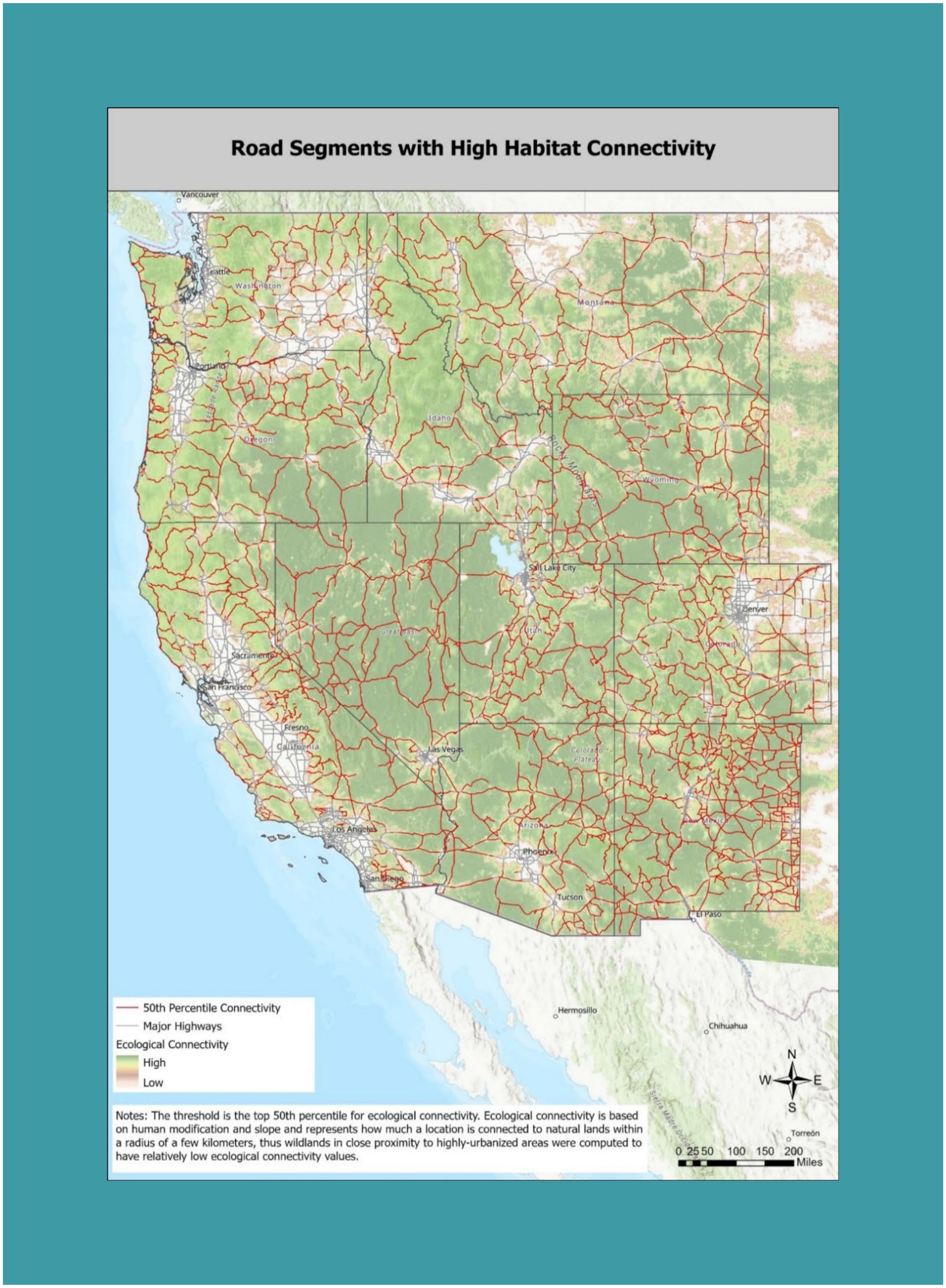

Figure 6. Road segments intersecting areas important for ecological connectivity, found in the top 50th percentile areas for ecological connectivity across the western U.S.

3.3. Collisions and Connectivity

The estimated number of road segments and miles that meet the combined 10th percentile for WVC rates and the 50th percentile for connectivity in each of the eleven western states is presented in Table 11. The road segments that meet both thresholds are called ‘collision/connectivity’ or ‘CC’ road segments.

There are 9,299 road segments totaling 2,005 mi within the top 10th percentile for WVC rates, and 356,741 road segments totaling 73,031 mi within the top 50th percentile for connectivity. When these are overlapped, 3,509 road segments totaling 777 mi exceed both the WVC and connectivity thresholds, as CC road segments (Table 11, Figure 7).

Table 11. Estimated number of road segments (seg) and number of miles (mi*) above percentile thresholds for WVC (top 10th) and connectivity (top 50th) (CC segments), distance to protected areas (PA), distance to critical habitat (CH), traffic volume (AADT), and economic mitigation costs, West-wide.

State	WVC & connectivity thresholds (CC segments)						CC segments													
							Distance to protected area or critical habitat						AADT				Economic mitigation threshold			
	Top 10th percentile WVC		Top 50th percentile cnncvty		CC segments		1 mi PA		¼ mi CH		PA & CH		AADT, cnncvty		AADT, CC		UFJ		UOFJ	
	Seg	Mi*	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi
Arizona	476	130	25,126	6,885	**362**	**99**	2,603	98	68	19	**68**	**19**	2,603	713	45	12	176	48	92	25
California	204	40	45,089	8,747	**52**	**10**	184	9	10	2	**9**	**2**	184	36	0	0	12	2	4	1
Colorado	1,730	529	20,204	6,182	**572**	**175**	1,018	163	57	17	**57**	**17**	1,018	312	66	20	278	85	130	40
Idaho	746	102	24,359	3,337	**188**	**26**	362	22	6	1	**6**	**1**	362	50	2	0	53	7	31	4
Montana	1,052	214	34,630	7,030	**227**	**46**	86	42	50	10	**47**	**10**	86	17	1	0	66	13	18	4
Nevada	11	4	16,418	6,272	**8**	**3**	276	3	0	0	**0**	**0**	276	105	0	0	1	0	0	0
New Mexico	772	130	74,925	12,587	**488**	**82**	3,075	60	26	4	**26**	**4**	3,075	517	6	1	290	49	191	32
Oregon	485	70	38,154	5,532	**159**	**23**	26	19	29	4	**24**	**3**	26	4	0	0	51	7	20	3
Utah	2,115	381	29,225	5,261	**727**	**131**	1,182	115	75	14	**42**	**8**	1,182	213	26	5	339	61	197	35
Washington	528	91	18,636	3,224	**125**	**22**	636	19	36	6	**36**	**6**	636	110	8	1	41	7	16	3
Wyoming	1,180	314	29,975	7,973	**601**	**160**	168	144	43	11	**43**	**11**	168	45	1	0	216	57	131	35
West-wide Total	9,299	2,005	356,741	73,031	**3,509**	**777**	**9,616**	**695**	**400**	**89**	**358**	**81**	**9,616**	**2,121**	**155**	**40**	**1,523**	**338**	**830**	**182**

*Estimated number of miles based on individual states’ road segment length means from Table 3.
Cnnctvty = Connectivity
UFJ = Underpasses, fence with apron, jump-outs
UOFJ = Under- and overpasses, fence with apron, jump-outs

3.4. Collisions, Connectivity, and Conservation

3.4.1. Protected Areas and Critical Habitat

Of the CC road segments, 3,097 (695 mi) are within one mile of a protected area, 400 (89 mi) are within a quarter mile of critical habitat, and of those, 358 (81 mi) are near both protected areas and critical habitat (Figure 8, Table 11).

We further examined the number of resulting segments that are *directly* adjacent to a protected area (Table 12). Across the Western states, 42 percent of the CC road segments are directly adjacent to protected areas, meaning 58 percent of segments are adjacent to unprotected areas (i.e., private lands without conservation easements).

Table 12. Estimated number and percent of road segments and miles* above thresholds for WVCs and connectivity (CC segments) that are directly adjacent to a protected area (PA), West-wide.

State	WVC & connectivity thresholds (CC segments)		CC segments directly adjacent to PA		CC segments *NOT* adjacent to PA		CC segments adjacent to PA	CC segments *NOT* adjacent to PA
	Seg	Mi	Seg	Mi	Seg	Mi	Percent	
Arizona	362	99	300	82	62	17	83%	17%
California	52	10	23	4	29	6	44%	56%
Colorado	572	175	184	56	388	119	32%	68%
Idaho	188	26	75	10	113	16	40%	60%
Montana	227	46	43	9	184	37	19%	81%
Nevada	8	3	6	2	2	1	75%	25%
New Mexico	488	82	129	22	359	60	26%	74%
Oregon	159	23	70	10	89	13	44%	56%
Utah	727	131	291	52	436	79	40%	60%
Washington	125	22	32	6	93	16	26%	74%
Wyoming	601	160	202	54	399	106	34%	66%
West-wide	3,509	777	1,355	308	2,154	469	**42%**	**58%**

*Estimated number of miles based on individual states' road segment length means from Table 3

We also examined the number of CC road segments that are *directly* adjacent to designated critical habitat. We found that 7 percent of the CC road segments are directly adjacent to designated critical habitat (Table 13).

Table 13. Number and percent of road segments and miles above thresholds for WVCs and connectivity (CC segments) that are directly adjacent to designated critical habitat (CH), West-wide.

State	CC segments		CC segments directly adjacent to CH			CC segments *not* adjacent to CH
	Segments	Mi	Segments	Mi	Percent	Percent
Arizona	362	99	55	15	15%	85%
California	52	10	7	1	13%	87%
Colorado	572	175	37	11	6%	94%
Idaho	188	26	2	0	1%	99%
Montana	227	46	6	1	3%	97%
Nevada	8	3	0	0	0%	100%
New Mexico	488	82	18	3	4%	96%
Oregon	159	23	7	1	4%	96%
Utah	727	131	58	10	8%	92%
Washington	125	22	13	2	10%	90%
Wyoming	601	160	27	7	4%	96%
West-wide	3,509	777	230	**53**	**7%**	**93%**

*Estimated number of miles based on individual states' road segment length means from Table 3
Cnnctvty = Connectivity

3.4.2. High Traffic Volume

There are 9,616 road segments (2,121 mi) that exceed the connectivity threshold and experience high traffic volume (Table 11, Figure 9). Of the CC road segments, 155 (40 mi) experience high traffic volume (AADT ≥ 15,000 vehicles per day).

3.5. Collisions, Connectivity, and Costs

Across the West, 1,523 CC road segments (338 mi) meet the economic threshold of $40,857/mile/year. This economic value is the point where investment in a mitigation measure using underpasses (with fencing with apron and jump-outs) equals or is less than the costs of WVCs. Of those, 830 CC road segments (182 mi) meet the economic mitigation threshold of $51,547 where under- and overpasses (with fencing with apron and jump-outs) are less expensive than allowing WVCs to continue to occur (Table 11, Figure 10).

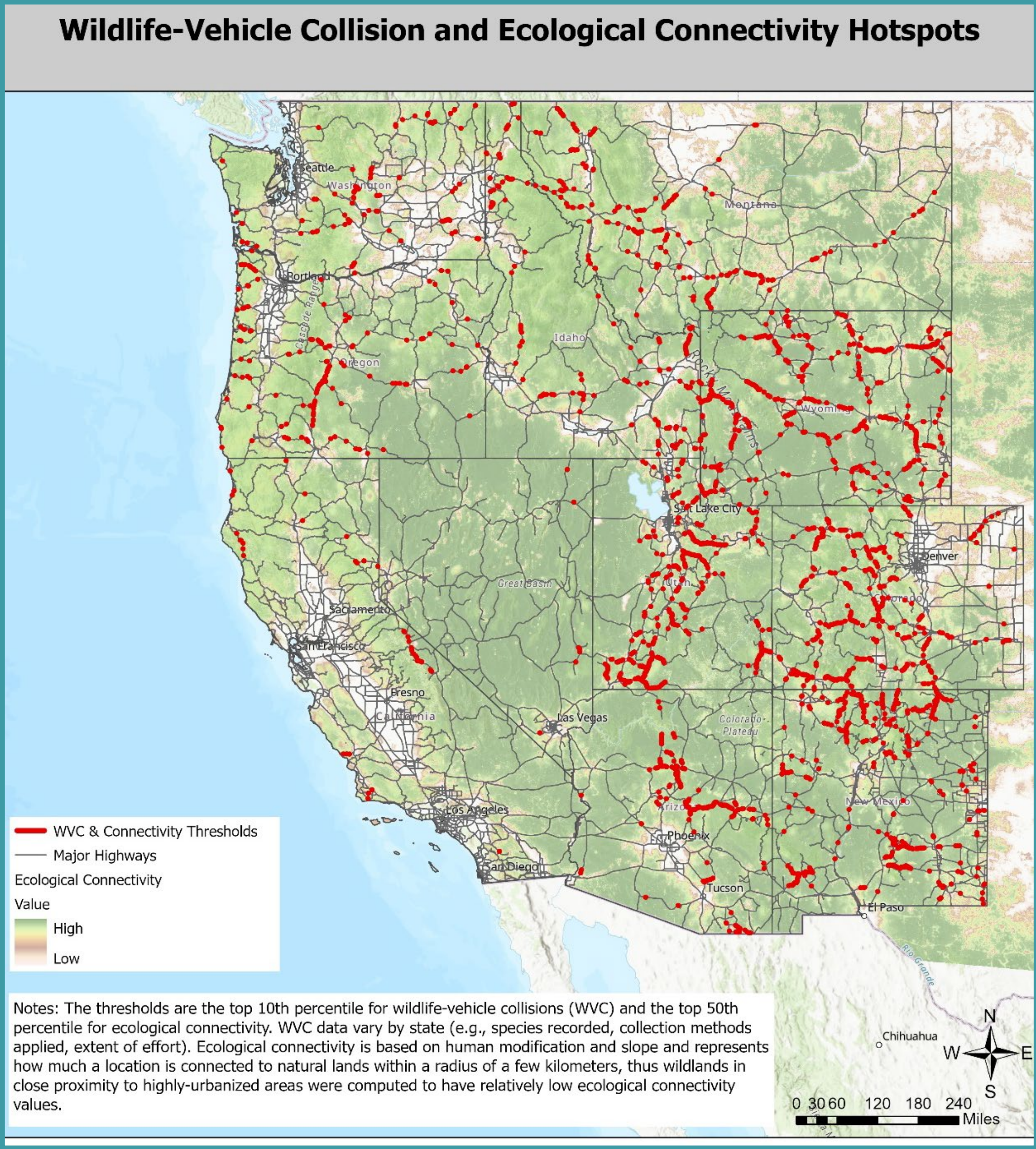

Figure 7. Road segments in the western U.S. above the top 10th percentile for WVCs and above the 50th percentile for ecological connectivity (called CC road segments).

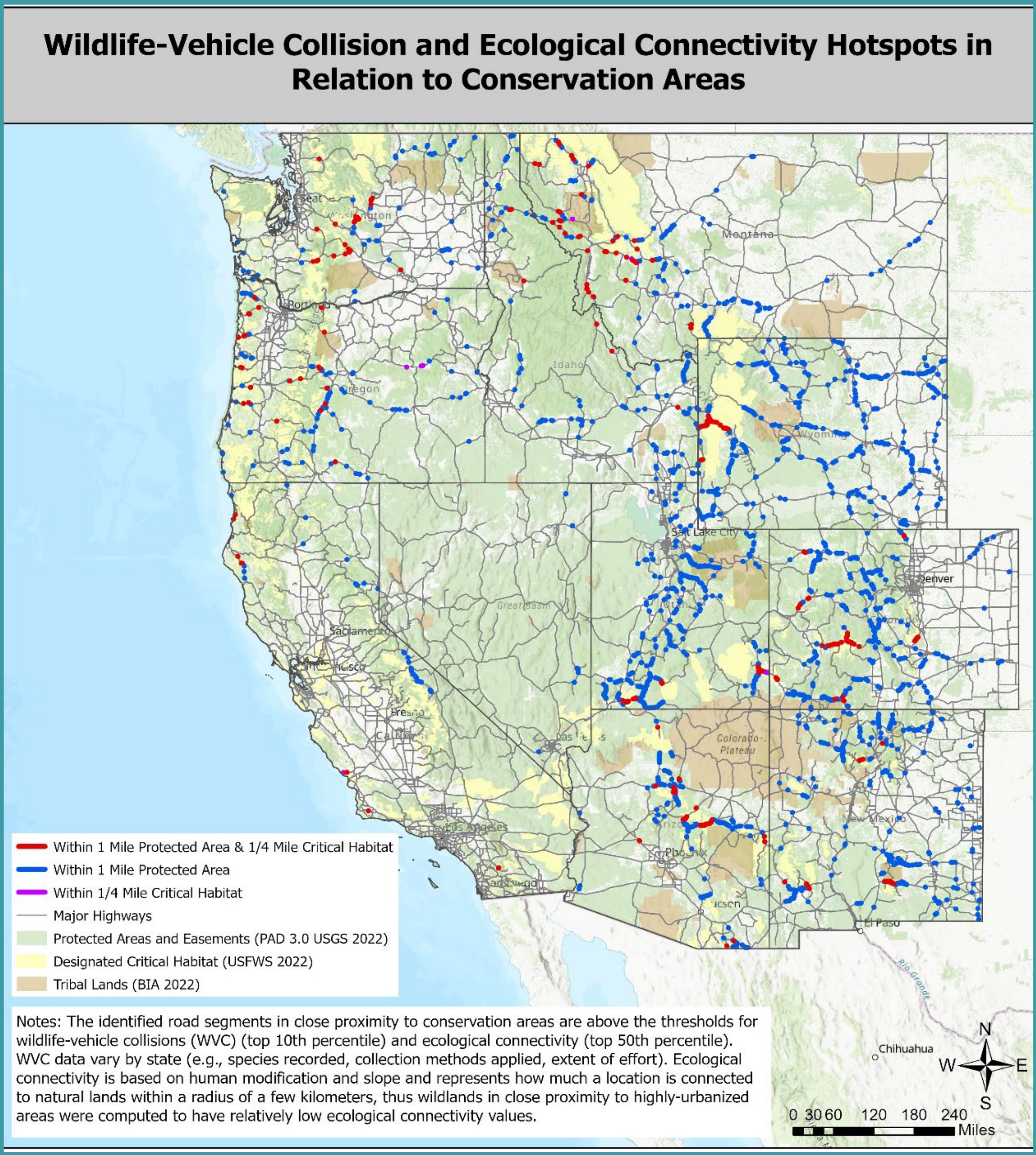

Figure 8. Road segments in the western U.S. above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat (purple), or c) within these distances of both types of conservation areas (red).

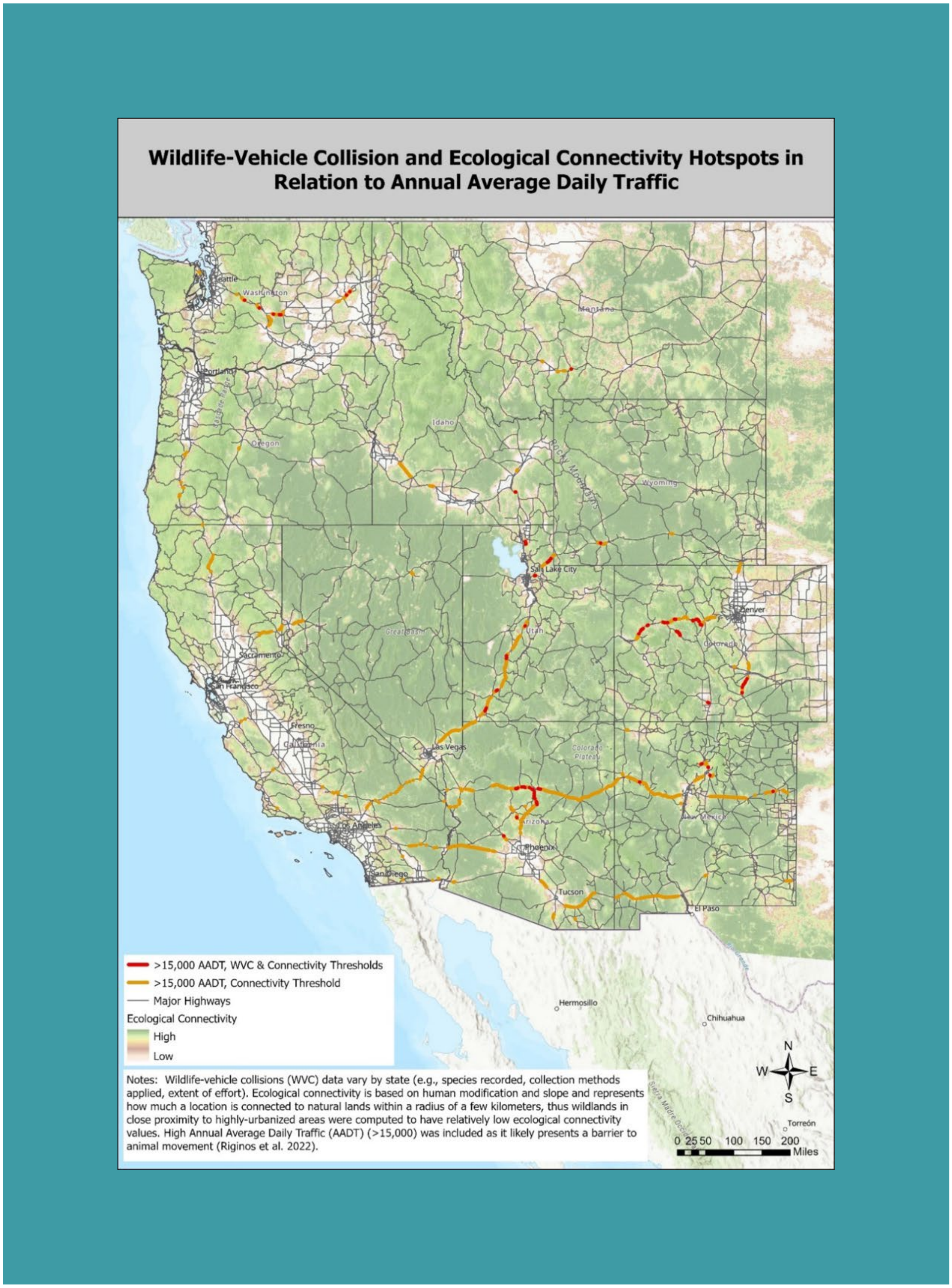

Figure 9. Road segments in the western U.S. i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

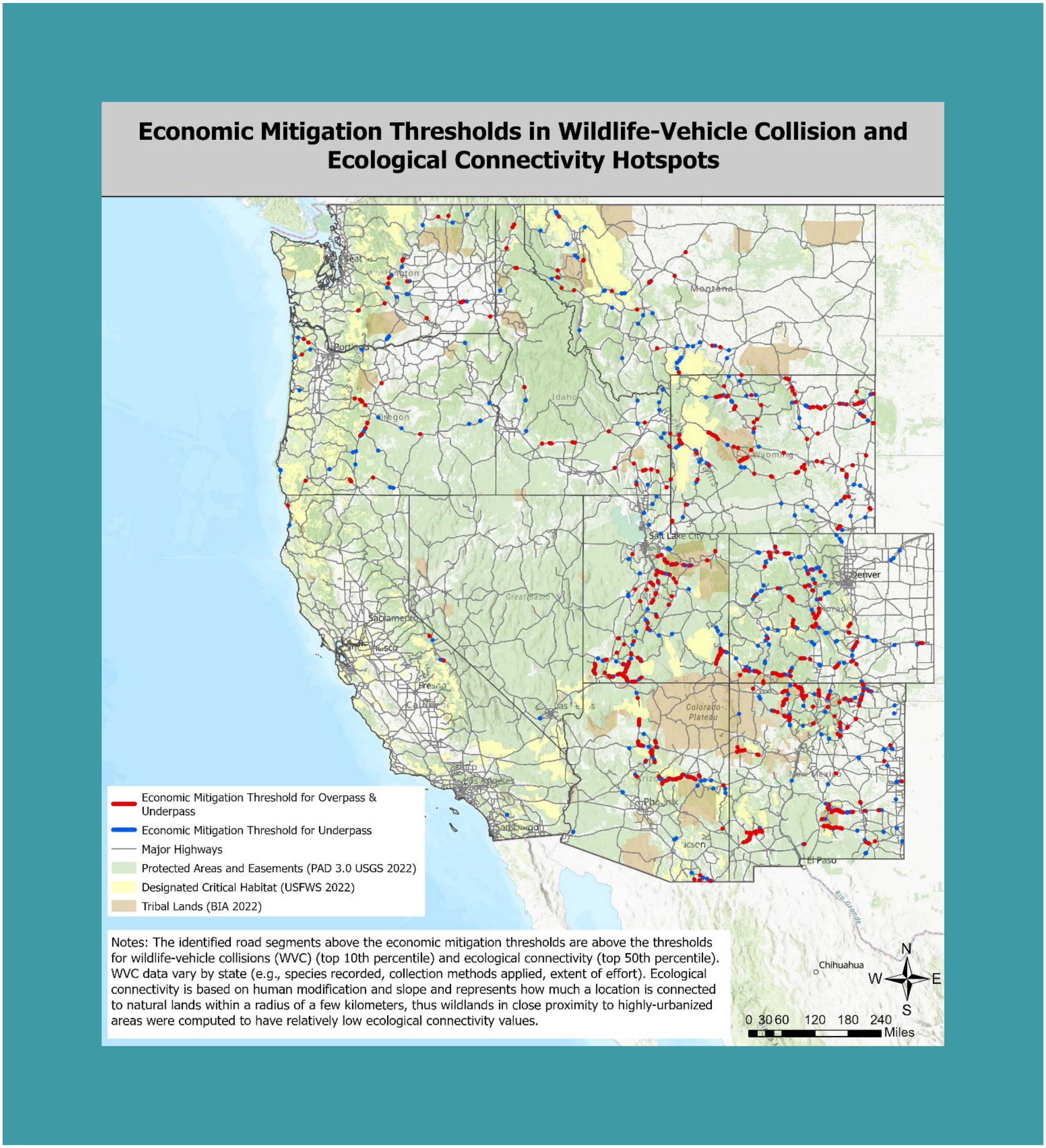

Figure 10. Road segments in the western U.S. above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

4. DISCUSSION

This Study provides an important regional vision of highway mitigation needs throughout the West. To the best of our knowledge, this assessment is the first to examine all western states using a consistent, methodological approach that incorporates collision risk, economic cost, and connectivity considerations in identifying priority locations for mitigation across the entire region. We incorporated spatial data on WVC rates, traffic volume, connectivity, public land protected areas, private land conservation easements, and designated critical habitat for threatened and endangered species. Our analysis of economic thresholds for mitigation measures is based on the costs of collisions with wildlife and building and maintaining wildlife crossings; it is one of the first uses of recently updated economic data on these topics.

In addition to examining the eleven western states as a whole, we also mapped and analyzed the same factors for each state separately (see Appendix). It is important to note that the prioritized sites for mitigation may differ between the West-wide and individual state output maps; priority locations were determined by percentiles, which produce different results at the different scales. Rather than a separate examination, tribal lands are incorporated into the state analyses.

4.1. Safety and Economics

4.1.1. Safety

Because reported crash data are generally more consistent over a larger area than that of carcass removal data (Huijser and Begley 2019), we chose to use crash data given the need for consistency across states in the West-wide analysis. Highly accurate comparisons of WVCs across states remains limited, however, since WVCs are reported differently for each state. As noted in the methodology (Section 2.1.2), some states identify and report specific species; some consistently collect data on only one species; and some states do not specify species at all (Cramer et al. 2022c). For example, California only documents deer-vehicle collision data while other states include collisions with multiple species. Thus, California's WVC rates appear far lower than those of other states (Table 4). This underscores the need to create a standardized methodology for collecting and reporting WVC and carcass data (Ament et al. 2021). Under the Infrastructure Investment and Jobs Act (IIJA) of 2021 (Pub. L. 117–58), the Department of Transportation is required to develop national WVC data standards, although their use will be voluntary.

Moreover, the methodology used to collect WVC crash data is not consistent in each state and is only recorded if an incident is reported to law enforcement. States like Nevada where there is a high proportion of truck traffic, poor cell phone signals, and a low human population in rural areas have fewer reported WVCs because it is less likely that a law enforcement officer is able to respond and make a report of an incident. Large trucks often hit wild animals without reporting incidents since there is often little damage to the truck.

Additionally, crash data (as well as carcass removal data) severely underestimate the total number of collisions with large wild mammals. In Virginia, a state DOT study found eight times more deer-vehicle collisions than were recorded in the law enforcement records, compared to deer carcass removal records in the same study area in the same period (Donaldson 2017). Thus, there is a high probability that the actual number of WVCs is far greater than the crash data sets used in this Study, and therefore, the costs of WVCs in the West is likely much higher as well.

4.1.2. Economics

Few states have incorporated economic considerations into their prioritization efforts (Table 1). Those that have done so are more likely to have used older cost values or based costs on the severity of a crash. This study used an updated cost-benefit analysis for mitigation measures based on direct costs in 2020 dollars of crashes with large wildlife species, as well as the passive use values of those species; the costs of building and maintaining wildlife crossings over a 75-year service life were also updated (Huijser et al. 2022a). Thus, the economic thresholds used in this project reflect the latest cost estimates of both collisions and mitigation measures.

Based on the reported crash data, it is estimated that the eleven western states have a cost associated with WVCs with large animals of $1.6 billion per year at a minimum (Table 9). This value can be considered conservative as the number of actual WVCs far exceeds the number that are reported as crashes by law enforcement personnel (as WVCs occur without being reported, species are hit that do not create as much damage, etc.). Implementing effective mitigation measures that reduce collisions with large, wild mammals in the CC road segments will substantially reduce the estimated state and West-wide costs over time.

Despite the limitations associated with the crash data, there are many CC road segments where the costs associated with WVCs with large animals exceed the costs associated with implementing wildlife crossing structures and wildlife fences. In other words, there are many road sections across the eleven western states where it is economically advantageous to implement wildlife crossings.

4.2. Ecological Connectivity

We modeled connectivity at a finer resolution (90m grid) than previous studies and applied a new percolation-based approach (Theobald et al. in prep) to map areas important for connectivity at multiple scales. We used the degree of human modification as an input to model connectivity (i.e., permeability probability and assume that many species will move through natural areas more easily than through areas heavily modified by human activities. Human modified areas are impacted by housing and industrial development, agriculture, energy production and mining, linear infrastructure (roads, railways, powerlines, and pipelines), and logging and wood harvesting (Theobald et al. 2020). This naturalness approach to characterizing connectivity may also reflect the ability of the landscape to support range shifts (Keeley et al. 2021) and can be complemented at a finer scale with focal species mapping.

In the resulting map, the value of every pixel in the landscape represents the probability that a given pixel is connected to nearby natural habitat within a radius of a few kilometers. Therefore, for example, connectivity will be low even for a group of high-naturalness pixels if it is surrounded by high human impact pixels. This approach has three advantages: (1) it represents the landscape condition with respect to connectivity as a gradient rather than as distinct classes, (2) the connectivity values are interpreted as probabilities, and (3) it is species-agnostic such that different versions of the maps accounting for the different dispersal capabilities of various species are not needed.

However, while computing connectivity at multiple scales is a powerful approach, so doing may fail to capture the connectivity values of natural areas if they are adjacent to highly urbanized areas. We noticed this especially for select southern California mountains where wild lands near Los Angeles were computed to have relatively low ecological connectivity values. Limiting the scales at which permeability is calculated could address this issue.

Because large parts of the western U.S. have low human modification (Theobald et al. 2020) and consequently high naturalness, most roads are crossing through areas important for connectivity (Figure 5). It is mainly in urban and agricultural areas that connectivity, in the model's parameters, is decreased by factors other than roads. Large agricultural areas with low connectivity value include, for example, the Central Valley of California, the Willamette Valley in Oregon, southeast Washington, northwest and parts of southern Idaho, northcentral and northeast Montana, and some areas in eastern Colorado.

4.3. Collisions and Connectivity

Throughout this project, we only included locations that met both the safety and the connectivity thresholds. We considered road segments in the 50th percentile of permeability values as located in areas important for connectivity. We set the threshold for WVC rates at the top 10th percentile and disregarded all road segments with lower WVC rates.

Focusing the study on road segments that meet both the WVC and the connectivity thresholds pinpoints highway locations where addressing safety concerns via the addition of wildlife crossings would also improve habitat connectivity. So doing reduced the 9,299 segments or 2,005 mi that experience the highest WVC rates, and the 356,741 segments or 73,031 mi intersecting landscapes important for ecological connectivity, to 3,509 CC road segments or 777 mi across the West where mitigation would help address *both* human and wildlife safety and ecological connectivity. This narrows the focus for decision-makers.

A study by McClure and Ament (2014) identified sites for potential mitigation in western Montana and northern Idaho to address human safety concerns and enhance ecological connectivity where it would be expected to matter most. However, they found poor alignment between sites identified as priorities for mitigating WVC risk and for enhancing connectivity. Instead, sites with high expected connectivity value tended to be far from populated areas, whereas sites associated with high risk of wildlife collisions were characterized by high traffic volumes, wide roads, and highly modified surrounding landscapes. The fact that this Study identified sites that were above both the WVC and connectivity thresholds may be explained by the different models used. In this Study, we set the connectivity threshold relatively broadly to capture more road segments that may be important for their local landscape connectivity. In addition, the West-wide study area was much larger and therefore different patterns can be expected to emerge.

Not all areas that may be regionally known as WVC hotspots and are assumed to also be important for connectivity have been identified in this analysis. There are several reasons for this: there may be a paucity of WVC information recorded for a state or region due to differences in WVC data collection; the permeability model may have omitted wildlands in close proximity to highly urbanized areas; or the percentile WVC threshold across the entire western region may have masked locally important areas. The lack of CC road segments is especially notable in California and is likely due to the exclusion of important areas in the connectivity model because of nearby high human impact, in conjunction with CalTrans' crash data, which only reports deer-vehicle collisions. Further, in Nevada, few sites were identified as CC road segments, primarily due to fewer recorded WVCs (Figure 10) than other states. This underreporting of WVCs is most likely due to a relatively smaller human population and lesser traffic, as well as inconsistent WVC reporting in its statewide crash database (pers comm, Nova Simpson, NDOT).

4.4. Collisions, Connectivity, and Conservation

4.4.1. Protected Areas and Critical Habitat

When determining where to invest in wildlife crossings, decision-makers may require that land on both sides of a road segment can serve as long-term wildlife habitat. If the land adjacent to a site is protected, a proposed wildlife crossing structure is considered a sensible public investment (Paul et al. 2023). Conversely, if a site is located adjacent to land that is not conserved (e.g., through a conservation easement or fee title), land may be developed such that wildlife will not be able to access a crossing structure, rendering the investment useless.

Therefore, we examined whether the land adjacent to the CC road segments is within proximity of a protected area (public land or private lands with conservation easement). Most of the CC road segments (3,509 segments, 777 mi) are within one mile of protected areas (3,097 segments, 695 mi, Figure 8). These locations are primarily driven by the 10th percentile WVC threshold rather than the ecological connectivity threshold (Figure 6) – again, Nevada and California, with fewer WVC data, do not have many road segments highlighted in this analysis.

A protected area *closer* than one mile is typically desirable when selecting locations for wildlife crossings. We looked more closely to determine the number of CC road segments located *directly* adjacent to protected areas (or, conversely, adjacent to unprotected areas) to point out where land protection is needed for a future wildlife crossing. We found that 58 percent (2,154 segments, 469 mi) of the CC road segments are not adjacent to protected lands. We suggest land trusts, other private land conservation organizations, and agencies examine these areas to determine whether conservation easements or other land protections may be undertaken at these locations. At the same time, the analysis determined that 42 percent of the CC road segments (1,355 segments, 308 mi) are directly adjacent to protected areas, and thus wildlife crossings may be more easily deployed since the adjacent lands are in the public domain or, if private, have easements. It should be noted that the wildlife fencing attached to a crossing structure can often parallel several miles of road on both sides. It is recommended that 3.1 mi (5 km) of fencing be used with wildlife crossing infrastructure. A meta-analysis of fencing length used with crossing structures determined that an average reduction in WVCs of 50 percent or more without fencing increased to over 80 percent when 3.1 mi (5 km) of fence was employed (Huijser et al. 2016).

It is the responsibility of transportation and wildlife agencies to address a highway project's impact to species listed under the Endangered Species Act; therefore, we included the locations of designated critical habitat for threatened and endangered species in the analysis. Most locations fall within both a quarter mile of critical habitat and within one mile of protected areas. We further identified CC road segments located *directly* adjacent to designated critical habitat, to pinpoint where decision-makers could implement wildlife crossings to help recover ESA-listed species and habitat connectivity. Across the western states, there are a small number of these locations (7 percent, 230 segments, totaling 53 mi).

Numerous ESA-listed species do not have designated critical habitat, numerous species of concern are not ESA-listed, and each state may also have state-listed species not incorporated into the analysis. Although the analysis focused on terrestrial connectivity, some priority road segments identified are near rivers important for fish species with designated critical habitat (e.g., bull trout (*Salvelinus confluentus*) in Montana).

4.4.2. High Traffic Volume

High traffic volumes have been shown to increase WVCs; however, when traffic becomes sufficiently high, roadways can have a barrier effect. An indication that a stretch of busy road serves as a barrier is a lack of WVCs despite adjacent habitat in areas identified as important for connectivity with healthy populations of large mammals. For this reason, it is important not only to look at areas with high rates of WVCs, but also to consider connectivity areas where there are few or no WVCs.

Some wildlife species are sensitive to or deterred from crossing a road once traffic volume reaches a certain level. In fact, wildlife may stop attempting to cross a highway once there are too many vehicles for a species' preferences or capabilities. Sensitivity to traffic volume has been poorly studied for most species. Existing species-specific studies at finer scales have demonstrated that even relatively low traffic volumes may create hesitancy or pose a risk for individual animals crossing a road. For example, it became increasingly unsafe for mule deer to attempt to cross highways in Wyoming as hourly traffic exceeded 60 vehicles per hour (roughly 2,000 AADT), a rate at which mule deer stopped trying to cross (Riginos et al. 2018). Another study found mule deer had fewer crossing attempts above 8,000 AADT (Coe et al. 2015). Similarly, based upon collar data and road use in northwest Montana, it has been hypothesized that grizzly bears will not cross a 2-lane highway when traffic exceeds 100 vehicles per hour (Waller and Servheen 2005; Waller and Miller 2015).

One of the challenges in identifying highway segments whose traffic has created a barrier for wildlife is that the metric commonly used for measuring traffic volume is AADT. Use of this average smooths out fluctuations or spikes in high traffic, for example due to seasonal travel, which may impact wildlife behavior and their ability to cross the road.

As a result, building wildlife crossings is crucial to re-establishing connectivity in high-traffic areas. To illustrate where road segments with high traffic volumes may pose barriers for ungulate movements in the West, we identified areas within our top 50th percentile of connectivity where road segments with AADTs of 15,000 or more, following Riginos and others (2022). This is an attempt to spotlight areas that are most likely are or are becoming a barrier for wildlife while using this relatively high and therefore more conservative barrier effect estimate, as our analysis did not focus on specific, sensitive species.

There are many (9,616, totaling 2,121 mi) road segments with high connectivity and high traffic volume that should be more closely examined for possible barrier effect concerns. Of these, just 155 (40 mi) areas overlap with the CC road segments where there is high WVC, high connectivity, and high traffic volume. Stretches of both high WVC-risk and expected barrier effect due to high traffic volumes are found mostly along interstate highways, outside of the cities, such as along I5 in northern California and Oregon; I10 and I15 from Los Angeles to Salt Lake City; I40, I25 and I70 in Colorado; and I90 in Washington. These stretches should be top candidates for further examination of the need for wildlife crossings.

4.5. Collisions, Connectivity, and Costs

Few analyses identify and prioritize possible locations for wildlife crossing structures based on economic analysis. Analyses carried out for Colorado and New Mexico include cost-benefit of mitigation measures (Kintsch et al. 2019; Cramer et al. 2022a). Other analyses have estimated the cost – though not the benefit – of proposed mitigations in prioritizations (e.g., Arizona, Williams et al. 2021). In the West-wide analysis, we assessed where collisions, connectivity, and costs (the Three Cs) overlap on road segments in order to prioritize mitigation where economic, safety, and conservation purposes align.

We examined which of the CC road segments have WVC costs that meet or surpass the costs to construct and maintain wildlife crossing structures and their fencing over their 75-year service life. Of the CC road segments identified, 1,523 segments (338 mi) meet the economic threshold for crossings using underpasses (with fencing with apron and jump-outs) and 830 of these segments (182 mi) meet the economic threshold where wildlife crossings with both under- and overpasses (with fencing with apron and jump-outs) are cost effective.

In these locations, the construction and related costs of the implementation of wildlife crossings can be recouped over time by reducing or avoiding the costs associated with WVCs. Across the West, *not* mitigating WVCs costs society an estimated $1.6 billion per year at a minimum. Rather than doing nothing and allowing WVCs to continue to occur, these costs can be reduced through implementing wildlife crossings (and fencing).

The analysis identifies those CC road segments where wildlife crossings will be cost-effective. This does not infer other areas are not economically defensible – the Huijser et al. economic model is a useful tool but should not be used as a litmus test for selection of wildlife mitigation placement. Similarly, the 0.2-mile road segment unit used in this Study does not reflect a singular discrete location essential for a crossing location. The combinations of mitigation measures used in the Huijser et al. study relate to longer road sections, so the degree of clustering of those 0.2-mile road segments would be more relevant to consider than individual 0.2-mile road sections. To get to a localized specification of crossing implementation locations using the economic threshold values would require a complicated analysis we did not undertake in this Study. The findings of this Study can be used as part of an early identification phase of highway segments to prioritize, with the understanding that further site-specific, fine-scale assessments are necessary to determine the specific location of wildlife crossings. Such assessments account for additional considerations such as target species' preference for crossing structure type, design considerations, adjacent habitats, land ownership, political viability, and key partner support (Huijser et al. 2008; Clevenger and Huijser 2011; Huijser et al. 2022b; Cramer et al. 2022b).

When examining Figure 9 and the website maps, users should keep in mind that the mitigation threshold in the West-wide analysis is highly conservative, as it is based on the average costs of deer collisions rather than a mix of deer and larger, more costly collisions with bear, elk and moose. We standardized all WVC costs as deer in the West-wide analysis, given that most states do not require documentation of species in crash data collection. In the state-by-state analyses, collision costs and economic thresholds for deploying a wildlife crossing are based on state-specific WVC data, which may include species-specific differentiation. Since collisions with moose, elk, and grizzly bear collisions have much higher costs than those with deer (Huijser et al. 2022a), mitigation may be even more cost-effective than shown in the West-wide analysis.

5. STUDY IMPLICATIONS

We prepared this *West-Wide Study to Identify Important Highway Locations for Wildlife Crossings* to offer useful information to transportation and natural resource agencies, their stakeholders and other related entities. Assessments of this type are geared to illustrate priorities for mitigation of problematic highways, develop a common vision among stakeholders, and promote energy and funding for connectivity conservation efforts (Keeley et al. 2019). Managers can use such information to coordinate across jurisdictions and with adjacent landowners to develop collaborative strategies for reducing WVCs and improve conservation outcomes across larger landscapes.

We hope state DOTs will examine the West-wide report and then delve further into the individual state results in the Appendix and explore the online mapping website. States that have already compiled and analyzed this type of information can use the results for comparative purposes or to locate convergent priority road segments. They can also use the information to aid in making decisions for implementation or applying for federal funding. For states that have not yet undertaken related efforts, we offer an essential step towards implementing wildlife crossings at locations based on the best available datasets and robust analyses. The economic analysis may be of interest to all states. State wildlife agencies can also take advantage of this report to consider threats to wildlife populations across their state and areas of importance for connectivity, including transboundary connections between states.

Federal land management agencies are responsible for preserving and enhancing wildlife connectivity, both through policies on the lands they manage and through conservation programs with partnering agencies. As national stewards of wildlife and habitat, federal land management agencies can enhance their missions by promoting wildlife crossings. For example, Bureau of Land Management Resource Areas or USDA National Forests can use the findings to inform Resource Management Plan or Forest Plan revisions, respectively, or in project considerations.

Multiple agencies can use the findings of this Study to consider areas for land acquisitions or conservation easements in important locations for ecological connectivity and the development of wildlife crossings. Private land organizations can use this report to determine areas in need of protection for potential future wildlife crossings. This report may also be useful for land trusts (and their funders), as the findings help assure their efforts are focused appropriately, and land trusts often take on risk when undergoing transactions that secure lands for conservation.

Local and regional coalitions that focus on conservation, wildlife connectivity, and wildlife crossing projects bring together multiple stakeholders to implement coordinated actions that address WVC and ecological connectivity problems, often in pinch-point locations. In many areas in the West, exurban development and other land use changes are limiting the potential for adoption of wildlife crossings in some locations. Existing and developing coalitions in the West should find the state-by-state analyses and online web map particularly useful.

Such coalitions often bring together groups and agencies that have a mixture of skill sets, knowledge, and authorities that enable the development of a variety of forward-thinking solutions.

Conservation organizations can also use this Study to consider areas of interest within the context of their own programs. For example, they may use this assessment to identify and/or pursue funding for wildlife crossing infrastructure design and implementation, develop local policy measures, conserve key private land parcels, support research and monitoring, or increase community understanding of connectivity needs (Penrod 2020; Penrod et al. 2021; Penrod 2023).

Research efforts like the Ungulate Migrations of the Western United States (Kauffman et al. 2022) can also use the information in this Study to compare and inform their work documenting migration pathways, opportunities, and barriers to ungulate movement. It is hoped that the findings can be used as an opportunity to develop cooperative, highway-based solutions.

The difficulty posed by the lack of national standards for WVC data collection is underscored by the methodology developed to conduct this analysis. Fortunately, the Infrastructure Investment and Jobs Act (IIJA) has provisions directing the Department of Transportation to promulgate voluntary standards. In addition to the Wildlife Crossings Pilot Program, the “Wildlife Crossing Safety” section of the statute (Sec. 11123(c)(1) of the IIJA) contains a suite of policy provisions to reduce WVCs and improve habitat connectivity. These include developing a (voluntary) standardized methodology for collecting and reporting wildlife collision and carcass data. Two additional needs for standardized data collection are: i) recording observations of live wildlife crossing a road, and ii) collecting wildlife data that identifies more than large ungulates. A thoughtfully designed data system could incorporate citizen scientists and other non-agency carcass data collectors. These data would help studies like this one.

5.1. Future Research

This project primarily focuses on areas where WVC and ecological connectivity values overlap. This inclusion of connectivity considerations is an important step beyond simply prioritizing WVC hotspot locations. We go a step further by examining areas with high traffic volume within the 50th percentile connectivity threshold and without inclusion of WVC data. This helps highlight those regions where road sections may have ecological problems in terms of the barrier effect for wildlife but where there are not human safety concerns – areas that are often overlooked for implementation of wildlife crossings and fencing. A further analysis using higher connectivity values (i.e., 10th percentile connectivity) could be undertaken, and perhaps using other conservation-based data layers, to further highlight those locations that should be prioritized based on ecological needs rather than primarily focusing on human safety needs, as is typically done. A policy and separate funding mechanism that supports the implementation of mitigation measures based primarily on ecological connectivity needs would be invaluable and better protect species that are not large, common wild ungulates (those most often struck by vehicles).

Future research should include a more nuanced private/public land analysis to understand the ownership and management of lands adjacent to priority crossing locations.

This project analyzed CC road segments without a focus on the specific needs of federal land management agencies and other federal landowners, such as the Department of Defense or Department of Energy. Since federal land holdings comprise nearly half or over half of the lands in several western states, incorporation of more information regarding the management of federal lands would help public agencies to identify road segments that further include their priorities.

The majority of tribal roads (those not managed by state DOTs) were not included in the analysis. Future analyses (e.g., Fairbank et al. 2019) could be conducted with tribal nations in order to consider WVC and wildlife data not available for this project.

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APPENDIX

State-By-State Analyses

In addition to examining the eleven western states as a whole, we mapped and analyzed each state separately. We hope state DOTs will examine the West-wide report and then delve further into the individual state results here and explore the online mapping website. *For a description of methods, an explanation of results, and related interpretation and discussion of each map or analysis, please see the main document.*

Many western state transportation and wildlife agencies have carried out analyses to identify priority areas and road segments for wildlife mitigation measures. Some states have identified and prioritized locations based primarily on concerns for human safety by focusing on wildlife-vehicle collision (WVC) locations, while other states have included wildlife conservation concerns by examining ecological connectivity and other factors. Some states have analyzed connectivity separately from transportation concerns.

States that have already compiled and analyzed this type of information can use the results for comparative purposes or to locate convergent priority road segments. They can also use the information to aid in making decisions for implementation or applying for federal funding. For states that have not yet undertaken related efforts, we offer an essential step towards implementing wildlife crossings at locations based on the best available datasets and robust analyses. The economic analysis may be of interest to all states. State wildlife agencies can also take advantage of this report to consider threats to wildlife populations across their state and areas of importance for connectivity.

The estimated number of road segments and miles that meet the WVC and connectivity percentile thresholds (called collision/connectivity or CC road segments), as well as the locations on maps, differ when assessing the data for each state (Table 1) when compared to the full West-wide analysis (Table 11 of report) because the data extents used for the percentiles differ.

Website

We developed an accompanying interactive web map (**http://largelandscapes.org/west-wide-mapping**) that allows users to examine the results at a variety of scales. The spatial layers can be examined individually or in various combinations on the interactive mapping website, where users can zoom in to areas of interest or zoom out for an overview of the entire western study area. A user guide explains how different layers in the tool can be used.

The data layers can be downloaded from the website. This will allow a user to include their own layers and datasets for comparison, to view local highway names, to examine parcel ownership, and so on. Existing bridges are a layer within the online map that can be used to examine potential retrofit for improvements to wildlife use of the bridges.

Table 1. Based on percentiles for individual states, the estimated number of road segments (seg) and number of miles* (mi) above thresholds for WVC (top 10th) and connectivity (top 50th) (CC road segments), distance to protected areas (PA), distance to critical habitat (CH), traffic volume (AADT), and economic mitigation costs, by state.

PER STATE PERCENTILES																								
State	WVC & connectivity thresholds (CC road segments)						CC road segments																	
							Distance to protected area or critical habitat						AADT				Economic mitigation thresholds							
	Top 10th percentile WVC		Top 50th percentile cnncvty		CC road segments		1 mi PA		¼ mi CH		PA & CH		AADT, cnncvty		AADT, CC		UFJ		UOFJ					
	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi	Seg	Mi				
Arizona	720	197	18,430	5,050	381	104	360	99	82	22	82	22	1,479	405	26	7	125	34	64	18				
California	540	105	74,773	14,506	352	68	284	55	62	12	59	11	1,024	199	9	2	34	7	10	2				
Colorado	983	301	22,939	7,019	391	120	361	110	35	11	34	10	1,414	433	67	21	368	113	258	79				
Idaho	884	121	29,091	3,985	331	45	279	38	23	3	23	3	589	81	7	1	85	12	52	7				
Montana	1,664	338	30,443	6,180	331	67	293	59	75	15	71	14	45	9	1	0	38	8	10	2				
Nevada	92	35	11,073	4,230	23	9	23	9	0	0	0	0	0	0	0	0	0	0	0	0				
New Mexico	534	90	48,747	8,189	139	23	97	16	3	1	3	1	1,173	197	1	0	124	21	108	18				
Oregon	665	96	40,464	5,867	232	34	194	28	46	7	40	6	36	5	0	0	54	8	20	3				
Utah	1,207	217	25,139	4,525	264	48	234	42	22	4	13	2	766	138	0	0	238	43	139	25				
Washington	847	147	35,734	6,182	494	85	439	76	153	26	153	26	2,777	480	109	19	200	35	151	26				
Wyoming	1,166	310	19,906	5,295	238	63	225	60	22	6	22	6	16	4	0	0	113	30	87	23				

*Estimated number of miles based on individual states' road segment length means from Table 3 of report.
Cnnctvty = Connectivity
UFJ = Underpasses, fence with apron, jump-outs
UOFJ = Under- and overpasses, fence with apron, jump-outs

1. ARIZONA

1.1 Safety and Economics

There was a total of 14,063 reported collisions with large wildlife over 11 years (2010-2020) in Arizona (Table 4 of report). These collisions consisted of 9,321 with wild game and 4,742 with wild non-game. The reported WVC crash data shows that crash rates ranged from 0 to 12.44 WVC/mi/yr (Table 7 of report). There are 19.5% of the road segments that have an identified WVC rate (> zero WVCs), and the top 10th percentile of segments has 1.27 WVC/mi/yr and higher (Table 8 of report, Figure 1).

Based on costs and number of collisions, Arizona's average cost of WVCs per year is $88,206,097 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 107 road segments (29 mi of road) that surpass the cost threshold and thus are cost-effective to install underpasses (with fencing with apron, jump-outs) and 130 segments (36 mi) where under- and overpasses (with fencing with apron, jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9, Figure 2 below).

1.1 Collisions and Connectivity

Arizona's road segment lengths were on average 0.27 mi in length (Table 3 of report). There are 720 road segments (totaling 197 mi) within the top 10th percentile for WVC and 18,430 road segments (totaling 5,050 mi) within the top 50th percentile for connectivity (Table 1). There are 381 road segments (totaling 104 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 3).

1.2 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 381 CC road segments, 360 (99 mi) are within one mile of a protected area, 82 (22 mi) are within a quarter mile of critical habitat, and 82 (22 mi) are near both protected areas and critical habitat (Table 1, Figure 4).

1.3 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 1,479 road segments (405 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 5). Of CC road segments, 26 (7 mi) of them experience high traffic volume (AADT ≥15,000 vehicles per day).

1.4 Collisions, Connectivity, and Costs

Of the CC road segments, 125 (34 mi) meet the economic mitigation threshold for where underpasses (with fencing with an apron and jump-outs) are cost-effective. Sixty-four road segments (18 mi) meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Table 1, Figure 6).

1.5 Other Resources to Examine

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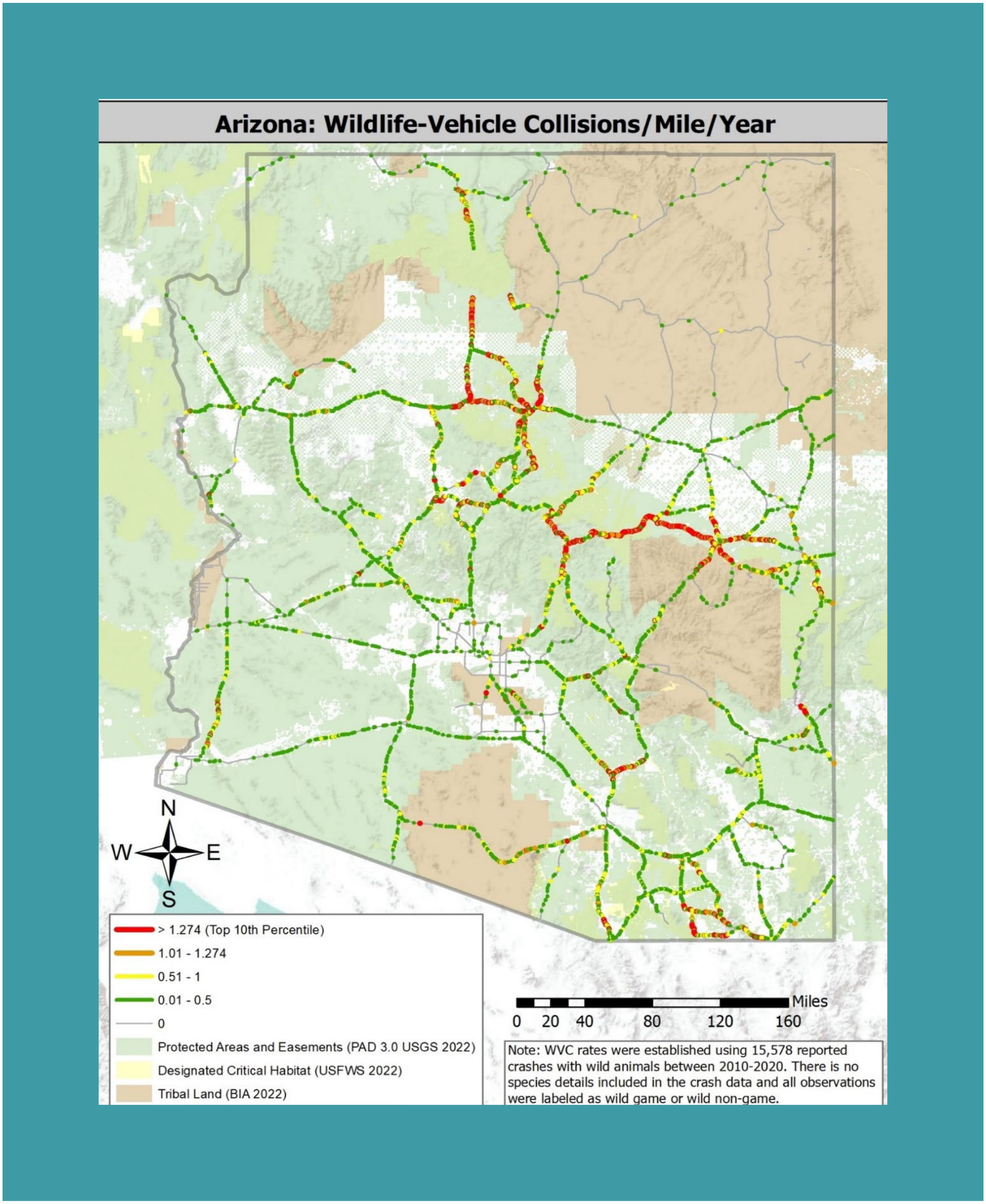

Figure 1. Average WVC rates for Arizona between 2010-2020.

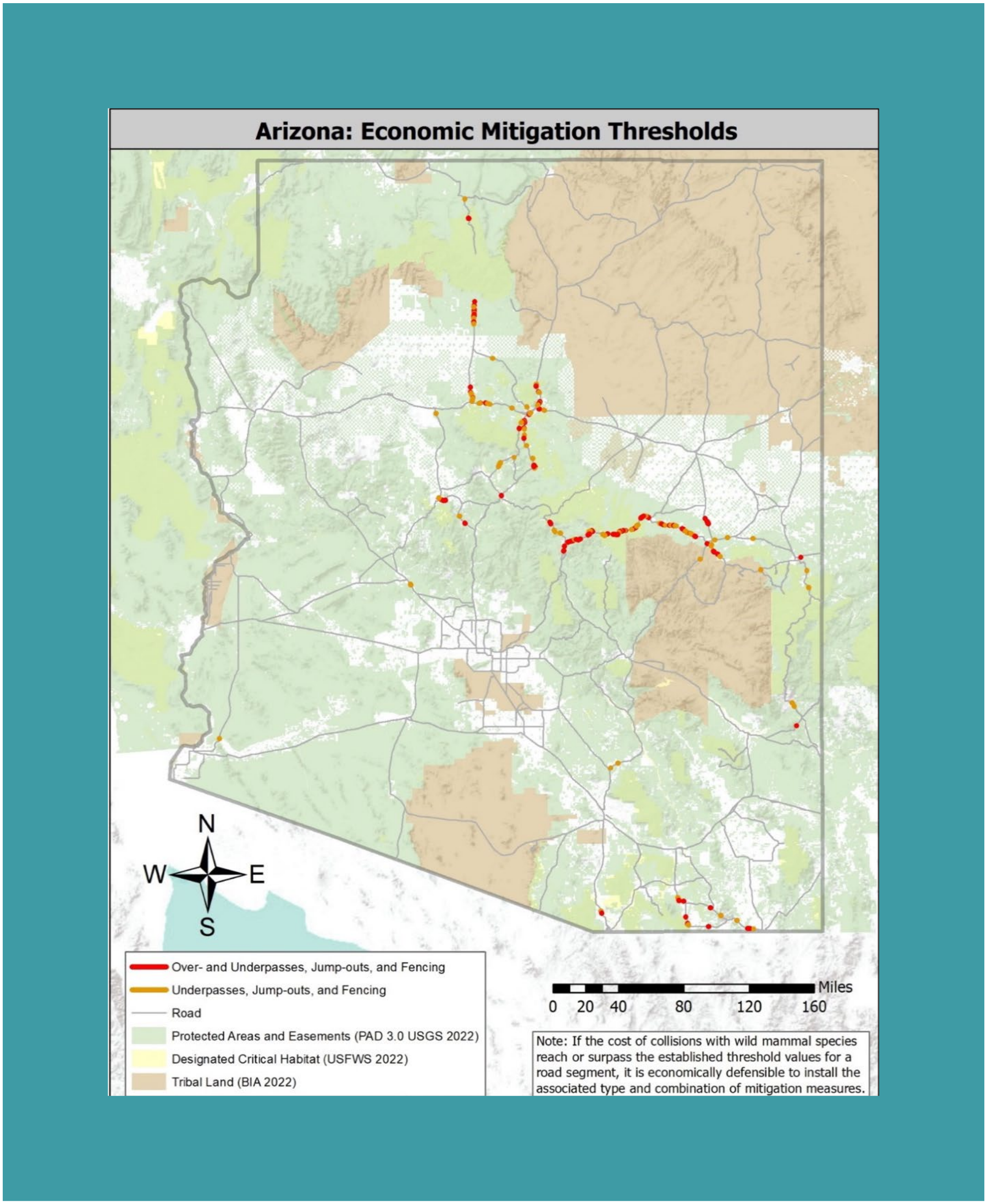

Figure 2. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

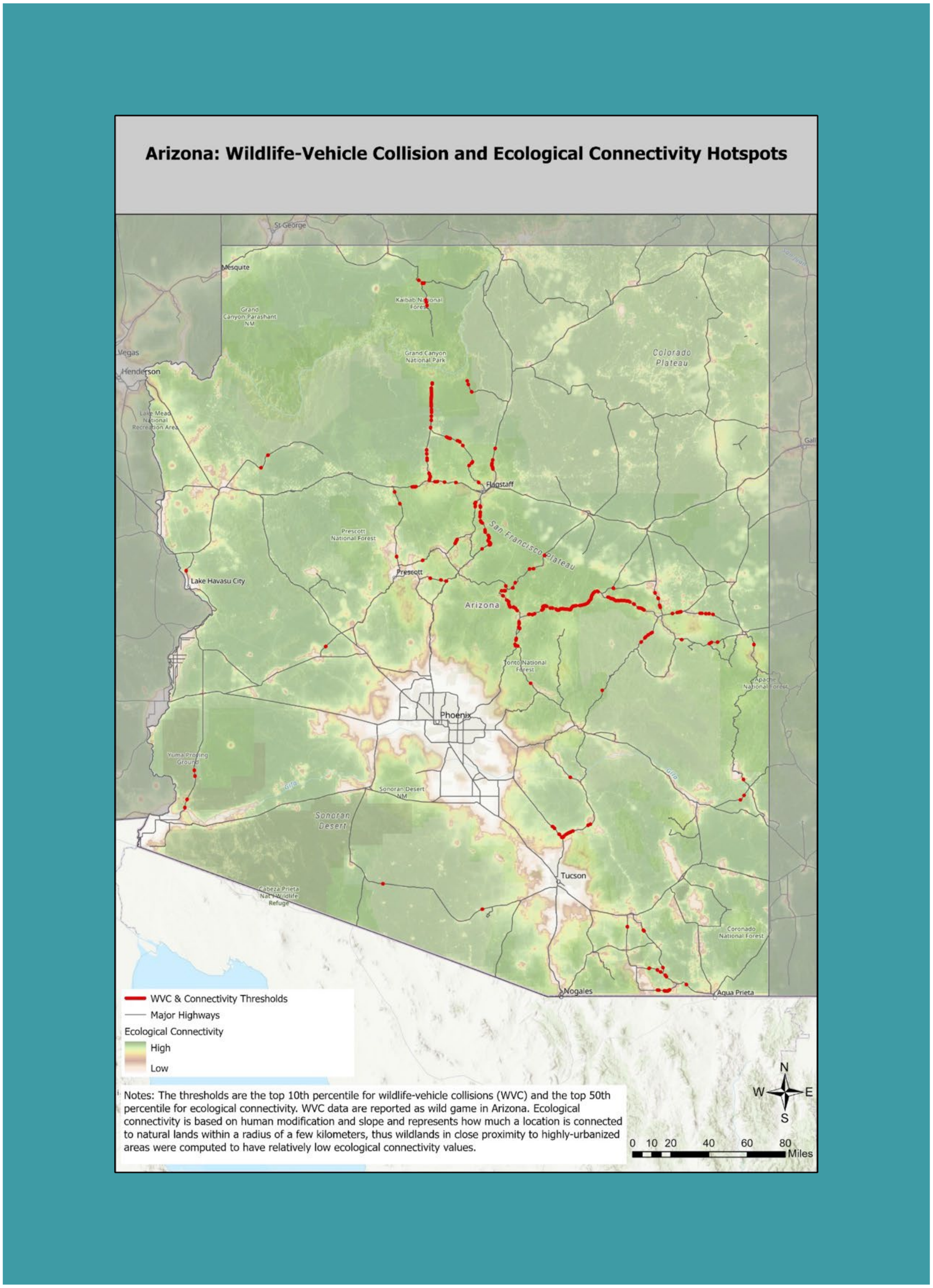

Figure 3. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

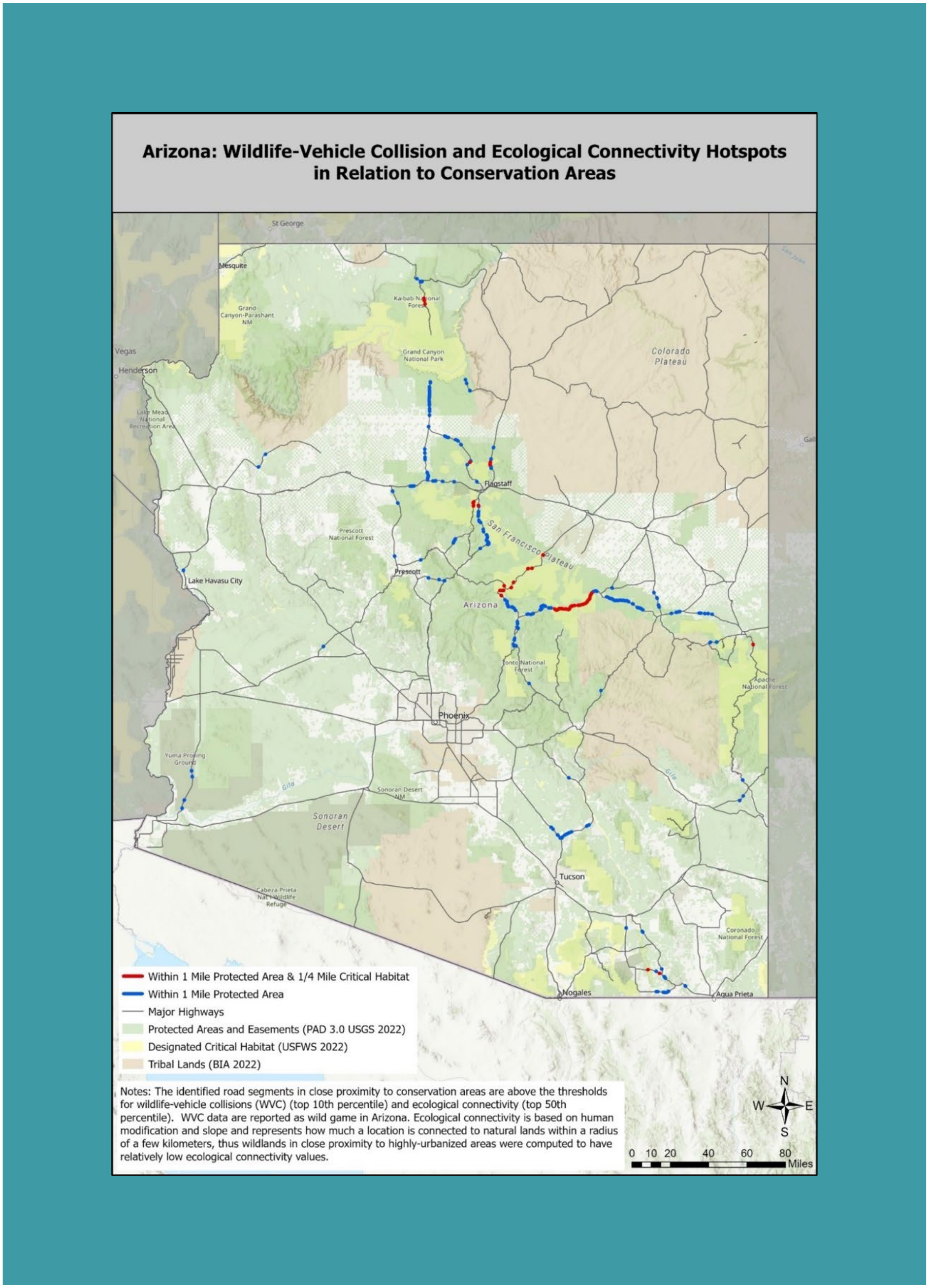

Figure 4. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

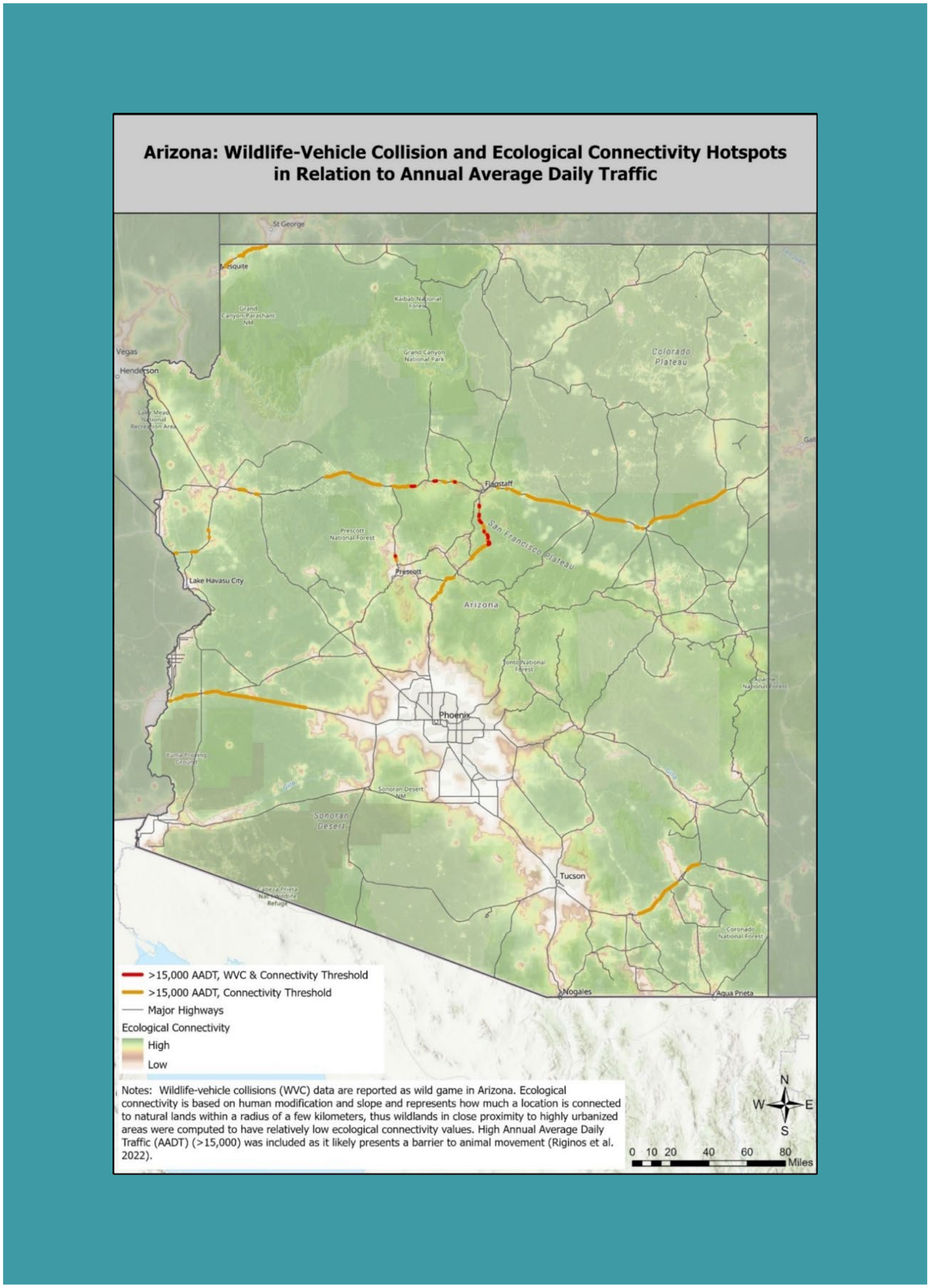

Figure 5. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

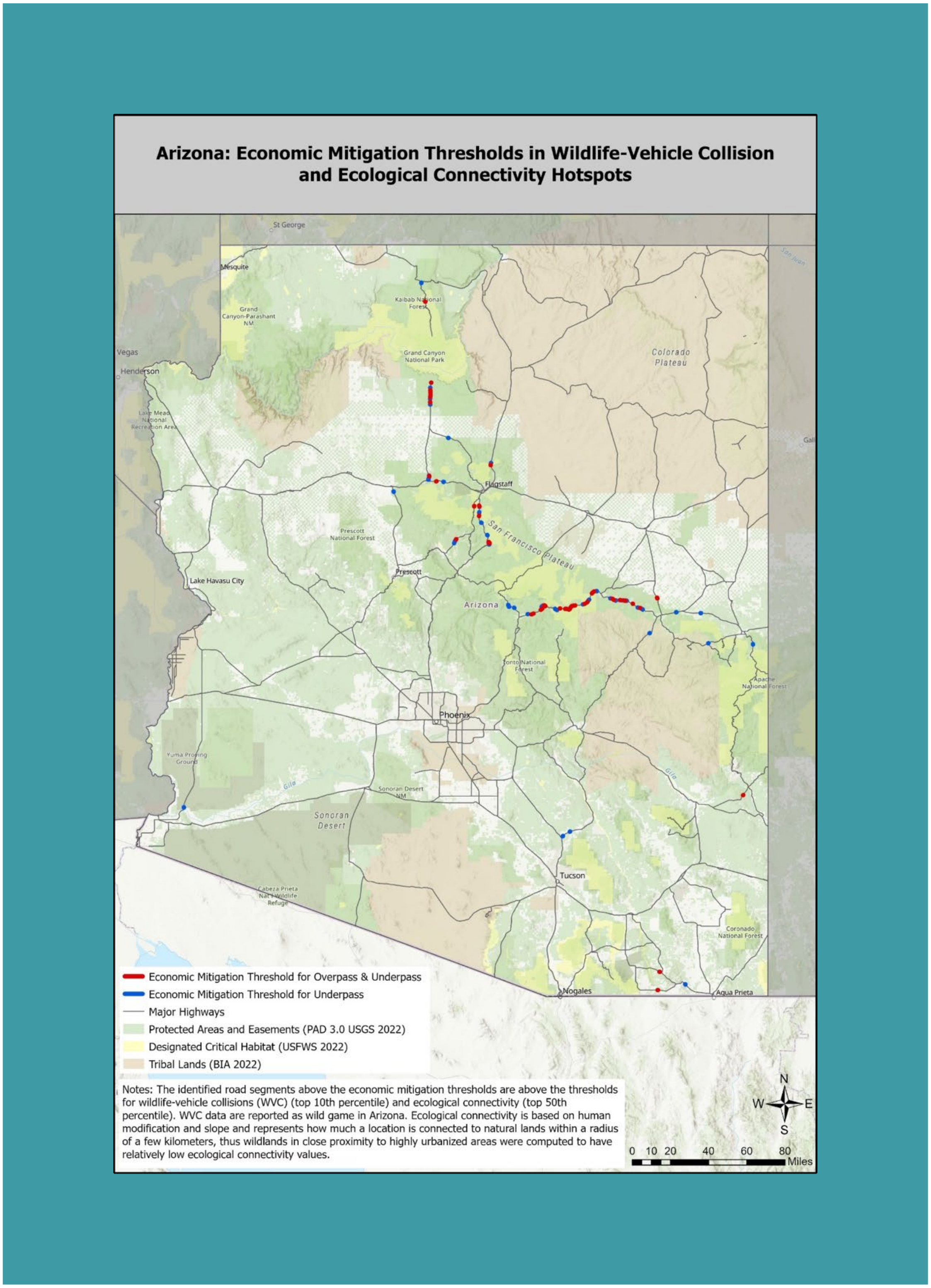

Figure 6. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

2. CALIFORNIA

2.1 Safety and Economics

There was a total of 6,892 reported collisions with deer over 10 years (2005-2014) in California (Table 4 of report). Deer-vehicle collisions (DVC) were the only crash data provided by the California Department of Transportation (Caltrans). For that reason, the results for California are underestimated because they do not include any other large species that are commonly hit along the roadway. The reported DVC crash data shows that crash rates ranged from 0 to 4.58 DVC/mi/yr (Table 7 of report). Only 3.6% of the road segments had identified DVC rates (> zero DVCs), with all other segments having no reported collisions. The top 10^{th} percentile of these identified segments has 1.07 DVC/mi/yr or greater (Table 8 of report, Figure 7).

Based on costs and number of collisions, California's average cost of DVCs per year is $67,243,699 (Table 9 of report). Across the state and without consideration of connectivity thresholds (see below), there are 38 road segments (7 mi) where underpasses (with fencing with apron, and jump-outs) are most cost-effective, and 21 segments (4 mi) where under- and overpasses (with fencing with apron, and jump-outs) are most cost-effective and should be considered from an economic perspective alone, when only investigating DVCs (Table 9, Figure 8).

2.2 Collisions and Connectivity

California's road segment lengths were on average 0.19 mi in length (Table 3 of report). There are 540 road segments (totaling 105 mi) within the top 10^{th} percentile for WVC and 74,773 road segments (14,506 mi) within the top 50^{th} percentile for connectivity (Table 1). There are 352 road segments, totaling 68 mi, that exceed both the WVC and connectivity thresholds (called CC road segments) (Table 1, Figure 9).

2.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 352 (68 mi) CC road segments, 284 (55 mi) are within one mile of a protected area, 62 (12 mi) are within a quarter mile of critical habitat, and 59 (11 mi) are near both protected areas and critical habitat (Table 1, Figure 10).

2.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 1,024 road segments (199 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 11). Of the CC road segments, 9 (2 mi) experience high traffic volume (AADT ≥ 15,000 vehicles per day).

2.5 Collisions, Connectivity, and Costs

Of the CC road segments, 34 (7 mi) meet the economic mitigation threshold for where underpasses (with fencing with an apron and jump-outs) are cost-effective and 10 road segments (2 mi) meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Table 1, Figure 12).

2.6 Other Resources to Examine

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Krause, C., M. Gogol-Prokurat, and S. Bisrat. 2015. Wildlife connectivity across the northern Sierra Nevada foothills. Technical report to the California Wildlife Conservation Board. Prepared by CDFW's Biogeographic Data Branch Conservation Analysis Unit. https://conservationcorridor.org/cpb/Krause_et_al_2015.pdf

Penrod, K., P. Beier, E. Garding, and C. Cabañero. 2012. A Linkage Network for the California Deserts. Produced for the Bureau of Land Management and The Wildlands Conservancy. Produced by Science and Collaboration for Connected Wildlands and Northern Arizona University, Flagstaff, Arizona http://www.scwildlands.org/reports/ALinkageNetworkForTheCaliforniaDeserts.pdf

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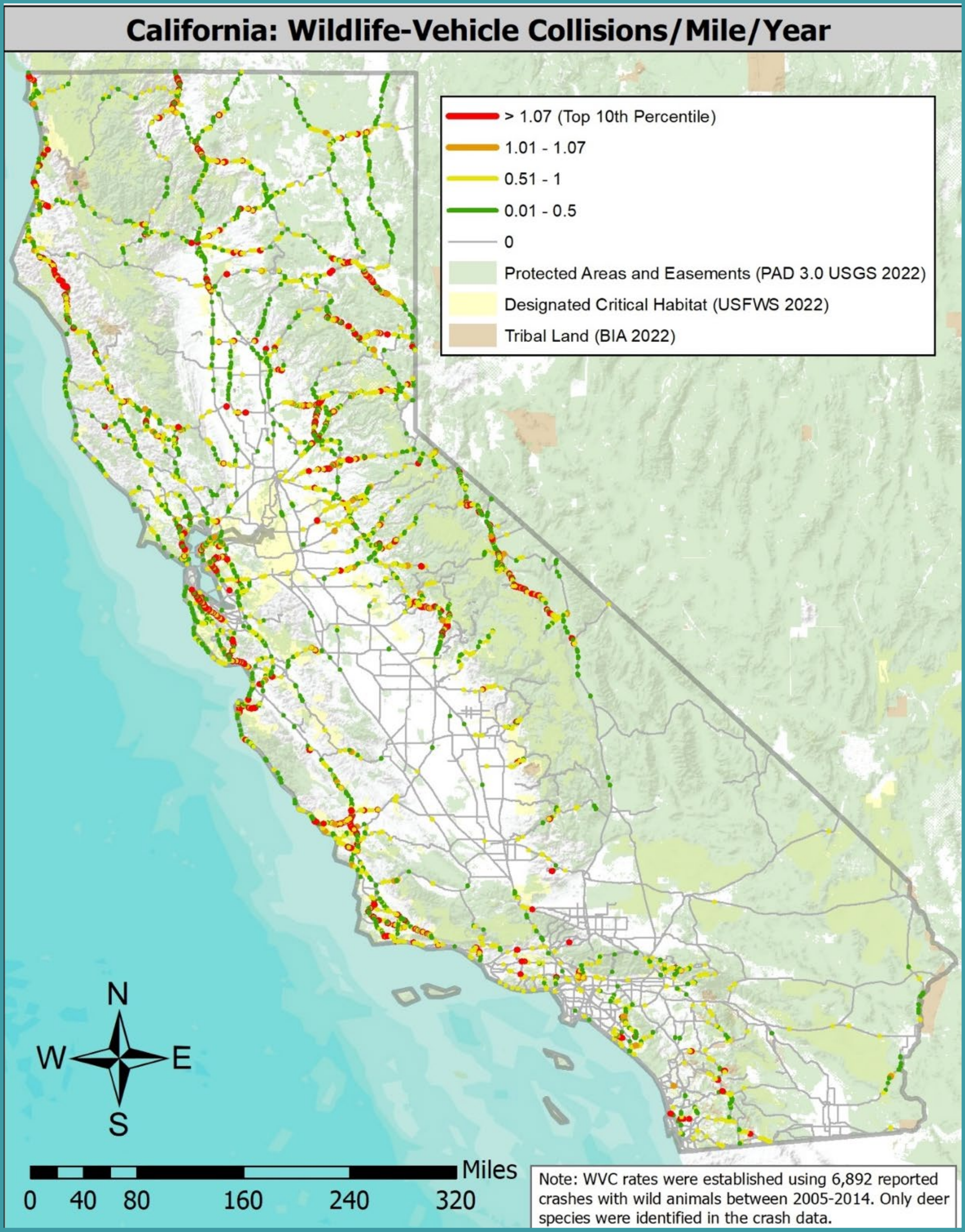

Figure 7. Average DVC rates for California between 2005-2014

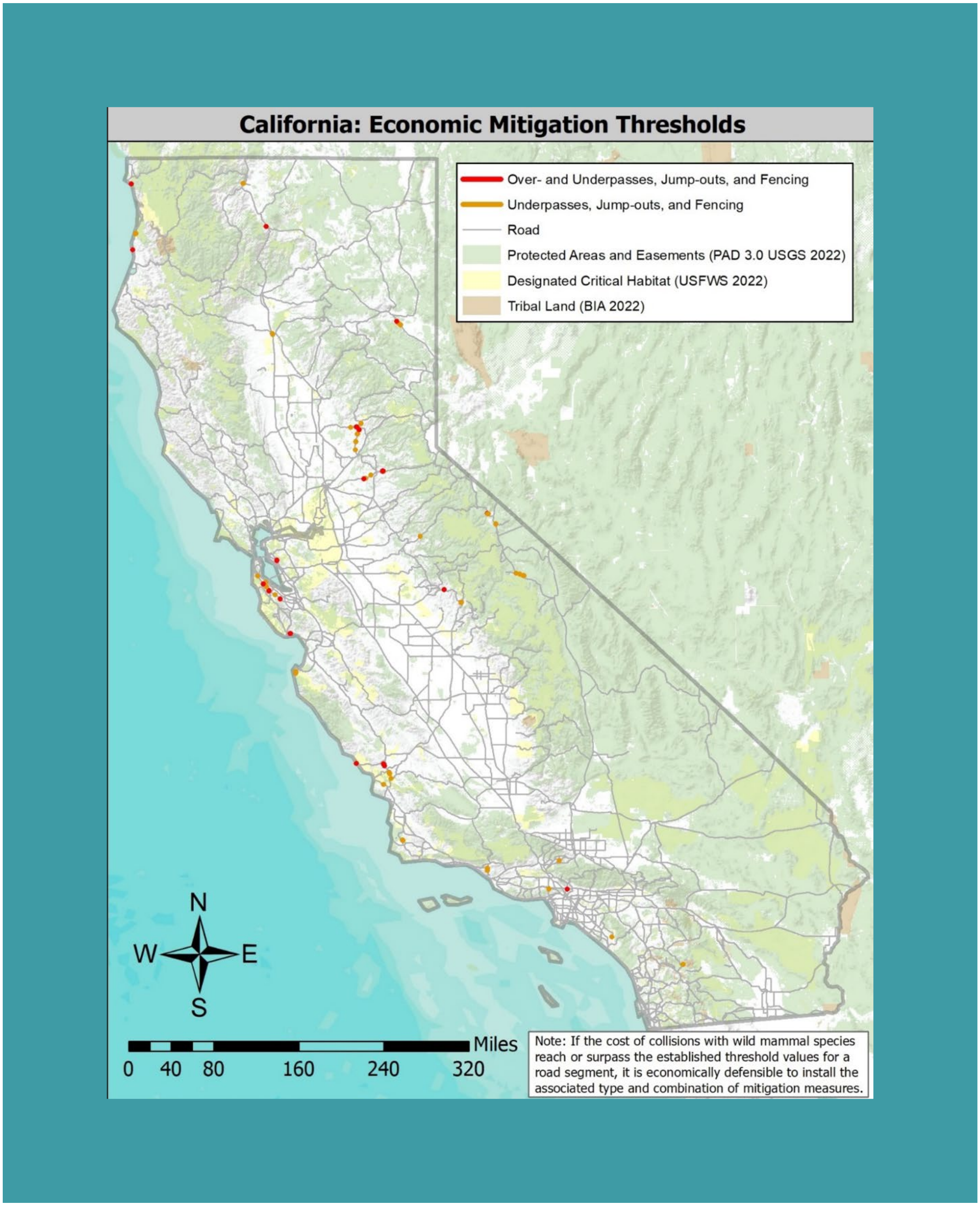

Figure 8. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

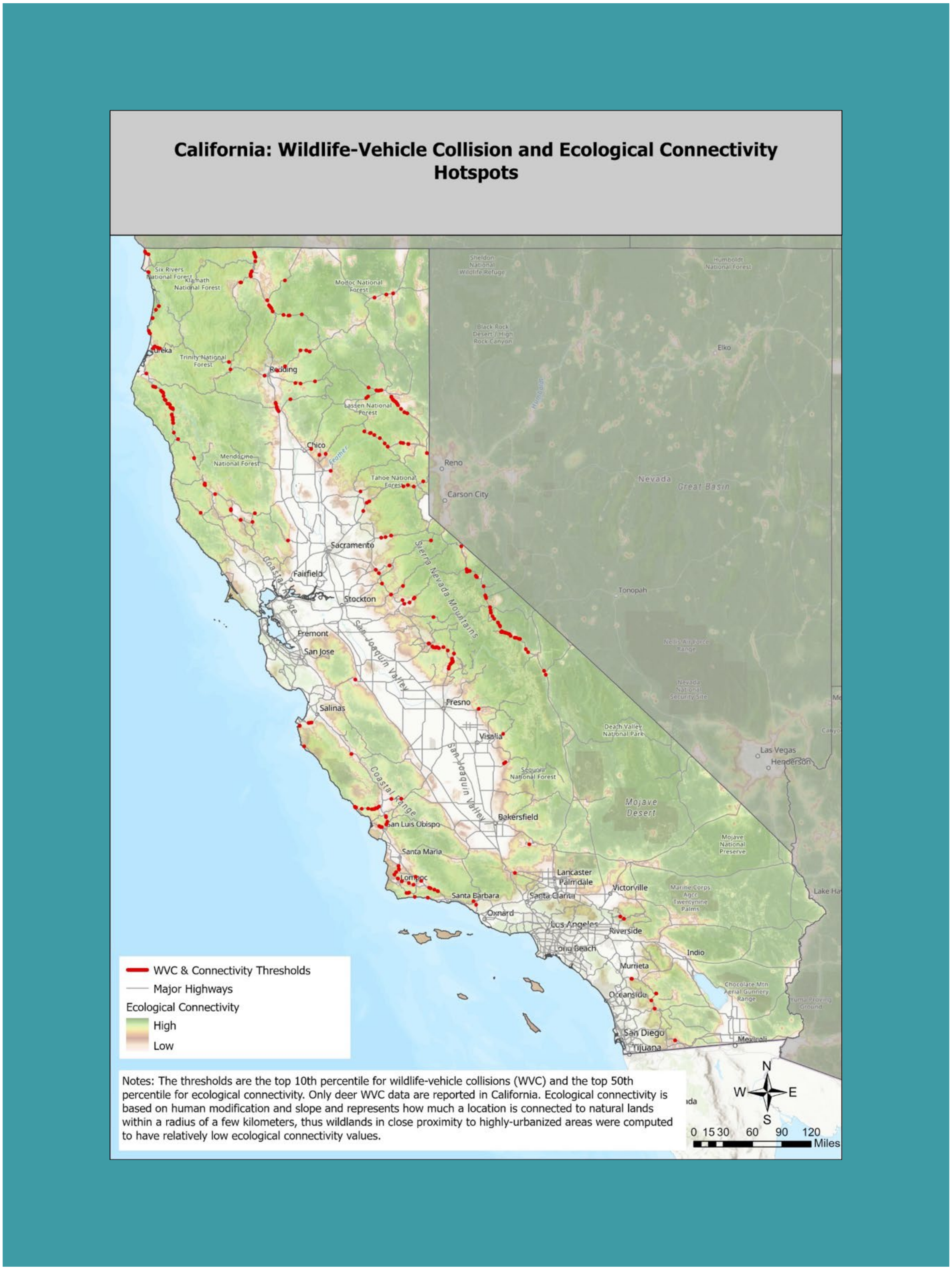

Figure 9. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

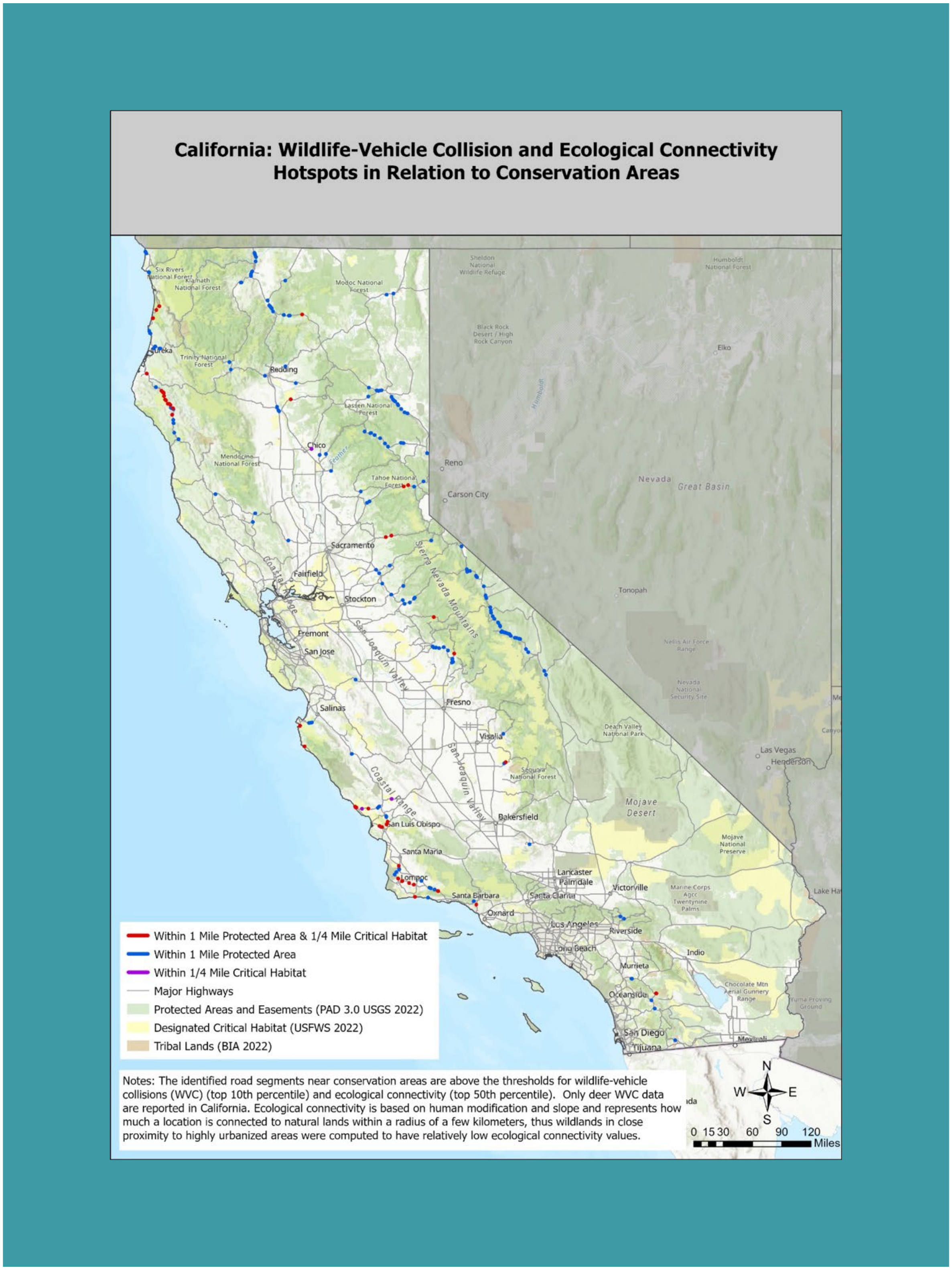

Figure 10. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

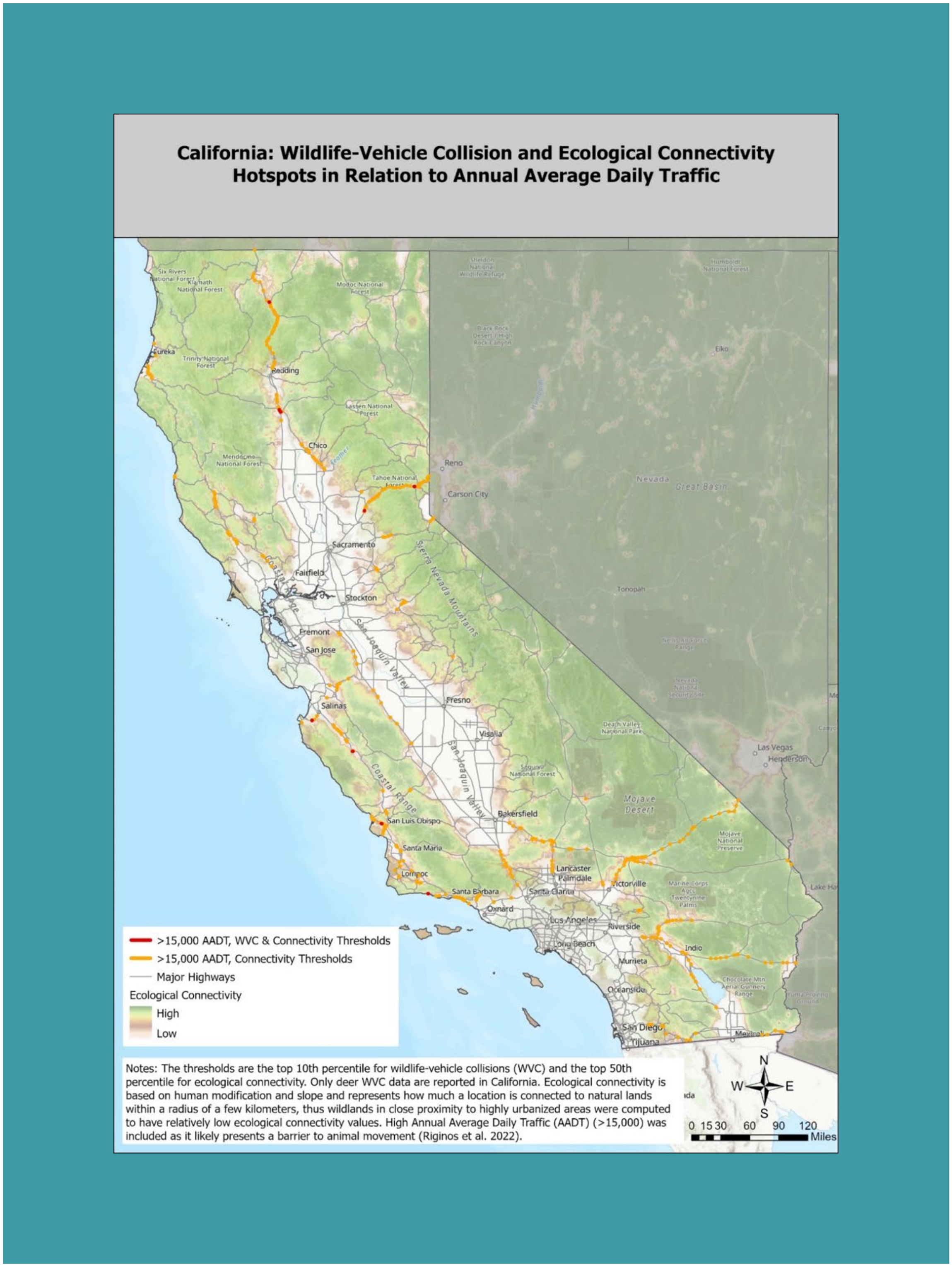

Figure 11. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

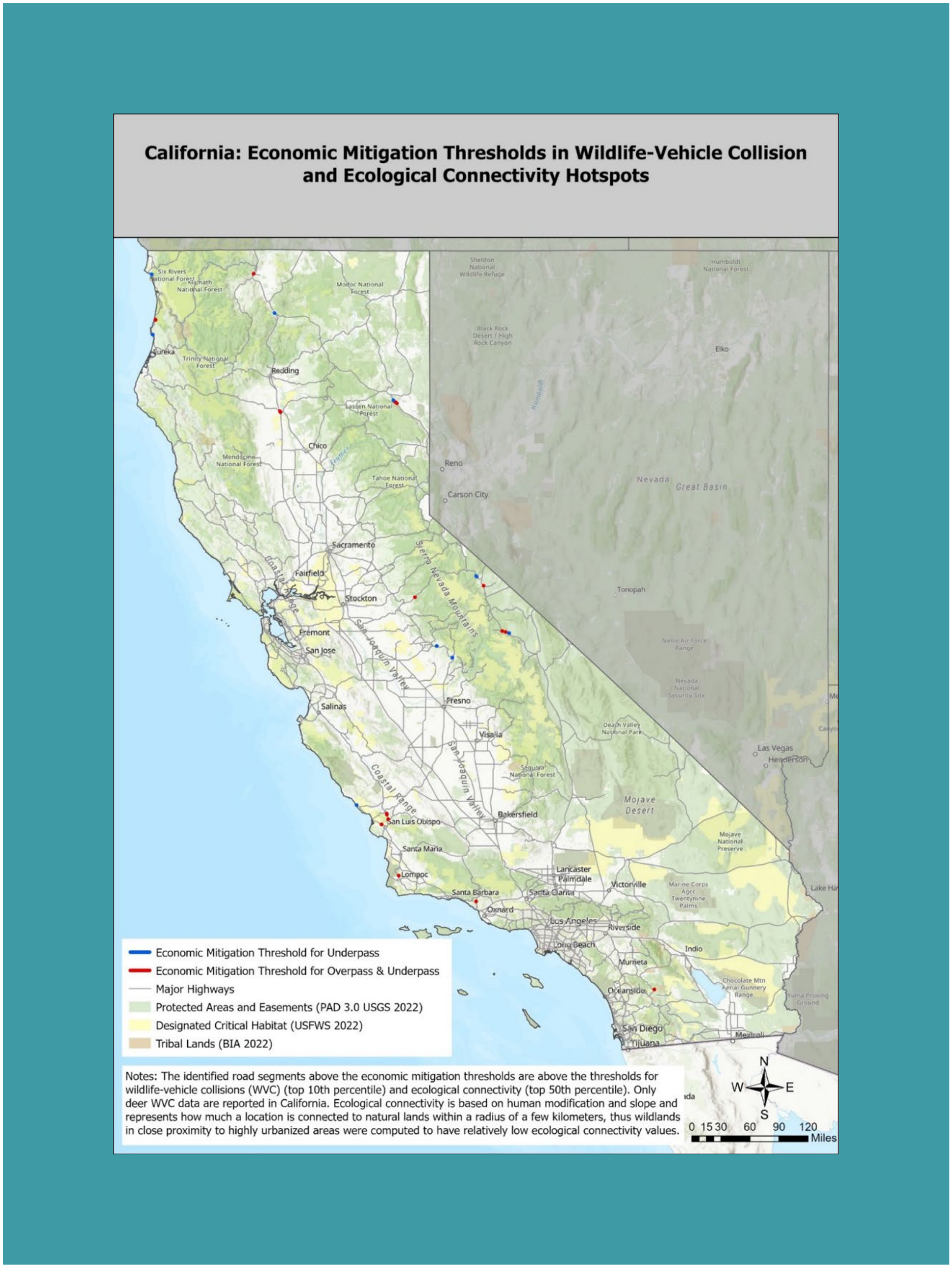

Figure 12. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

3. COLORADO

3.1 Safety and Economics

There was a total of 18,559 reported collisions with large wildlife over 6 years (2013-2018) in Colorado (Table 4 of report). These collisions consisted of 15,885 with deer, 2,070 with elk, 128 with moose, 112 with antelope, and 284 with bear. The remaining 80 WVC locations were unidentified large wildlife. The reported WVC crash data shows that crash rates ranged from 0 to 24.7 WVC/mi/yr (Table 7 of report). There are 21.4% of the road segments that have an identified WVC rate (> zero WVCs), and the top 10th percentile of these identified segments has 2.05 WVC/mi/yr and higher (Table 8 of report, Figure 13).

Based on costs and number of collisions, Colorado's average cost of WVCs per year is $254, 889,399 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 711 segments (218 mi) where underpasses (with fencing with apron, and jump-outs) are most cost-effective, and 1,124 segments (344 mi) where under- and overpasses, (with fencing with apron, and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 14).

3.2 Collisions and Connectivity

Colorado's road segment lengths were on average 0.36 mi in length (Table 3 of report). There are 983 road segments (301 mi) within the top 10th percentile for WVC and 22,939 road segments (7,019 mi) within the top 50th percentile for connectivity (Table 1). There are 391 road segments (120 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 15).

3.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the CC road segments, 361 (110 mi) are within one mile of a protected area, 35 (11 mi) are within a quarter mile of critical habitat, and 34 segments (10 mi) near critical habitat are also within one mile to a protected area (Table 1, Figure 16).

3.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 1,414 road segments (433 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 17). Of the 391 (120 mi) CC road segments, 67 (21 mi) experience high traffic volume (AADT≥ 15,000 vehicles per day).

3.5 Collisions, Connectivity, and Costs

Of the CC road segments, 368 (113 mi) meet the economic mitigation threshold where underpasses (with fencing with an apron and jump-outs) are cost-effective and there are 258 road segments (79 mi) that meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Table 1, Figure 18).

3.6 Other Resources to Examine

Cooley, C. P., A. Holland, M. Cowardin, M. Flenner, T. Balzer, J. Stiver, E. Slezak, B. Marette, D. Neumann, T. Elm and J. Holst. 2020. Status report: Big game winter range and migration corridors. Colorado Parks and Wildlife. https://cpw.state.co.us/Documents/Hunting/BigGame/2020BigGameWinterRangeandMigrationCorridorsReport.pdf

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Crooks, K.R, D.M. Theobald, S. Baruch-Mordo, M. Sherburne, J. Norman, and K. Wilson. 2006. Highway corridor wildlife mitigation/habitat connectivity study - Phase I report: Biological prioritization of highway segments in Colorado based on landscape connectivity. Colorado Department of Transportation. Final Report.

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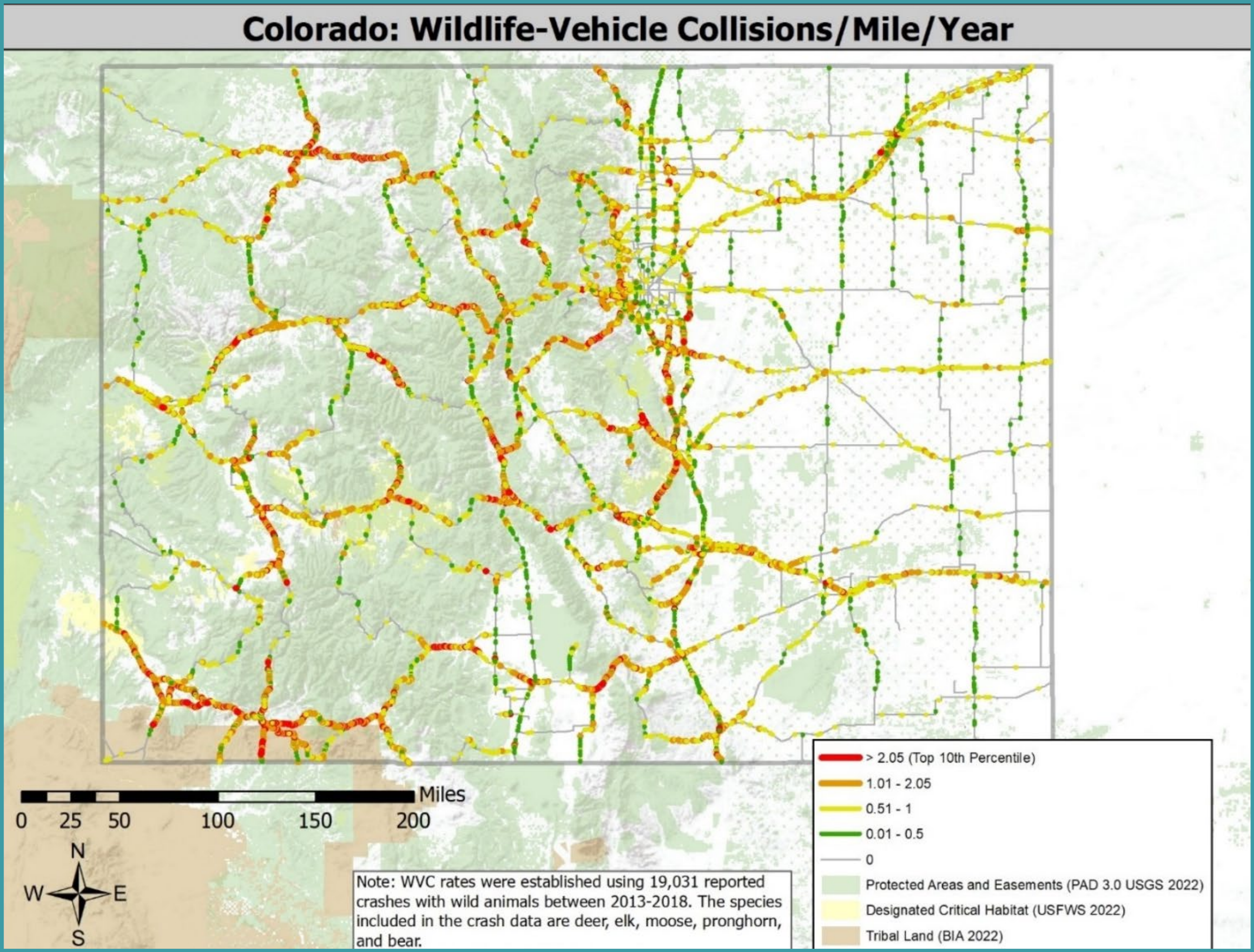

Figure 13. Average WVC rates for Colorado between 2013-2018.

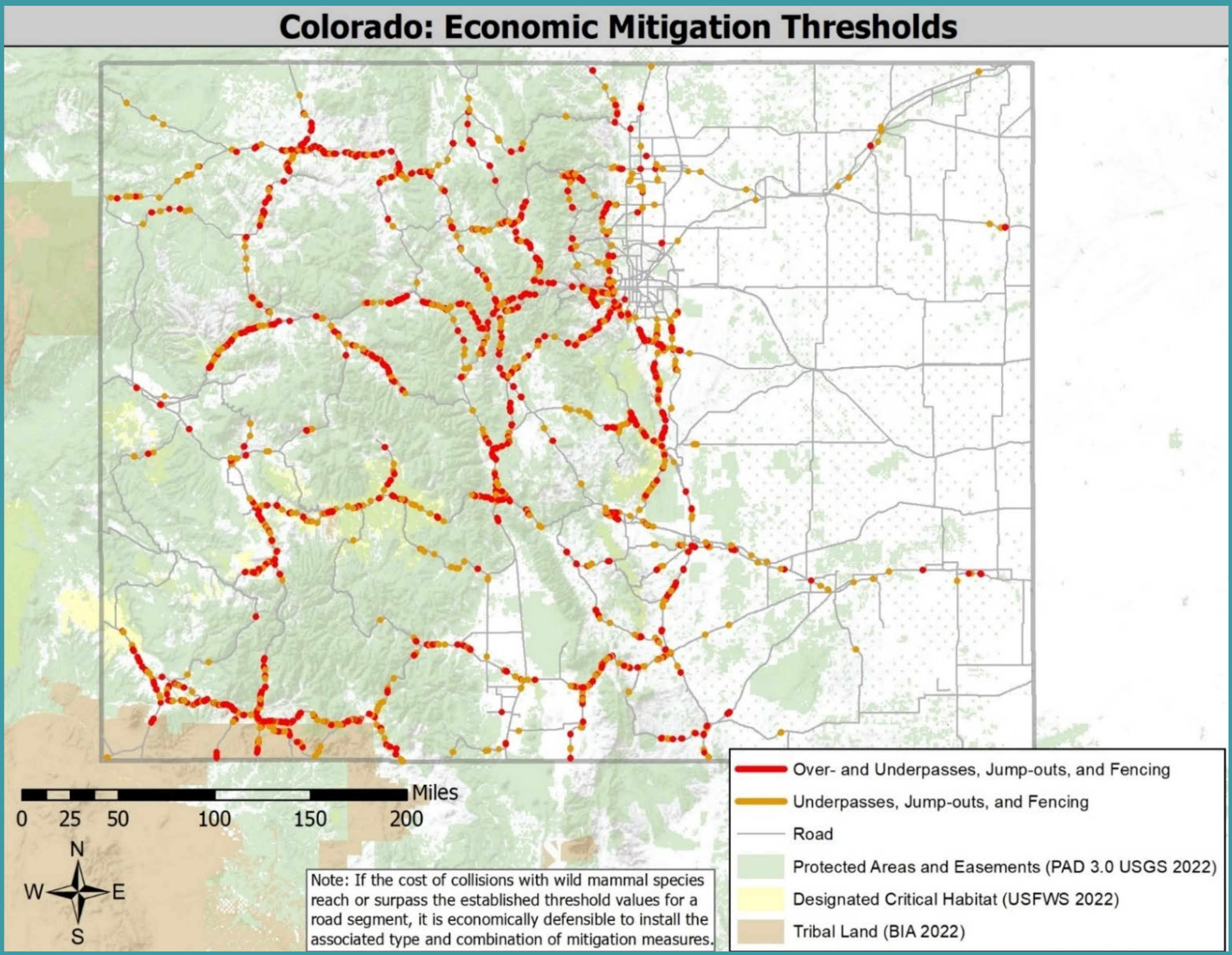

Figure 14. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

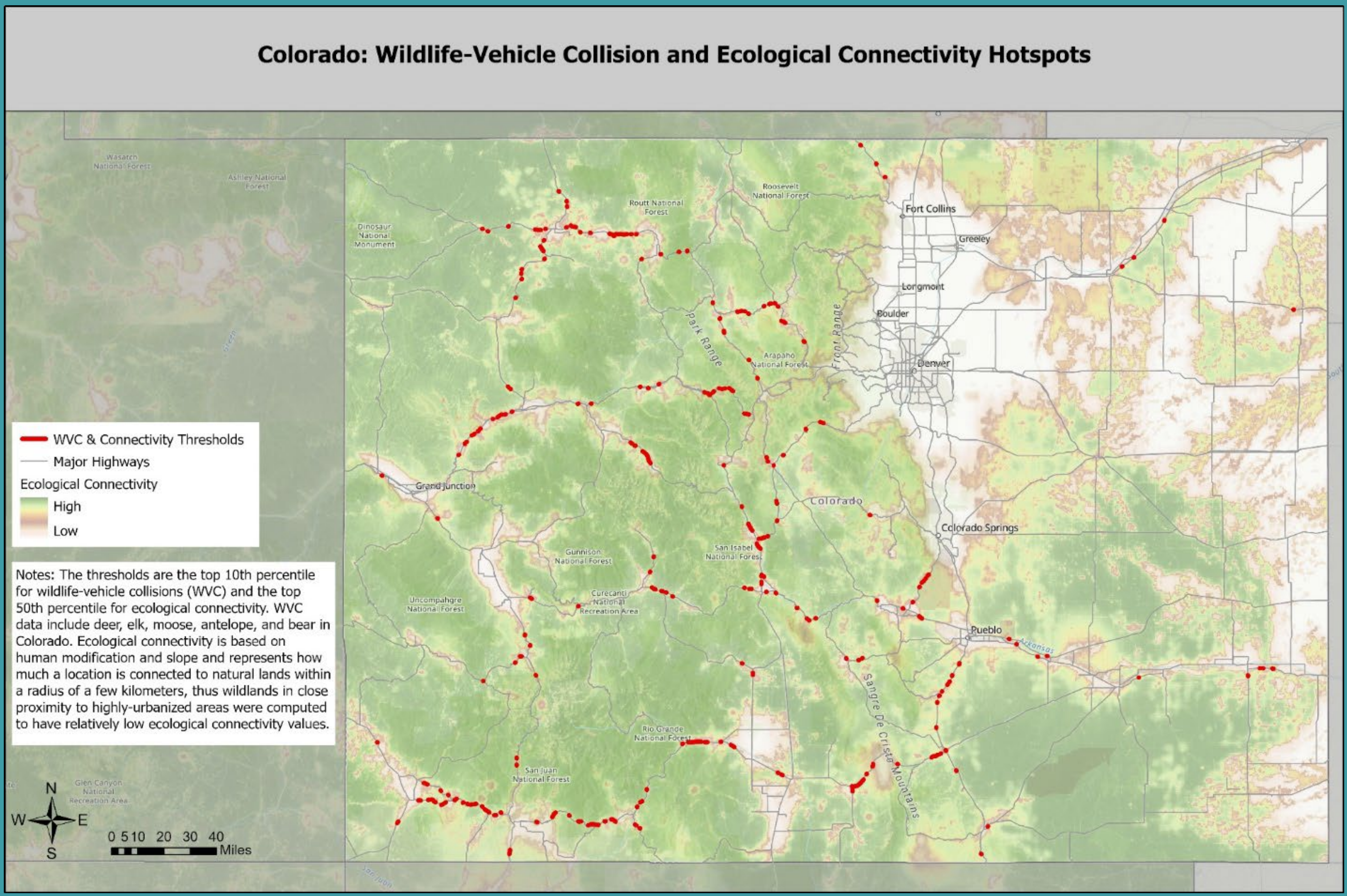

Figure 15. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

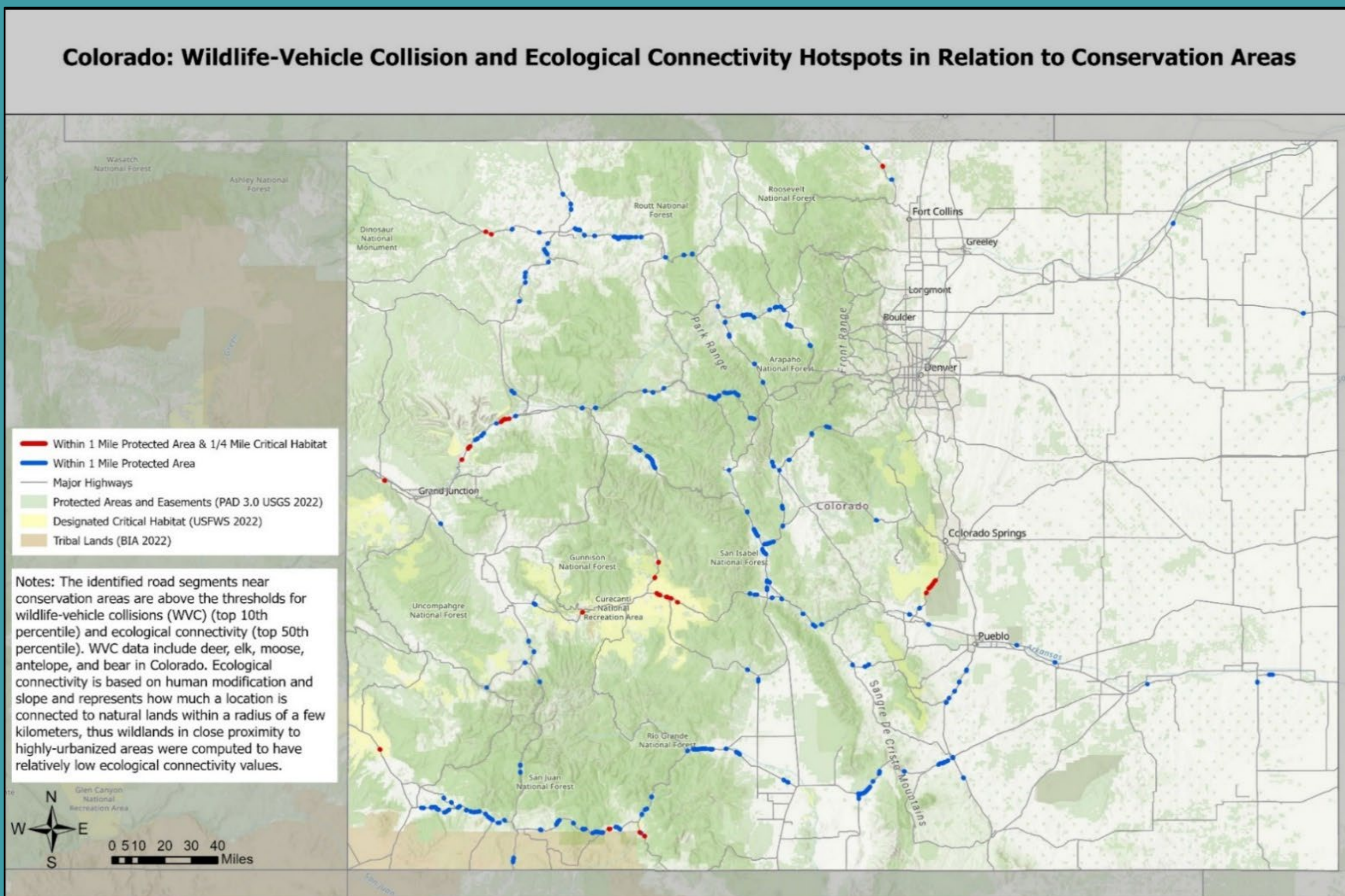

Figure 16. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

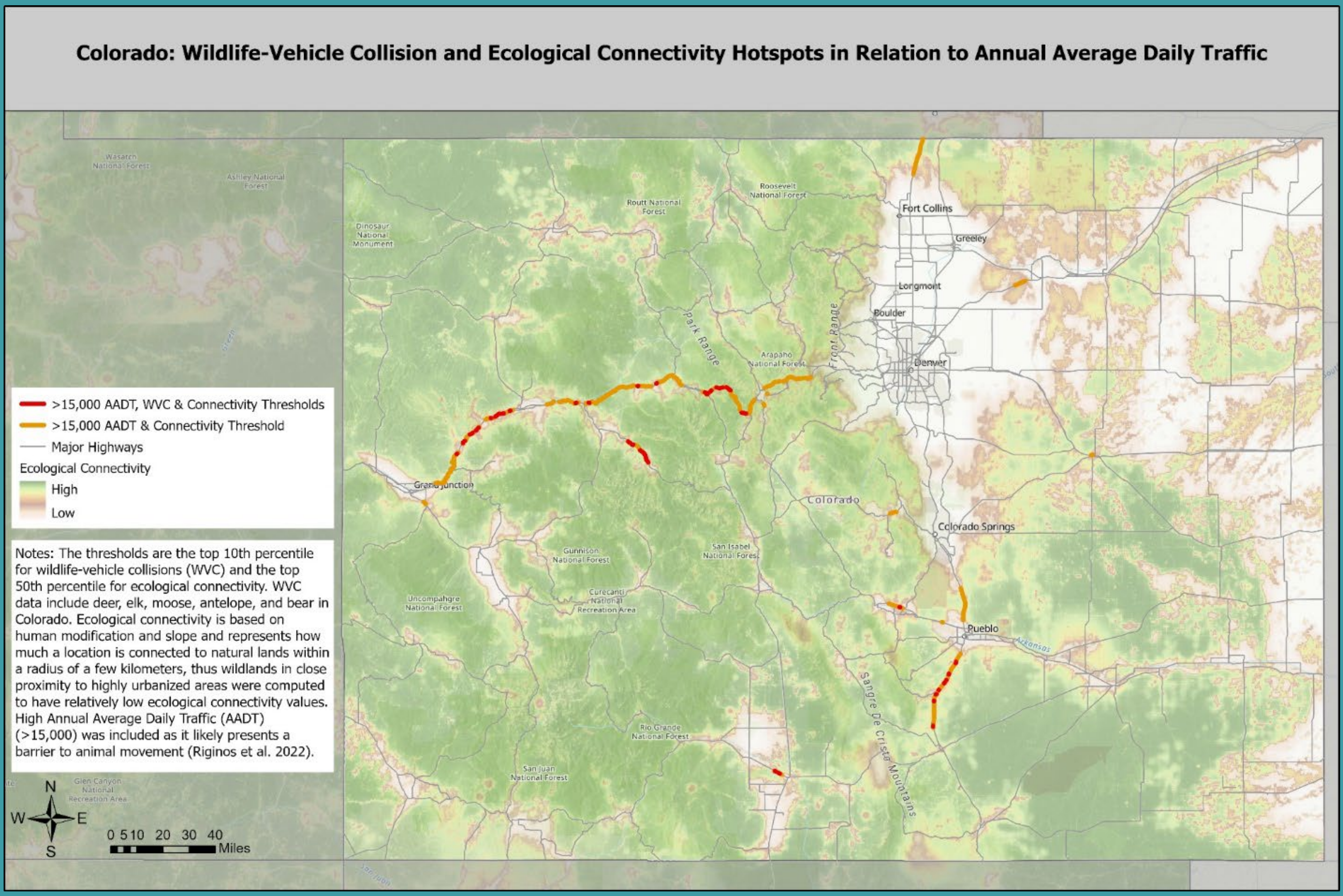

Figure 17. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

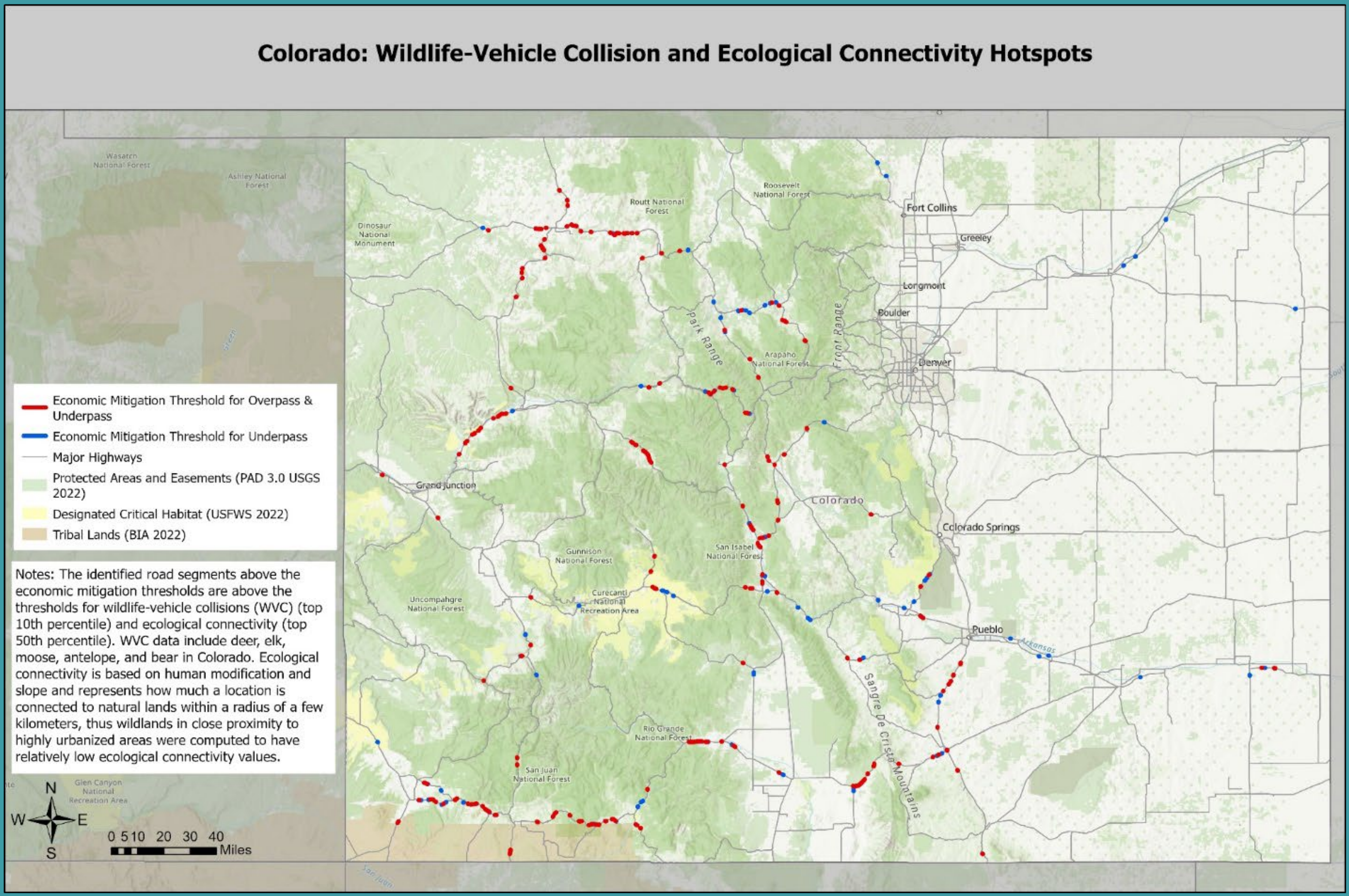

Figure 18. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

4. IDAHO

4.1 Safety and Economics

There was a total of 12,635 reported collisions with large wildlife over 12 years (2009-2020) in Idaho (Table 4 of report). The reported WVC crash data shows that crash rates ranged from 0 to 7.03 WVC/mi/yr (Table 7 of report). There are 15.2% of the road segments that have an identified WVC rate (> zero WVCs), and the top 10th percentile of the identified segments has 1.41 WVC/mi/yr and higher (Table 8 of report, Figure 19).

Based on costs and number of collisions, Idaho's average cost of WVCs per year is $143,697,736 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 136 segments (19 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective and 135 segments (19 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 20).

4.2 Collisions and Connectivity

Idaho's road segment lengths were on average 0.14 mi in length (Table 3 of report). There are 884 road segments (121 mi) within the top 10th percentile for WVC and 29,091 road segments (3,985 mi) within the top 50th percentile for connectivity (Table 1). There are 331 road segments (45 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 21Figure 21).

4.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the CC road segments, 279 (38 mi) are within one mile of a protected area, 23 (3 mi) are within a quarter mile of critical habitat, and each of the 23 road segments (3 mi) near critical habitat are also within one mile to a protected area (Table 1, Figure 22).

4.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 589 road segments (81 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 23). Of the CC road segments, 7 segments (1 mi) experience high traffic volume (AADT ≥ 15,000 vehicles per day).

4.5 Collisions, Connectivity, and Costs

Of the CC road segments, 85 (12 mi) meet the economic mitigation threshold where underpasses (with fencing with an apron and jump-outs) are cost-effective and 52 (7 mi) road segments meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Table 1, Figure 24).

4.6 Other Resources to Examine

Cramer P., S. Gifford, B. Crabb, C. McGinty, D. Ramsey, F. Shilling, J. Kintsch, S. Jacobson, and K. Gunson. 2014. Methodology for prioritizing appropriate mitigation actions to reduce wildlife-vehicle collisions on Idaho highways. Report for Idaho Transportation Department, Boise, Idaho. Report No. FHWA-ID-14-229. https://rosap.ntl.bts.gov/view/dot/28515

Cramer, P. 2016. Safety Solutions for Wildlife-Vehicle Collisions on Idaho's US 20 and SH 87. Report for Idaho Transportation Department, Boise, Idaho. https://static1.squarespace.com/static/60baf2ed8791194056e335f8/t/6311181585566f705cc3b917/1662064811927/ITD_Wildlife_Safety_Soltns_US20_SR87_FInal_Report_2017.pdf

Huijser, M.P., A.V. Kociolek, L. Oechsli and D. E. Galarus. 2008. Wildlife data collection and potential highway mitigation along State Highway 75, Blaine County, Idaho. Report 4W1403B, Western Transportation Institute – Montana State University, Bozeman, Montana, USA. https://www.mphetc.com/_files/ugd/9d46fb_519077b47ac74d6f9519b8d23a81eb25.pdf

McClure, M. L., and R.J. Ament. 2014. Where people and wildlife intersect: Prioritizing mitigation of road impacts on wildlife corridors. Center for Large Landscape Conservation, Bozeman, MT, USA. https://largelandscapes.org/wp-content/uploads/2019/06/Where-People-Wildlife-Intersect-Prioritizing-Mitigation.pdf

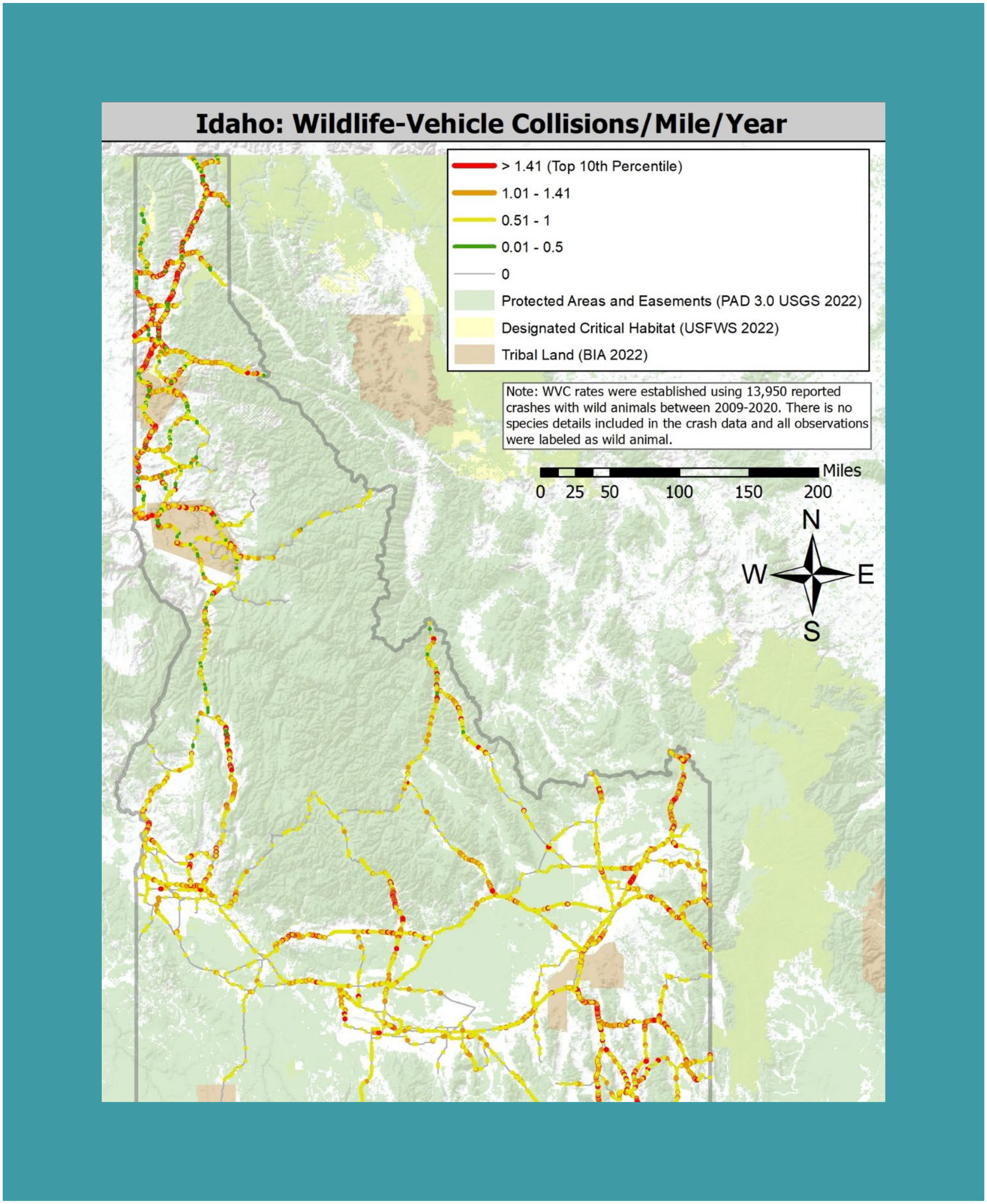

Figure 19. Average WVC rates for Idaho between 2009-2020.

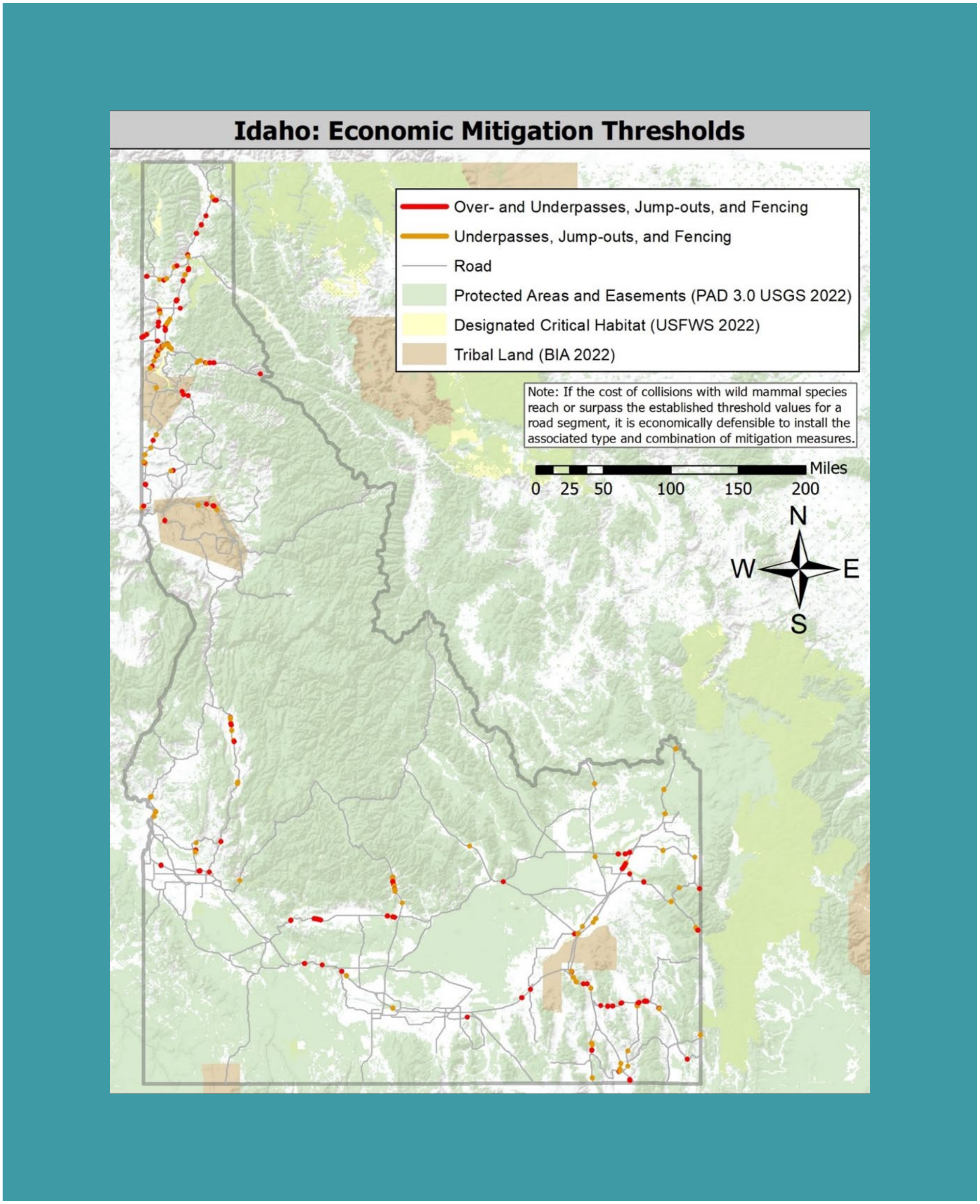

Figure 20. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

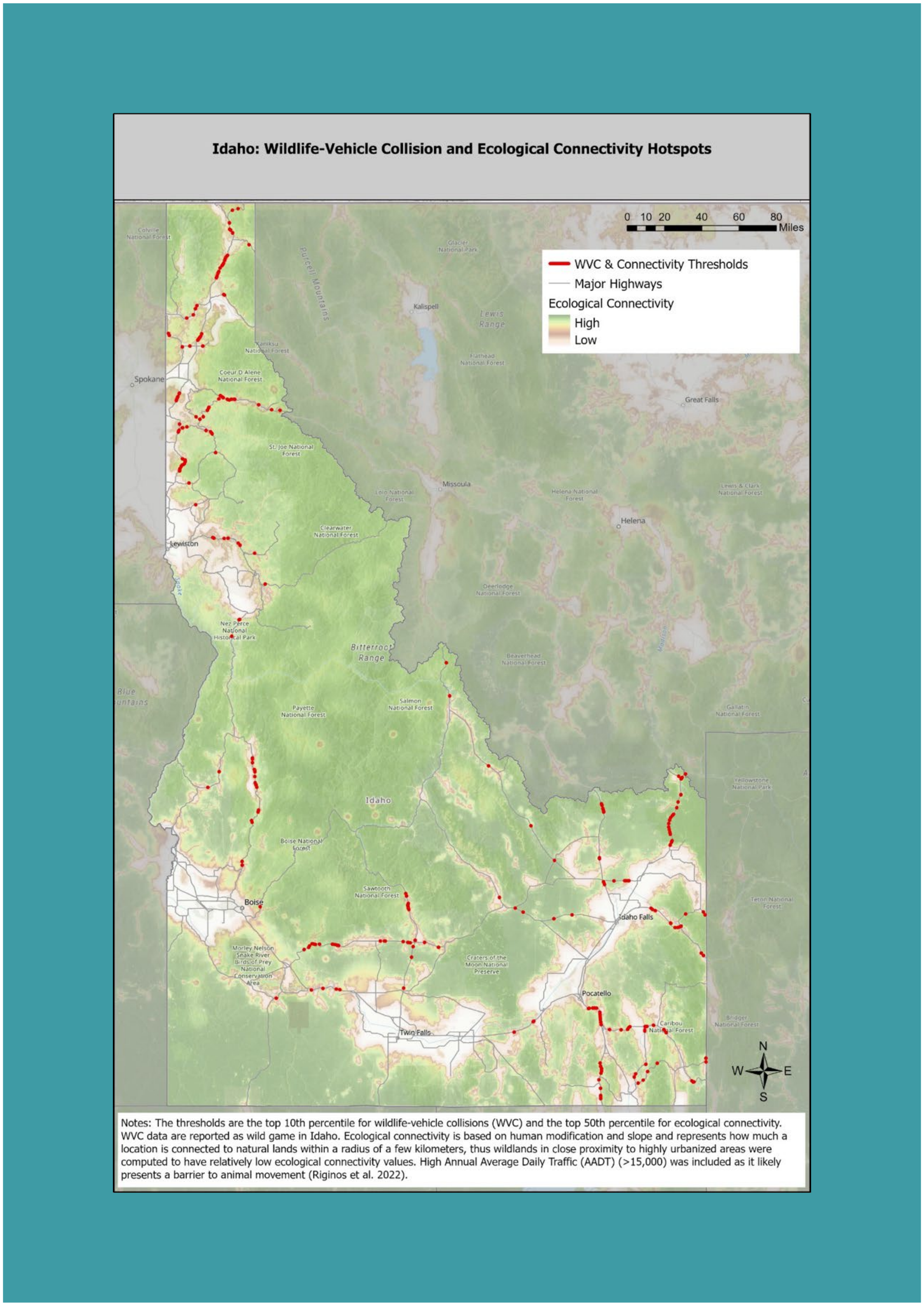

Figure 21. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

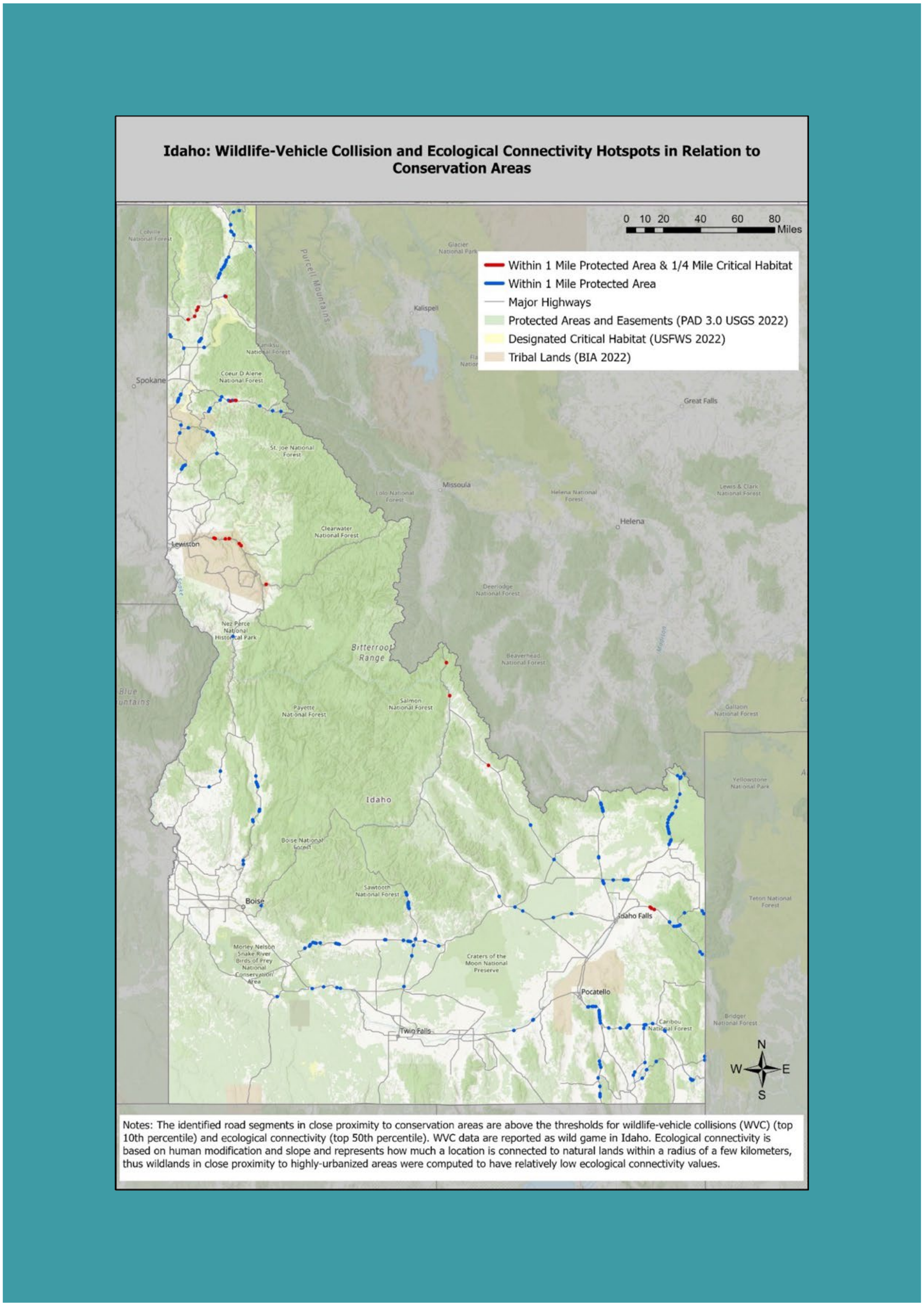

Figure 22. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

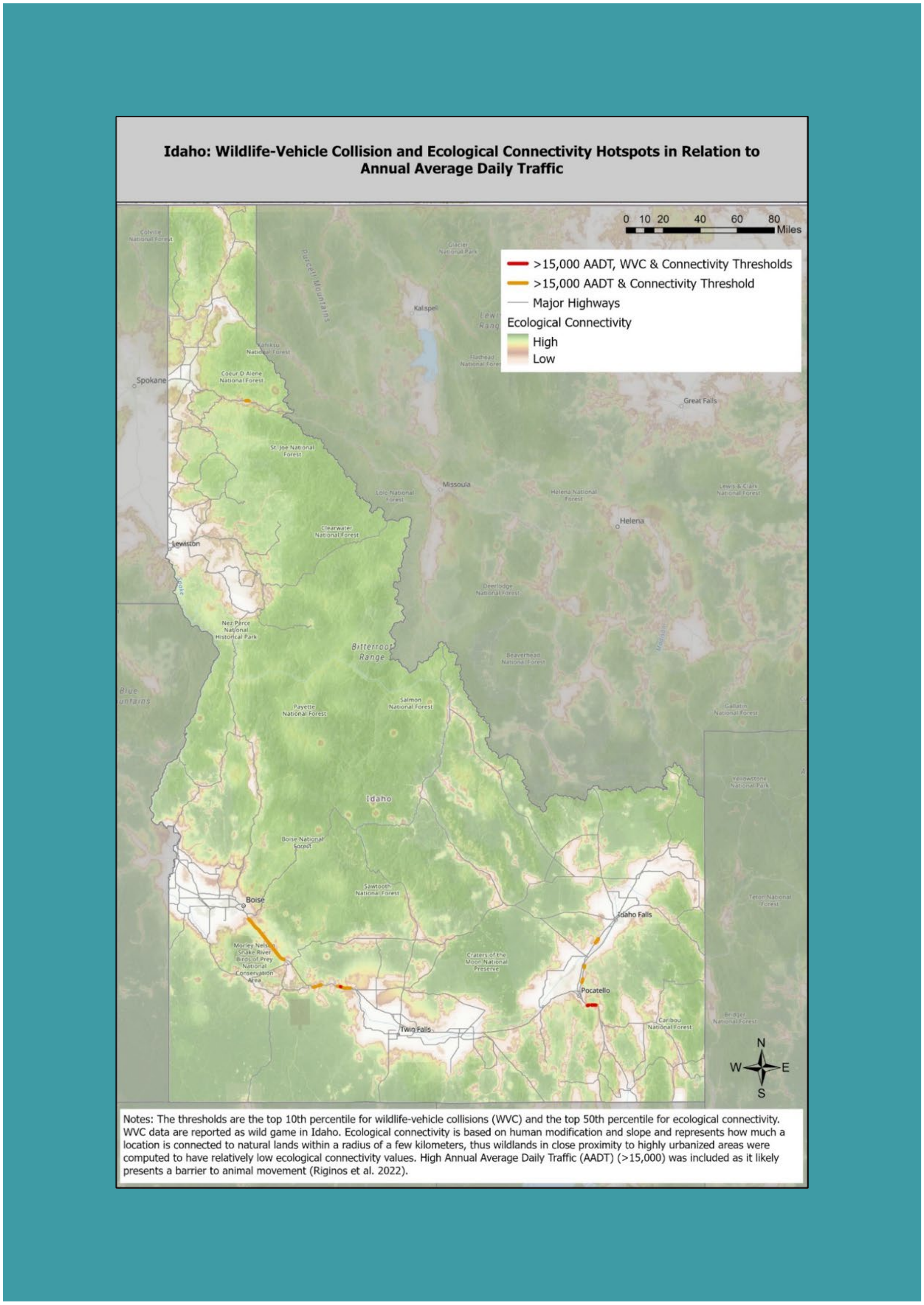

Figure 23. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

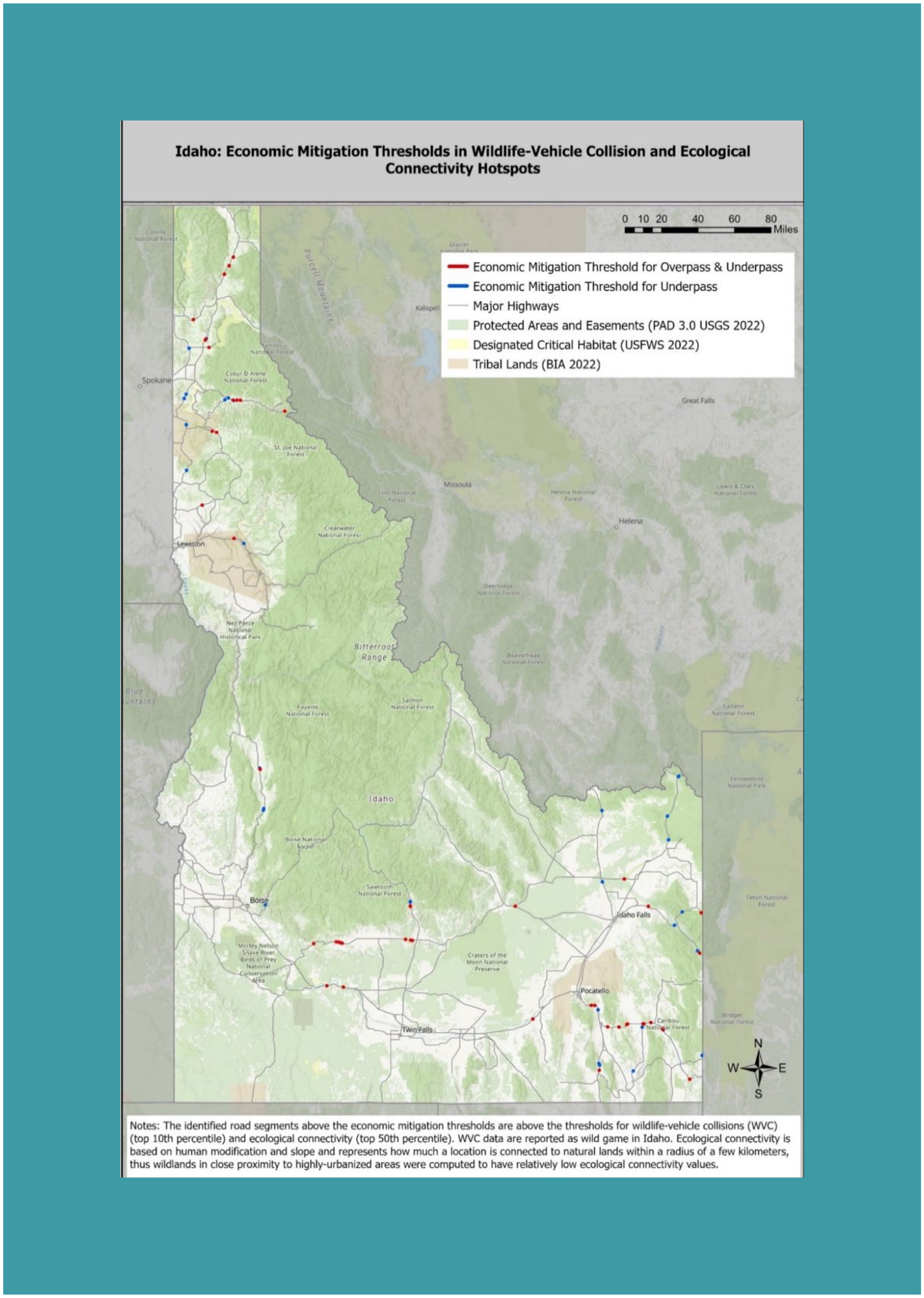

Figure 24. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

5. MONTANA

5.1 Safety and Economics

There was a total of 29,644 reported collisions with large wildlife over 13 years (2008-2020) in Montana (Table 4 of report). The reported WVC crash data shows that crash rates ranged from 0 to 8.53 WVC/km/yr (Table 7 of report). There are 27.3% of the road segments that have an identified WVC rate (> zero WVCs), and the top 10th percentile of the identified segments has 1.28 WVC/mi/yr and higher (Table 8 of report, Figure 25).

Based on costs and number of collisions, Montana's average cost of WVCs per year is $212,511,197 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there 277 segments (56 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective, and 200 segments (41 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 26).

5.2 Collisions and Connectivity

Montana's road segment lengths were on average 0.20 mi in length (Table 3 of report). There are 1,664 road segments (338 mi) within the top 10th percentile for WVC and 30,443 road segments (6,180 mi) within the top 50th percentile for connectivity (Table 1). There are 331 road segments (67 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 27).

5.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 331 (67 mi) CC road segments, 293 (59 mi) are within one mile of a protected area, 75 (15 mi) are within a quarter mile of critical habitat, and 71 (14 mi) are near both protected areas and critical habitat (Table 1, Figure 28).

5.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 45 road segments (9 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 29). Of the CC road segments, one segment experiences high traffic volume (AADT ≥ 15,000 vehicles per day).

5.5 Collisions, Connectivity, and Costs

Of the CC road segments, 38 (8 mi) meet the economic mitigation threshold where underpasses (with fencing with an apron and jump-outs) are cost-effective and 10 road segments (2 mi) meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Table 1, Figure 30).

5.6 Other Resources to Examine

Adams, P.J., M.P. Huijser and S.C. Getty. 2023. An assessment of existing and potential future mitigation measures related to grizzly bears along US Highway 93, Flathead Indian Reservation, Montana, USA. Confederated Salish and Kootenai Tribes, Pablo, Montana, USA. https://www.mphetc.com/_files/ugd/9d46fb_a2a83ae097794257bb23df021a51fca5.pdf

Ament, R., P. McGowen, M. McClure, A. Rutherford, C. Ellis and J. Grebenc. 2014. Highway mitigation for wildlife in northwest Montana. Sonoran Institute, Northern Rockies Office, Bozeman, MT. https://largelandscapes.org/wp-content/uploads/2019/06/Highway-Mitigation-Wildlife-NW-Montana_1.pdf

Craighead, L., A. Craighead, L. Oechsli, and A.V. Kociolek. 2010. Bozeman Pass post-fencing wildlife monitoring. No. FHWA/MT-10-006/8173. Montana. Dept. of Transportation. https://rosap.ntl.bts.gov/view/dot/20349

Cramer, P., and R. Hamlin. 2017. Evaluation of Wildlife Crossing Structures on US 93 in Montana's Bitterroot Valley. MDT # HWY – 308445-RP. Final Report to Montana Department of Transportation. www.mdt.mt.gov/research/projects/env/us93_wildlife.shtml

Creech, T., M. McClure, and R. Callahan. 2016. High-risk zones for ungulate-vehicle collisions during Montana's fall migration season. Center for Large Landscape Conservation, Bozeman, Montana, USA. https://largelandscapes.org/wp-content/uploads/2019/03/High-Risk-Zones-Ungulate-Vehicle-Collisions-Montana-Fall-Migration.pdf

Fairbank, E.R., A.R. Callahan, T. Creech, M.P. Huijser, and R. Ament. 2019. Blackfeet Nation animal-vehicle collision reduction master plan. Center for Large Landscape Conservation, Bozeman, MT, USA. https://largelandscapes.org/wp-content/uploads/2021/04/Blackfeet-Nation-Animal-Vehicle-Collision-Reduction-Master-Plan.pdf

Huijser, M.P., W. Camel-Means, E.R. Fairbank, J.P. Purdum, T.D.H. Allen, A.R. Hardy, J. Graham, J.S. Begley, P. Basting and D. Becker. 2016. US 93 North post-construction wildlife-vehicle collision and wildlife crossing monitoring on the Flathead Indian Reservation between Evaro and Polson, Montana. FHWA/MT-16-009/8208. Western Transportation Institute – Montana State University, Bozeman, Montana, USA. https://westerntransportationinstitute.org/wp-content/uploads/2018/04/4W2972_US93_PHASE_II_FINAL_REPORT_MDT_Cover.pdf

Huijser, M.P. and J.S. Begley. 2016. Wildlife Mitigation Opportunities along U.S. Hwy 2, Northwestern Montana. Western Transportation Institute – Montana State University, Bozeman, Montana, USA. https://westerntransportationinstitute.org/wp-content/uploads/2016/08/4W5362_final-report-hwy-2-mt-160112.pdf

Huijser, M.P., A. Kociolek, P. McGowen, A. Hardy, A.P. Clevenger and R. Ament. 2007. Wildlife-vehicle collision and crossing mitigation measures and associated costs and benefits: A toolbox for the Montana Department of Transportation. FHWA/MT-07-002/8117-34. Western Transportation Institute – Montana State University, Bozeman, Montana, USA. westerntransportationinstitute.org/wp-content/uploads/2016/08/4W1357_Final_Report.pdf

Huijser, M. P., K.E. Gunson, and C. Abrams. 2006. Animal-vehicle collisions and habitat connectivity along Montana Highway 83 in the Seeley-Swan Valley, Montana: a Reconnaissance. No. FHWA/MT-06-002/8177. Western Transportation Institute – Montana State University, Bozeman, Montana, USA. https://westerntransportationinstitute.org/wp-content/uploads/2016/08/425569_Final_Report.pdf

Kociolek, A., L. Craighead, A. Craighead, and B. Brock. 2016. Evaluating wildlife mortality hotspots, habitat connectivity and potential accommodation along US 287 and MT 87 in the Madison Valley, Montana. No. Project Summary Report 8217-001. Montana Department of Transportation. https://rosap.ntl.bts.gov/view/dot/31845

McClure, M. L., and R.J. Ament. 2014. Where people and wildlife intersect: Prioritizing mitigation of road impacts on wildlife corridors. Center for Large Landscape Conservation, Bozeman, MT, USA. https://largelandscapes.org/wp-content/uploads/2019/06/Where-People-Wildlife-Intersect-Prioritizing-Mitigation.pdf

MWTP 2023. Montana Wildlife and Transportation Partnership (MWTP) Data and Information Work Group Planning Tool Summary Report. www.mdt.mt.gov/other/webdata/external/Planning/MWT/MWTP-Program/Planning-Tool-Summary-Report.pdf

Peck, C.P., F.T. Van Manen, C.M. Costello, M.A. Haroldson, L.A. Landenburger, L.L Roberts, D.D. Bjornlie, and R.D. Mace. 2017. Potential paths for male-mediated gene flow to and from an isolated grizzly bear population. Ecosphere 8(10). https://doi.org/10.1002/ecs2.1969

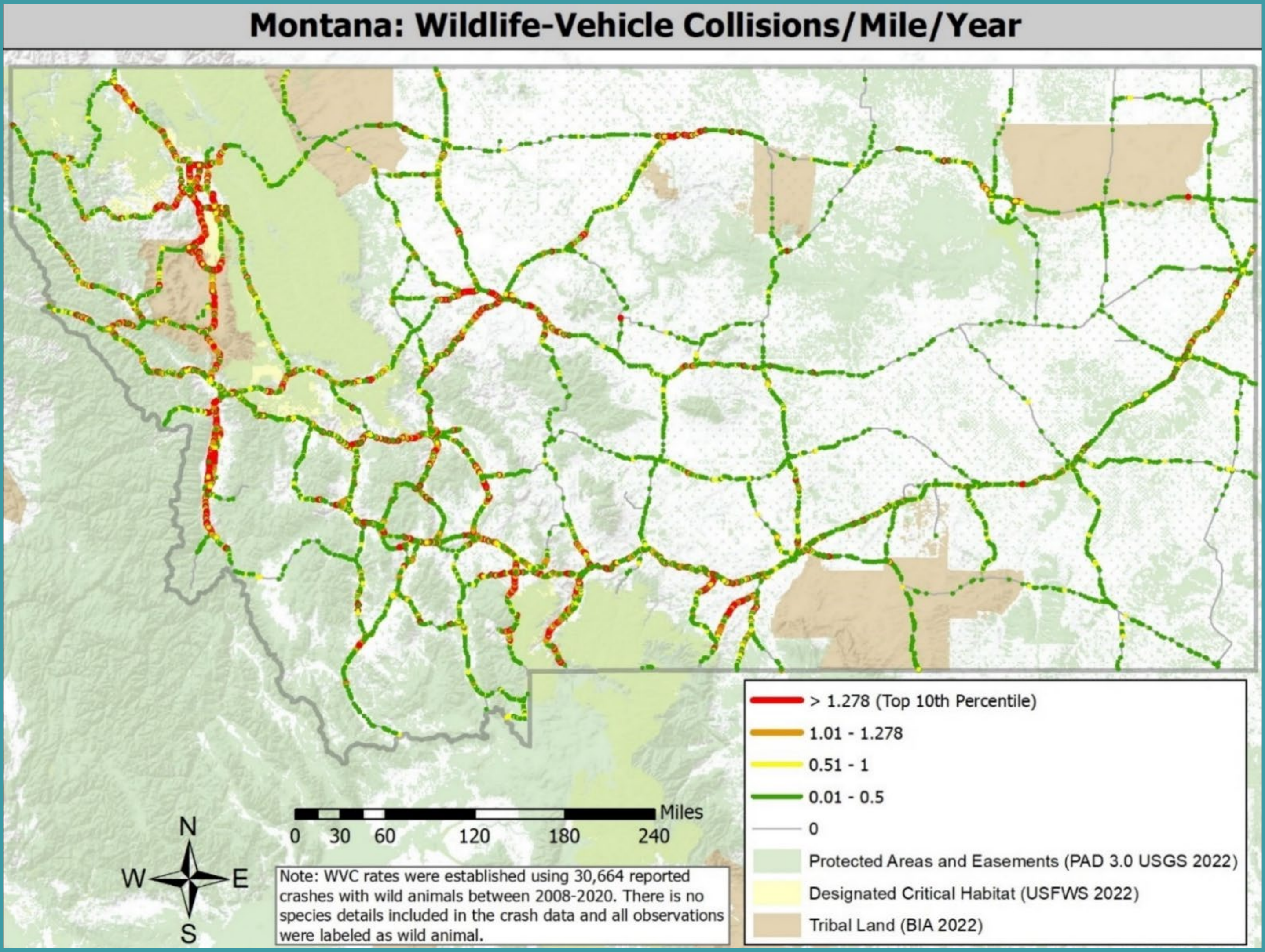

Figure 25. Average WVC rates in Montana between 2008-2020.

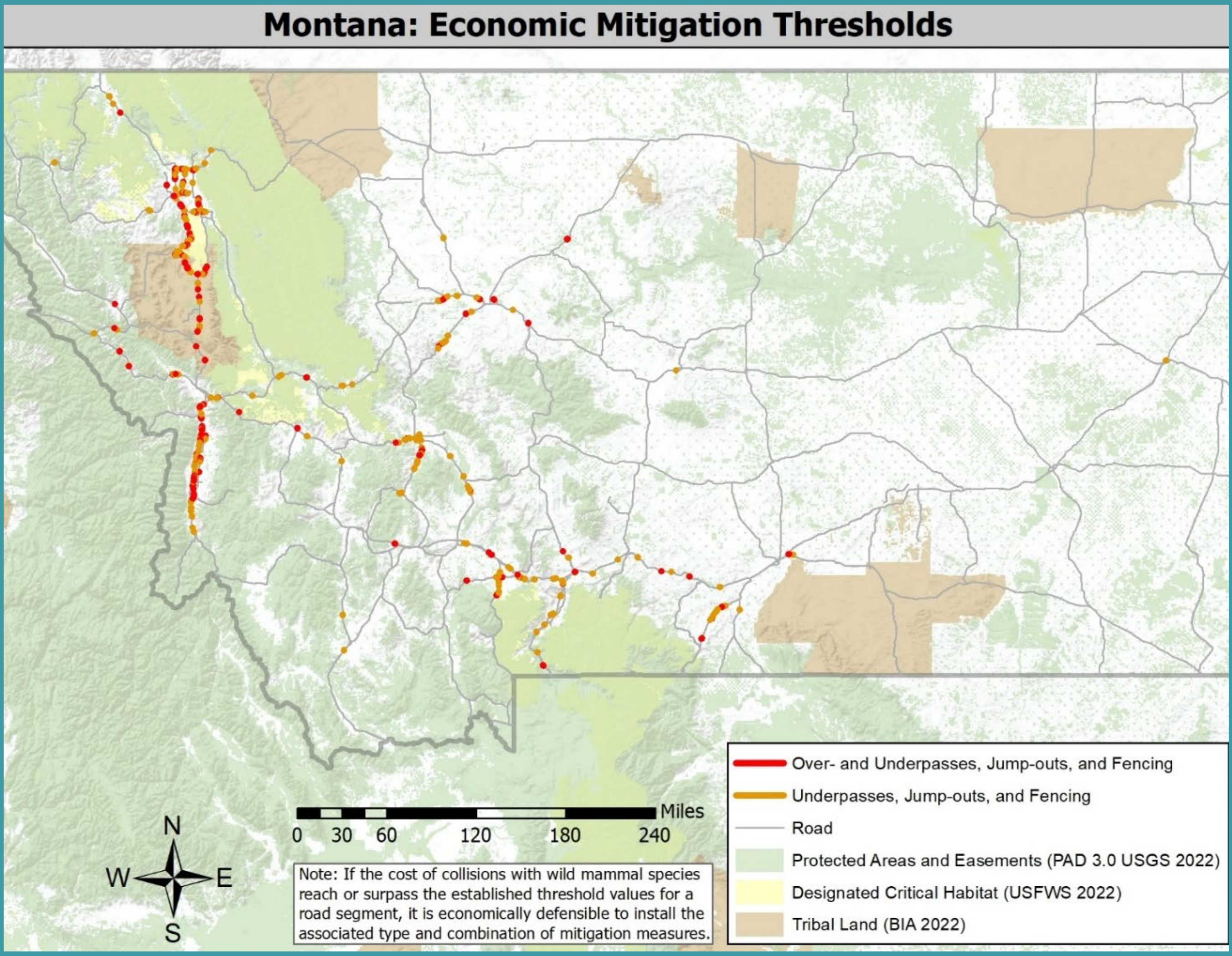

Figure 26. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

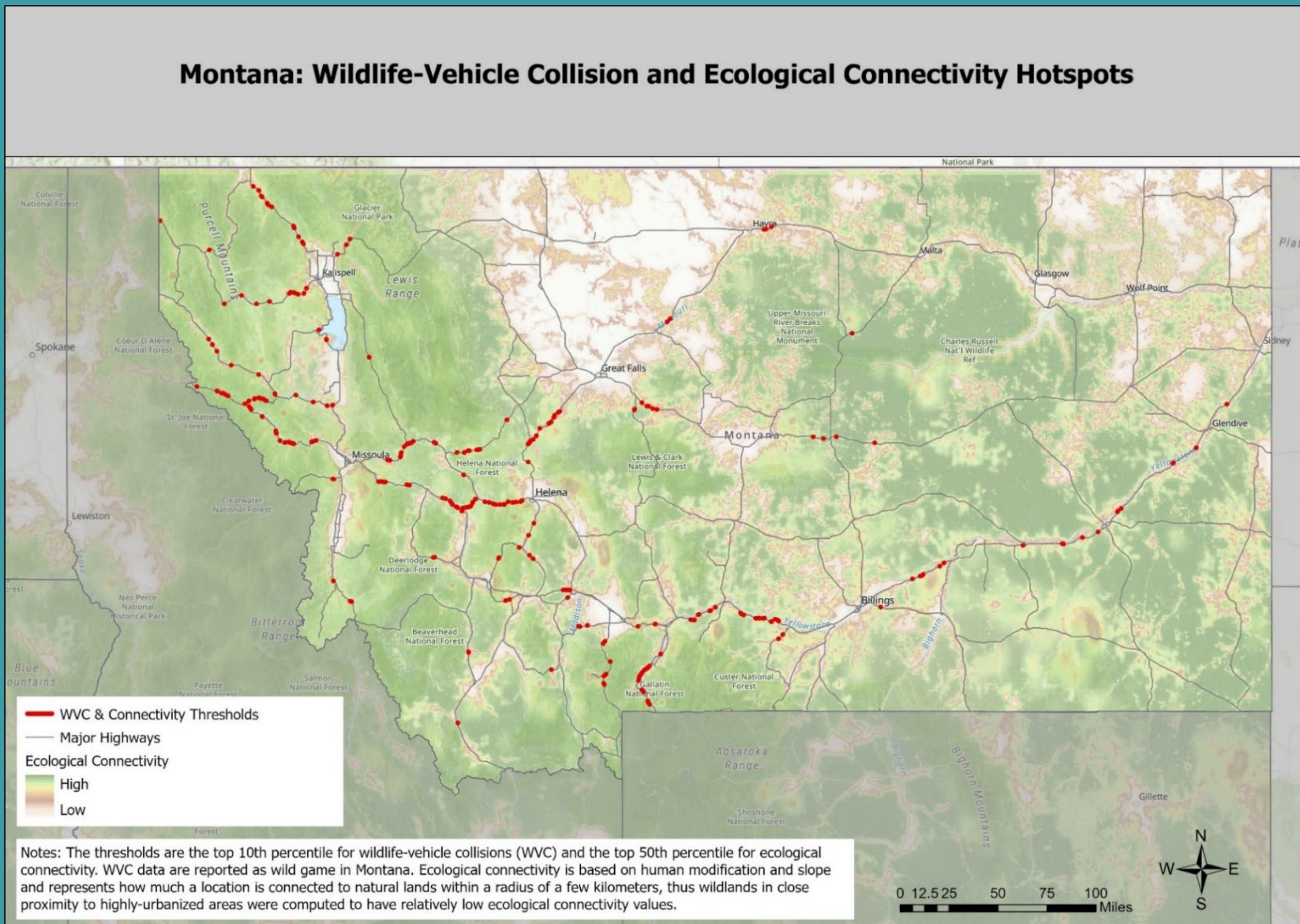

Figure 27. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

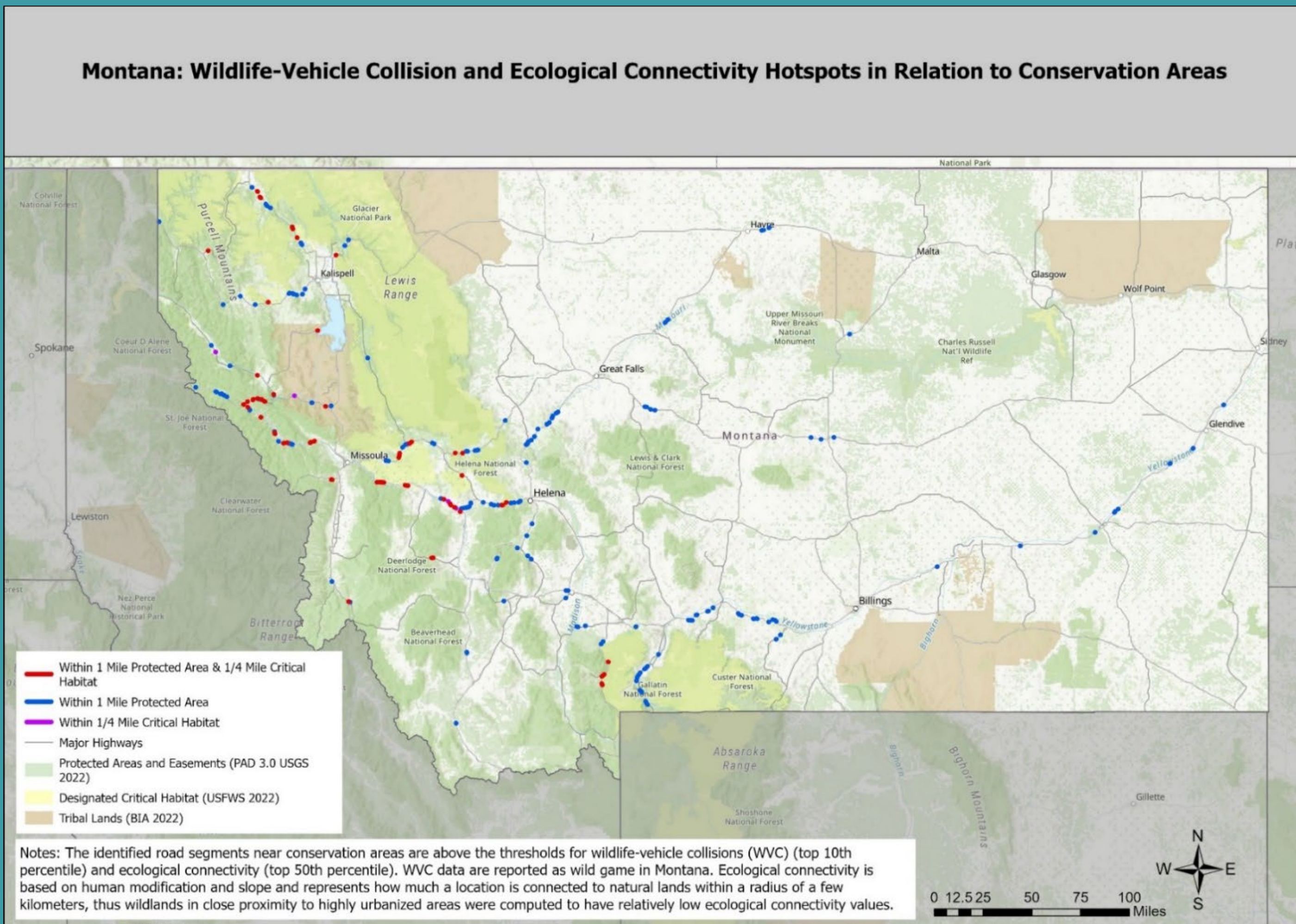

Figure 28. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

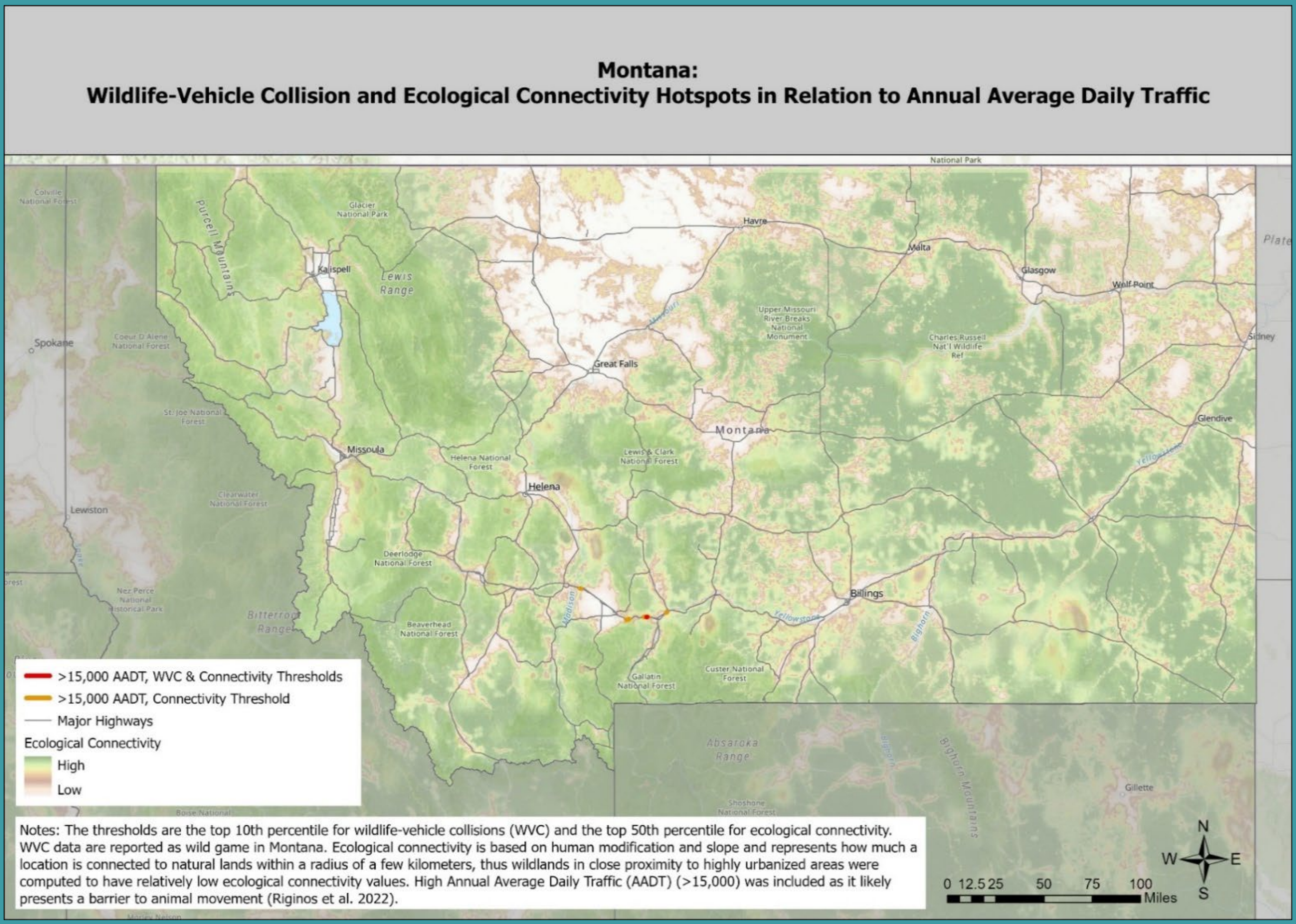

Figure 29. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

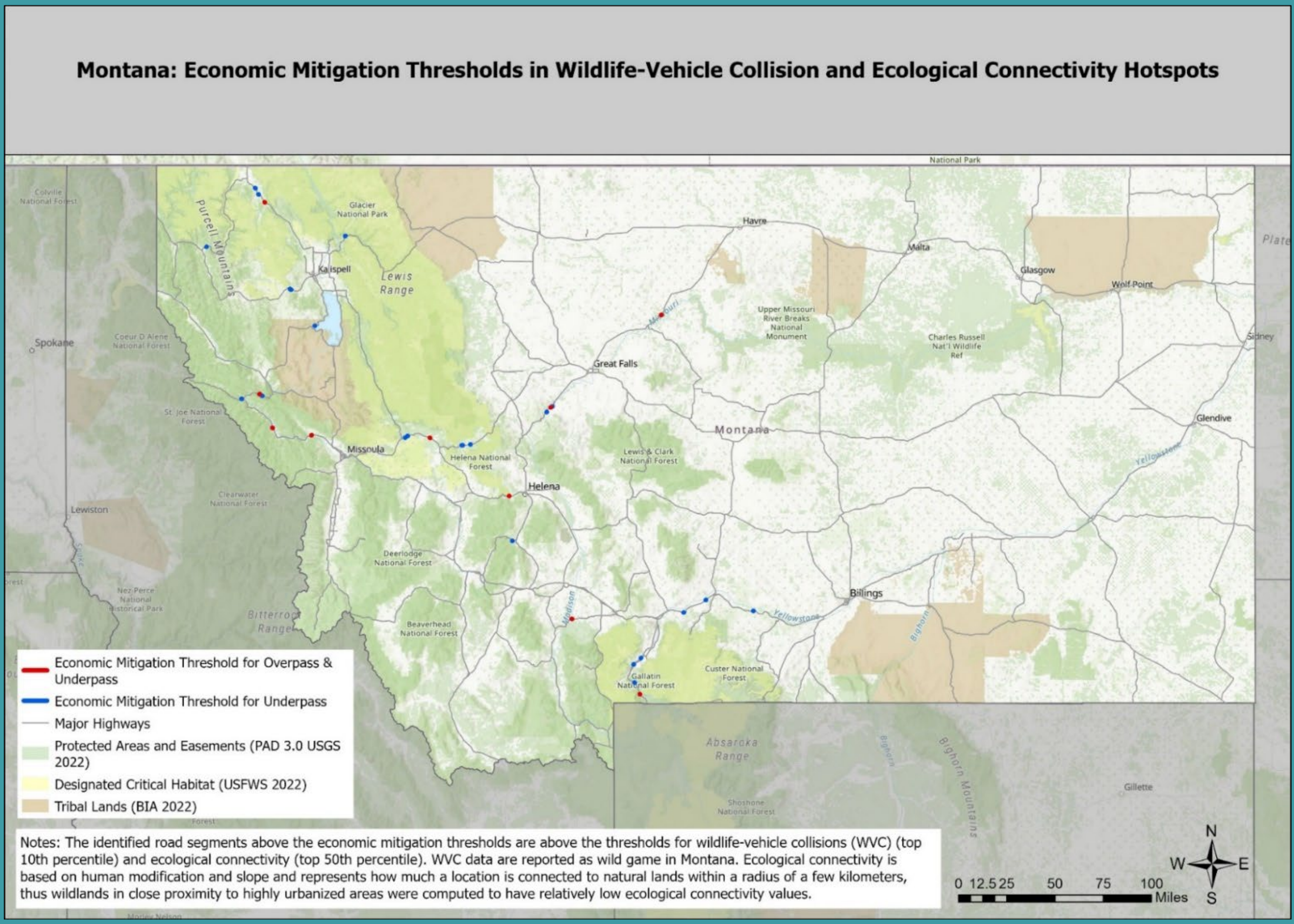

Figure 30. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

6. NEVADA

6.1 Safety and Economics

There was a total of 1,310 reported collisions with large wildlife over 7 years (2013-2019) in Nevada (Table 4 of report). These collisions consisted of 1,117 with deer, 122 with elk, 43 with antelope, 18 with bighorn sheep, and 10 with bear. The reported WVC crash data shows that crash rates ranged from 0 to 2.92 WVC/mi/yr (Table 7 of report). Only 4.7% of the road segments had WVC rates greater than zero, and the top 10th percentile of the identified segments has 0.76 WVC/mi/yr and higher (Table 8 of report, Figure 31).

Based on costs and number of collisions, Nevada's average cost of WVCs per year is $11,054,221 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 9 segments (3 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective, and 8 segments (3 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 32).

6.2 Collisions and Connectivity

Nevada's road segment lengths were on average 0.38 mi in length (Table 3 of report). There are 92 road segments (35 mi) within the top 10th percentile for WVC and 11,073 road segments (4,230 mi) within the top 50th percentile for connectivity (Table 1). There are 23 road segments (9 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 33).

6.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 23 (9 mi) CC road segments, each of them is within one mile of a protected area, but none is near critical habitat (Table 1, Figure 34).

6.4 Collisions, Connectivity, and Conservation – High Traffic Volume

The road segments that experience high traffic volume (ADDT ≥15,000 vehicles per day) do not overlap with the CC road segments (Figure 33).

6.5 Collisions, Connectivity, and Costs

There are no road segments that reached the economic mitigation threshold for an under- or overpass above the WVC and connectivity hotspots.

6.6 Other Resources to Examine

Cramer, P. and C. McGinty. 2018**.** Prioritization of Wildlife-Vehicle Conflict in Nevada. Final Report to Nevada Department of Transportation. 604-16-03. www.dot.nv.gov/home/showpublisheddocument/16038/636820992282700000

Nevada Department of Transportation. Safety Overpasses/Underpasses.
https://www.dot.nv.gov/safety/roadway-safety-improvements/wildlife-safety-overpasses-underpasses

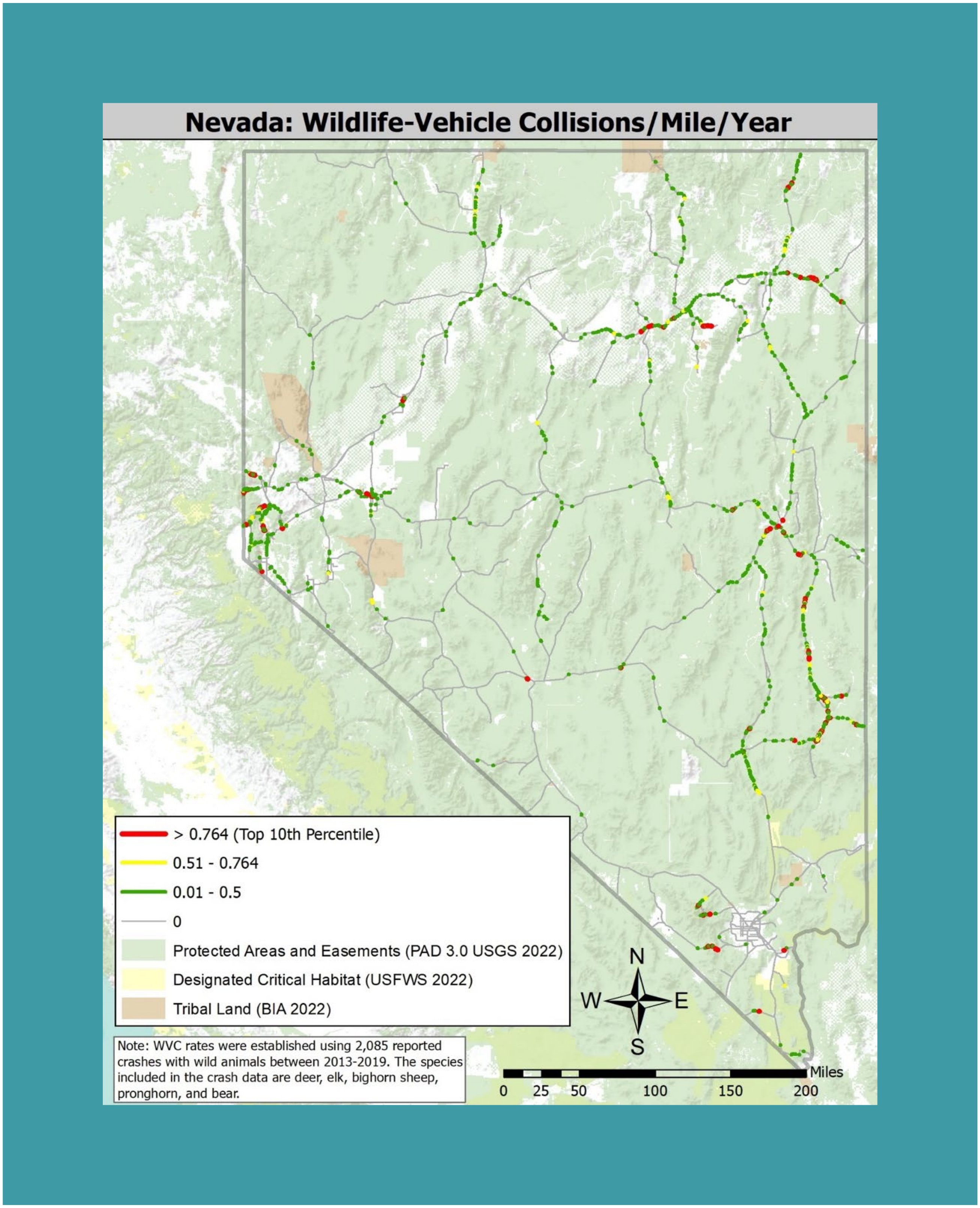

Figure 31. Average WVC rates for Nevada between 2013-2019.

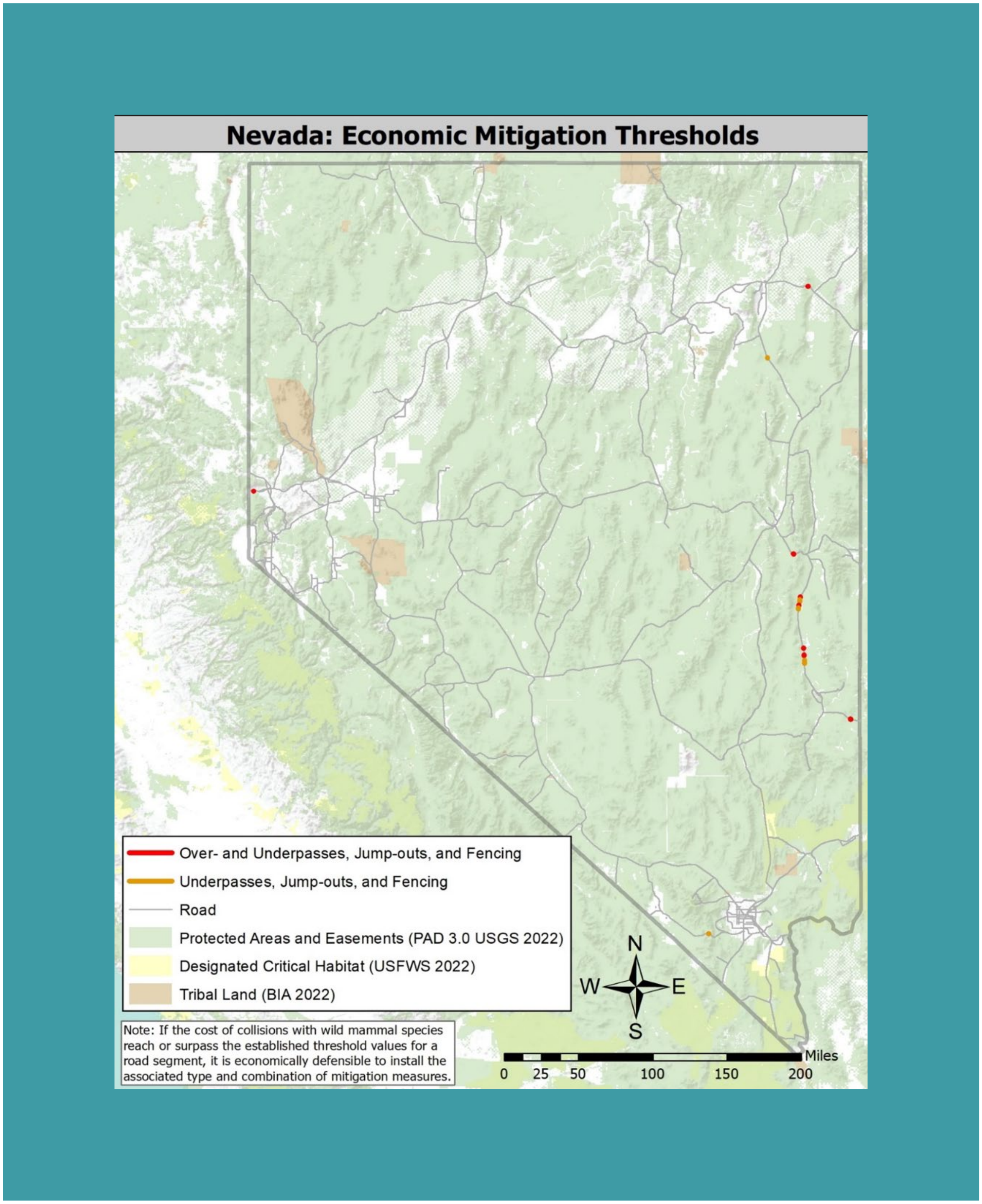

Figure 32. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

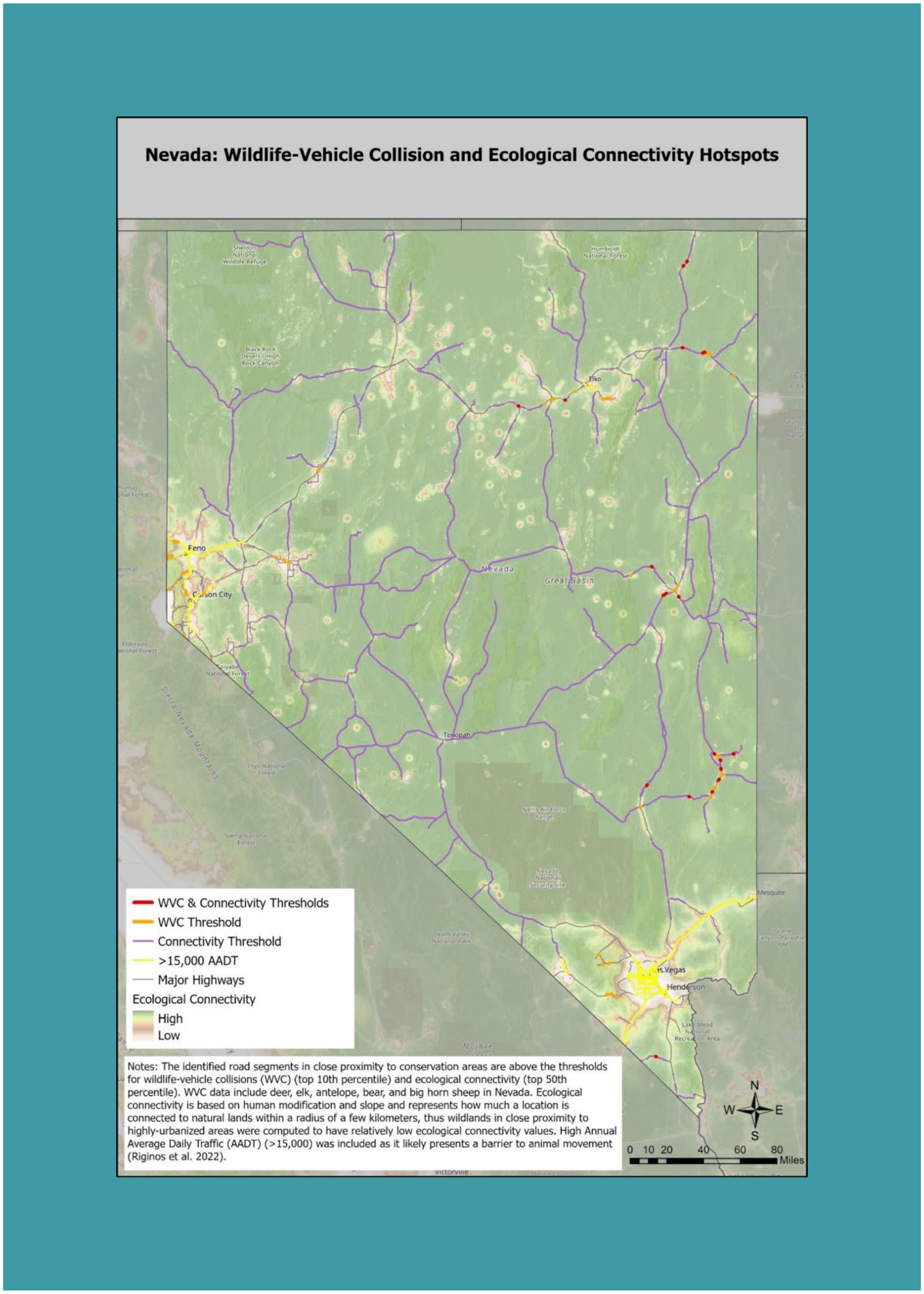

Figure 33. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments), and roads with high traffic volume (≥15,000 AADT).

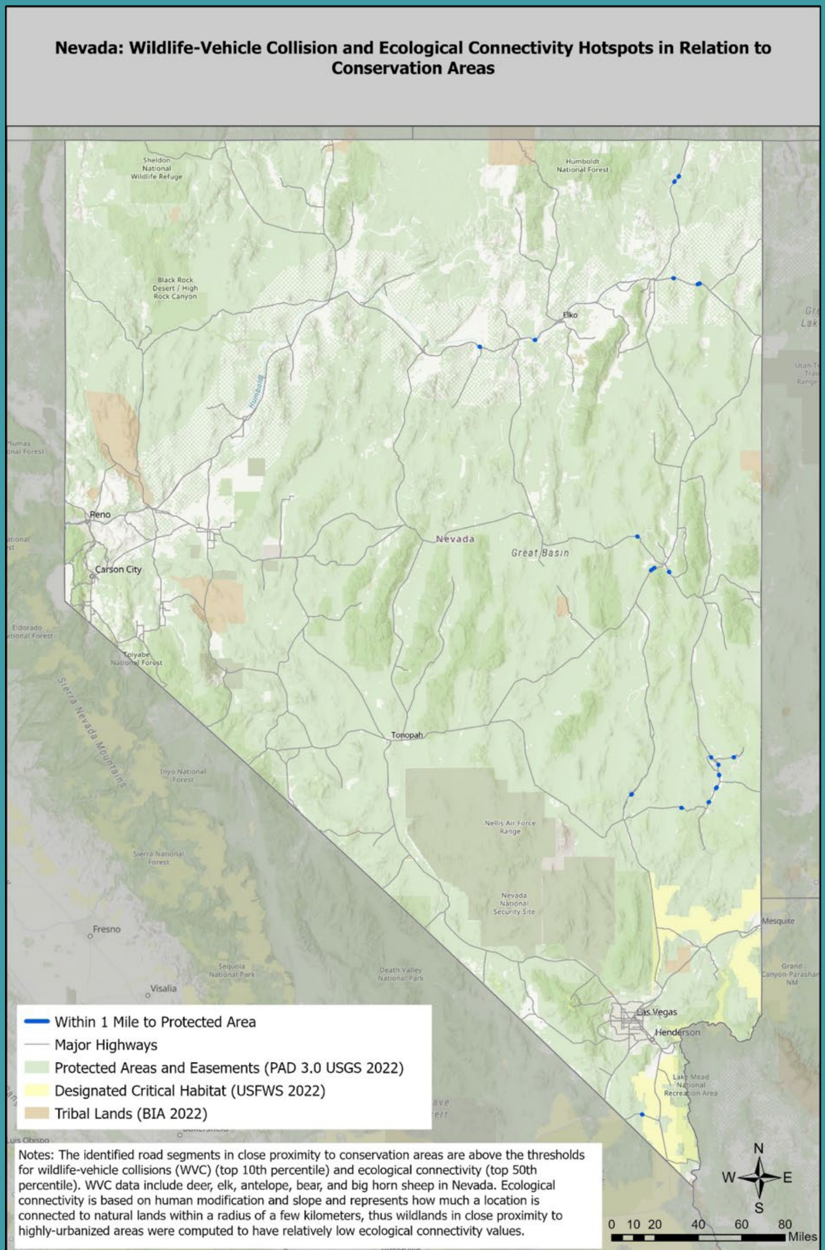

Figure 34. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

7. NEW MEXICO

7.1 Safety and Economics

There was a total of 8,897 reported collisions with large wildlife over 9 years (2010-2018) in New Mexico (Table 4 of report). These collisions consisted of 6,336 with deer, 1,823 with elk, 132 with antelope, 25 with cougar, and 132 with bear. The remaining 449 WVC locations were unidentified large wildlife. The reported WVC crash data shows that crash rates ranged from 0 to 24.32 WVC/mi/yr (Table 7 of report). Only 5.5% of the road segments had WVC rates (> zero WVCs) and out of the identified segments with collisions, the top 10th percentile has 2.10 WVC/mi/yr and higher (Table 8 of report, Figure 35).

Based on costs and number of collisions, New Mexico's average cost of WVCs per year is $174,442,754 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 680 segments (114 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective, and 871 segments (146 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 36).

7.2 Collisions and Connectivity

New Mexico's road segment lengths were on average 0.17 mi in length (Table 3 of report). There are 534 road segments (90 mi) within the top 10th percentile for WVC and 48,747 road segments (8.189 mi) within the top 50th percentile for connectivity (Table 1). There are 139 road segments (23 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 37).

7.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 139 (23 mi) CC road segments, 97 (16 mi) are within one mile of a protected area, 3 (1 mi) are within a quarter mile of critical habitat, and each of the 3 road segments (1 mi) near critical habitat are also within one mile to a protected area (Table 1, Figure 38).

7.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 1,173 road segments (197 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 39). Of the 139 CC road segments, one road segment experiences high traffic volume (AADT ≥ 15,000 vehicles per day).

7.5 Collisions, Connectivity, and Costs

Of the CC road segments, 124 (21 mi) meet the economic mitigation threshold where underpasses (with fencing with an apron and jump-outs) are cost-effective (Table 1). There are 108 road segments (18 mi) that meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Figure 40).

7.6 Other Resources to Examine

Cramer, P., J.L. Cartron, K. Calhoun, J. Gagnon, M. Haverland, M. Watson, S. Cushman, H.Y. Wan, J. Kutz, J. Romero, T. Brennan, J. Walther, C. Loberger, H. Nelson, T. Botkin, and J. Hirsch. 2022. New Mexico wildlife corridors action plan. New Mexico Department of Transportation and New Mexico Department of Game & Fish. https://wildlifeactionplan.nmdotprojects.org/

Loberger, C. D., J. W. Gagnon, H. D. Nelson, C. A. Beach, and S. C. Sprague. 2021. Determining the effectiveness of wildlife-vehicle collision mitigation projects: Phase I Final Report. For New Mexico Department of Transportation. https://wildlifeactionplan.nmdotprojects.org/wp-content/uploads/sites/39/2021/09/NM17ENV-01_PhaseOne_FinalReport_20210308.pdf

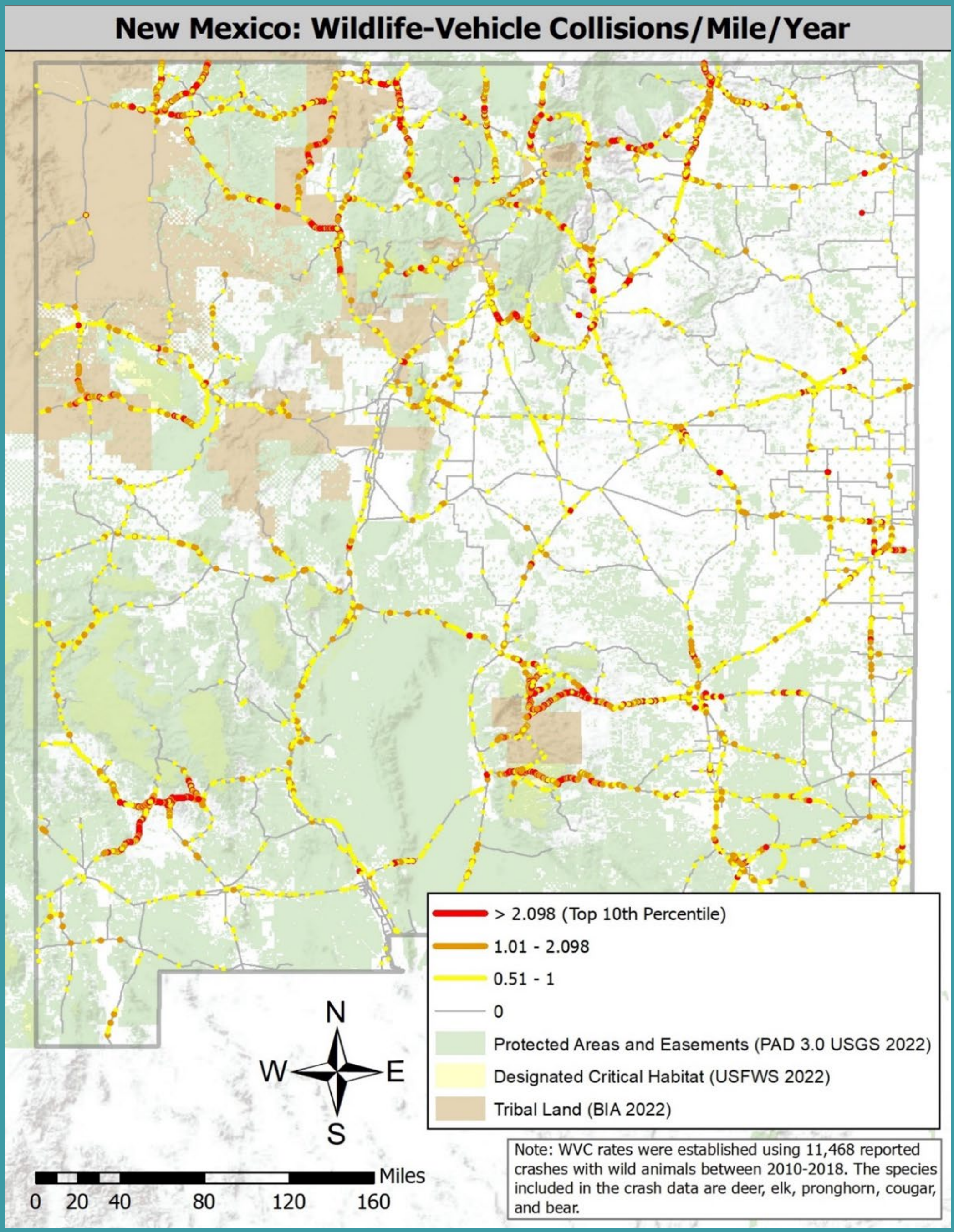

Figure 35. Average WVC rates for New Mexico between 2010-2018.

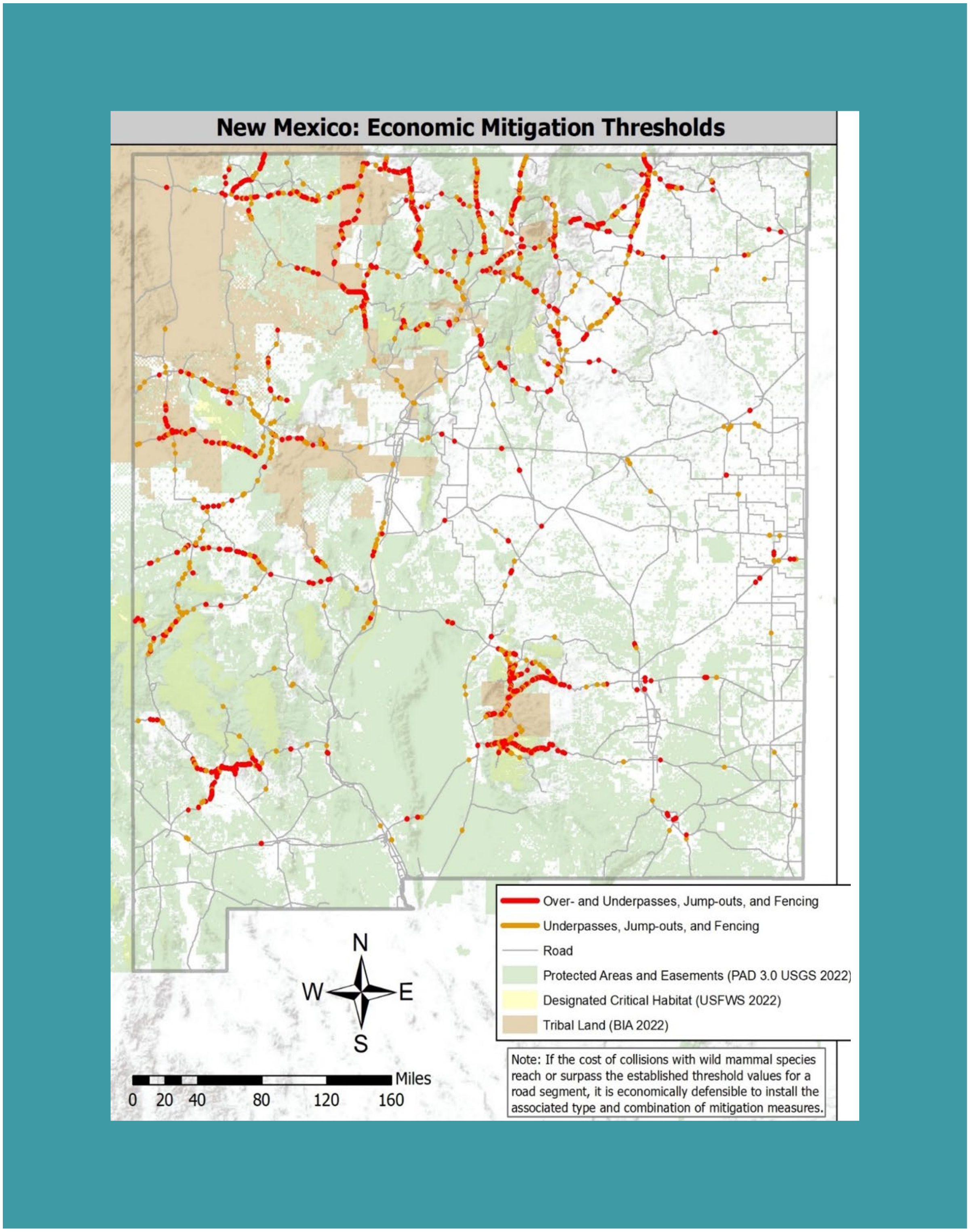

Figure 36. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

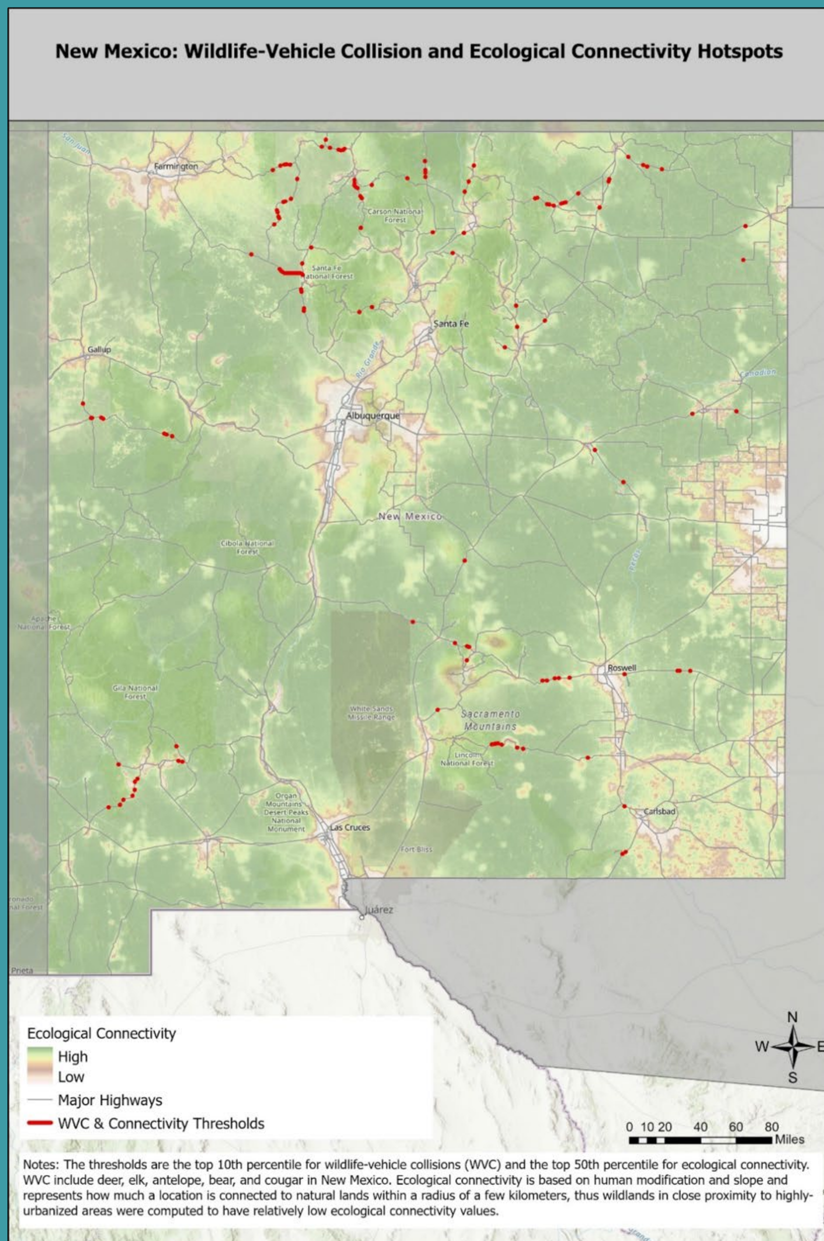

Figure 37. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

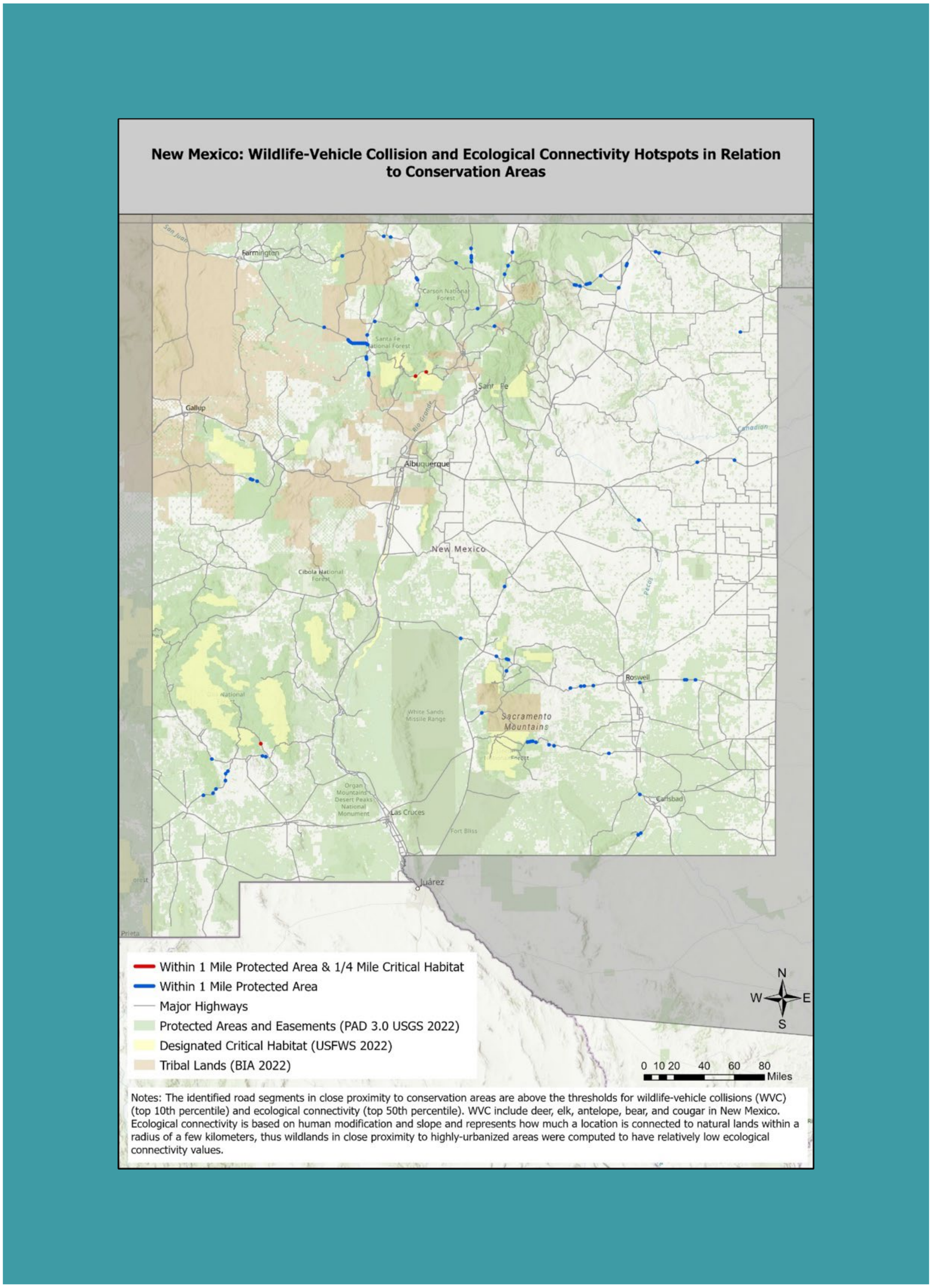

Figure 38. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

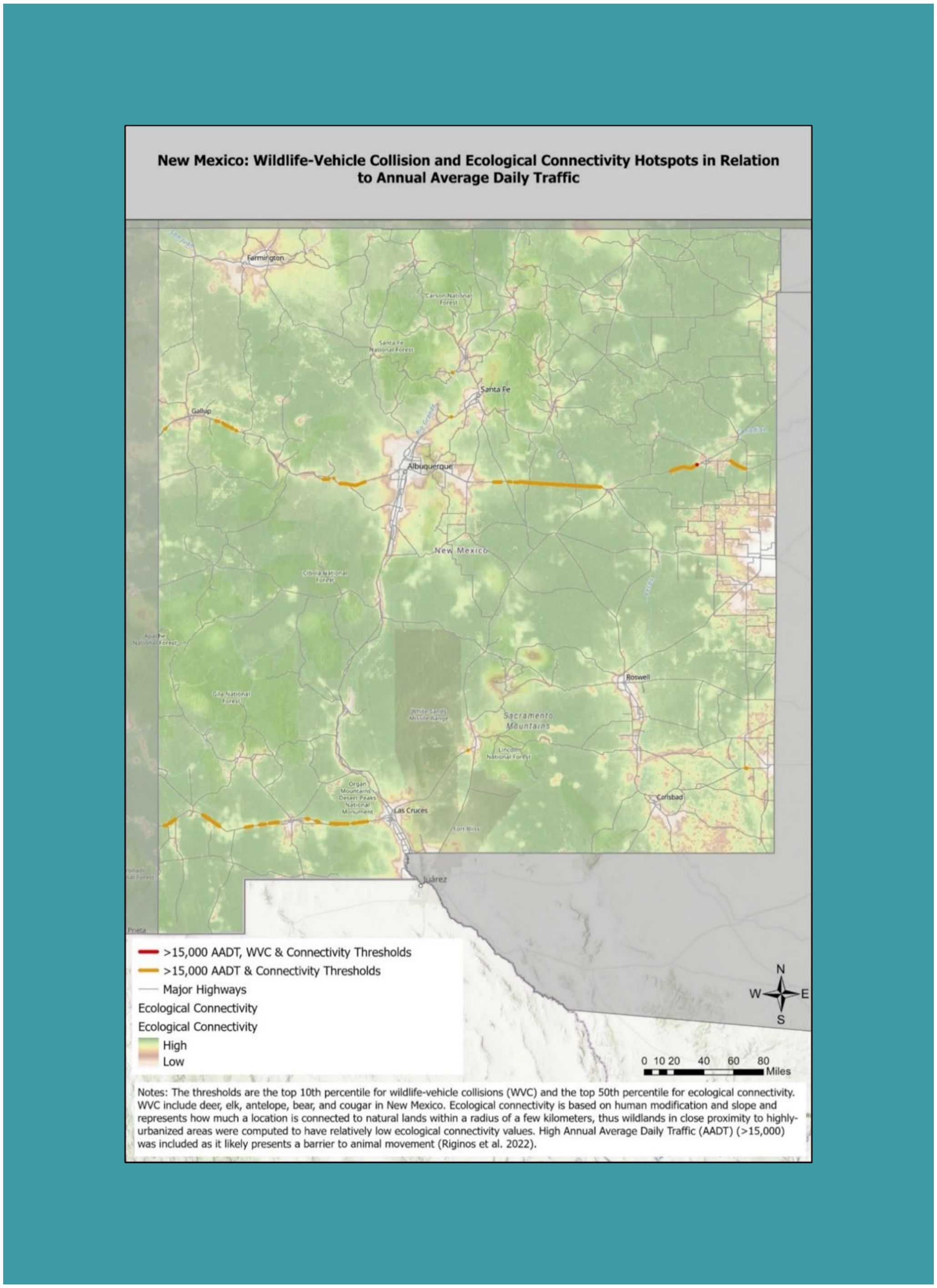

Figure 39. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

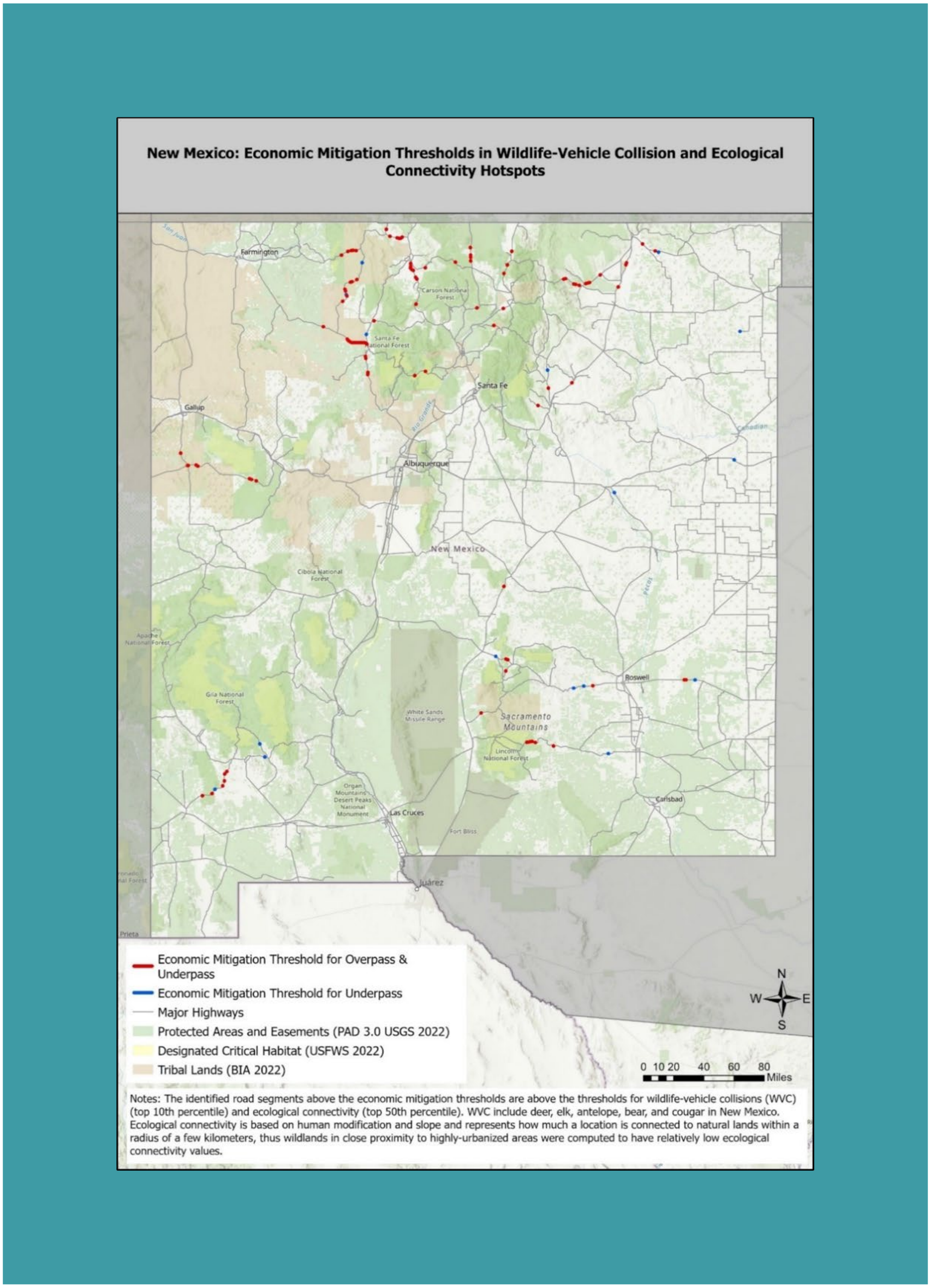

Figure 40. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

8. OREGON

8.1 Safety and Economics

There was a total of 8,105 reported collisions with large wildlife over 10 years (2010-2019) in Oregon (Table 4 of report). These collisions consisted of 7,441 with deer or elk, and 664 with wild game that are not deer or elk. The reported WVC crash data shows that crash rates ranged from 0 to 5.14 WVC/mi/yr (Table 7 of report). Only 8.2% of the road segments had WVC rates (> zero WVCs), with all other segments having no reported collisions. The top 10th percentile of the identified road segments has 1.38 WVC/mi/yr and higher (Table 8 of report, Figure 41).

Based on costs and number of collisions, Oregon's average cost of WVCs per year is $106,666,000 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 87 segments (13 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective, and 52 segments (8 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 42).

8.2 Collisions and Connectivity

Oregon's road segment lengths were on average 0.15 mi in length (Table 4 of report). There are 665 road segments (96 mi) within the top 10th percentile for WVC and 40,464 road segments (5,867 mi) within the top 50th percentile for connectivity (Table 1). There are 232 road segments (34 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 43).

8.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 232 CC road segments, 194 (28 mi) are within one mile of a protected area, 46 (7 mi) are within a quarter mile of critical habitat, and 40 (6 mi) are near both protected areas and critical habitat (Table 1, Figure 44).

8.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 36 road segments (5 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 45). Of the 232 CC road segments, no segments experience high traffic volume (AADT ≥ 15,000 vehicles per day).

8.5 Collisions, Connectivity, and Costs

Of the 232 CC road segments, 54 (8 mi) meet the economic mitigation threshold where underpasses (with fencing with apron and jump-outs) are cost-effective (Table 1). There are 20 road segments (3 mi) that meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Figure 46).

8.6 Other Resources to Consider

Buttrick, S., K. Popper, B. McRae, B. Unnasch, M. Schindel, A. Jones, and J. Platt. 2015. Identifying Resilient Terrestrial Landscapes in the Pacific Northwest Conserving Nature's Stage: Pacific Northwest and Northern California. Final Report to the Doris Duke Charitable Foundation. The Nature Conservancy, Portland, OR. http://nature.ly/resilienceNW

Cascades to Coast Landscape Collaborative. 2022. Coastal Northwest Landscape Conservation Mapper. https://www.ctoclc.org/conservationresources and https://fws.maps.arcgis.com/apps/webappviewer/index.html?id=a3c518e00ccf488db8cc0c8cd4646bce

de Rivera, C. M. Lafrenz, and D. Taylor-Rodriguez. 2019. Research project work plan for habitat connectivity assessment and mapping for prioritization of wildlife crossing projects. For ODOT and FHWA. www.oregon.gov/odot/Programs/ResearchDocuments/spr836wp.pdf

Frost, E. 2018. A review and synthesis of ecological connectivity assessments relevant to the Cascade-Siskiyou landscape in Southwest Oregon and adjacent California. Prepared for Selberg Institute by Wildwood Consulting. https://docslib.org/doc/8749056/a-review-and-synthesis-of-ecological-connectivity-assessments-relevant-to-the-cascade-siskiyou-landscape-in-southwest-oregon

Hatch, A., S. Wray, S. Jacobsen, M. Trask, and K. Roberts. 2008. Oregon Wildlife Linkage Project Final Report. Oregon Department of Fish and Wildlife, Salem, OR. https://www.dfw.state.or.us/conservationstrategy/docs/Linkages_Report_Final_2009.pdf

McRae, B., K. Popper, A. Jones, M. Schinde, S. Buttrick., K. Hall, R. Unnasch, and J. Platt. 2016. Conserving Nature's Stage: Mapping Omnidirectional Connectivity for Resilient Terrestrial Landscapes in the Pacific Northwest. https://doi.org/10.13140/RG.2.1.4158.6166

Oregon Department of Fish and Wildlife (ODFW). 2023. Oregon Wildlife Connectivity Implementation Plan. https://oregonconservationstrategy.org/media/Oregon-Wildlife-Connectivity-Implementation-Plan-FINAL_1.13.2023.pdf

Oregon Department of Fish and Wildlife. 2022. Oregon Connectivity Assessment and Mapping Project. https://oregonconservationstrategy.org/success-story/the-oregon-connectivity-assessment-and-mapping-project-ocamp/

Oregon Department of Fish and Wildlife. 2019. Oregon Connectivity Assessment and Mapping Project: Implementation Plan. Salem, OR. https://oregonconservationstrategy.org/media/OCAMP-Implementation-Plan.pdf

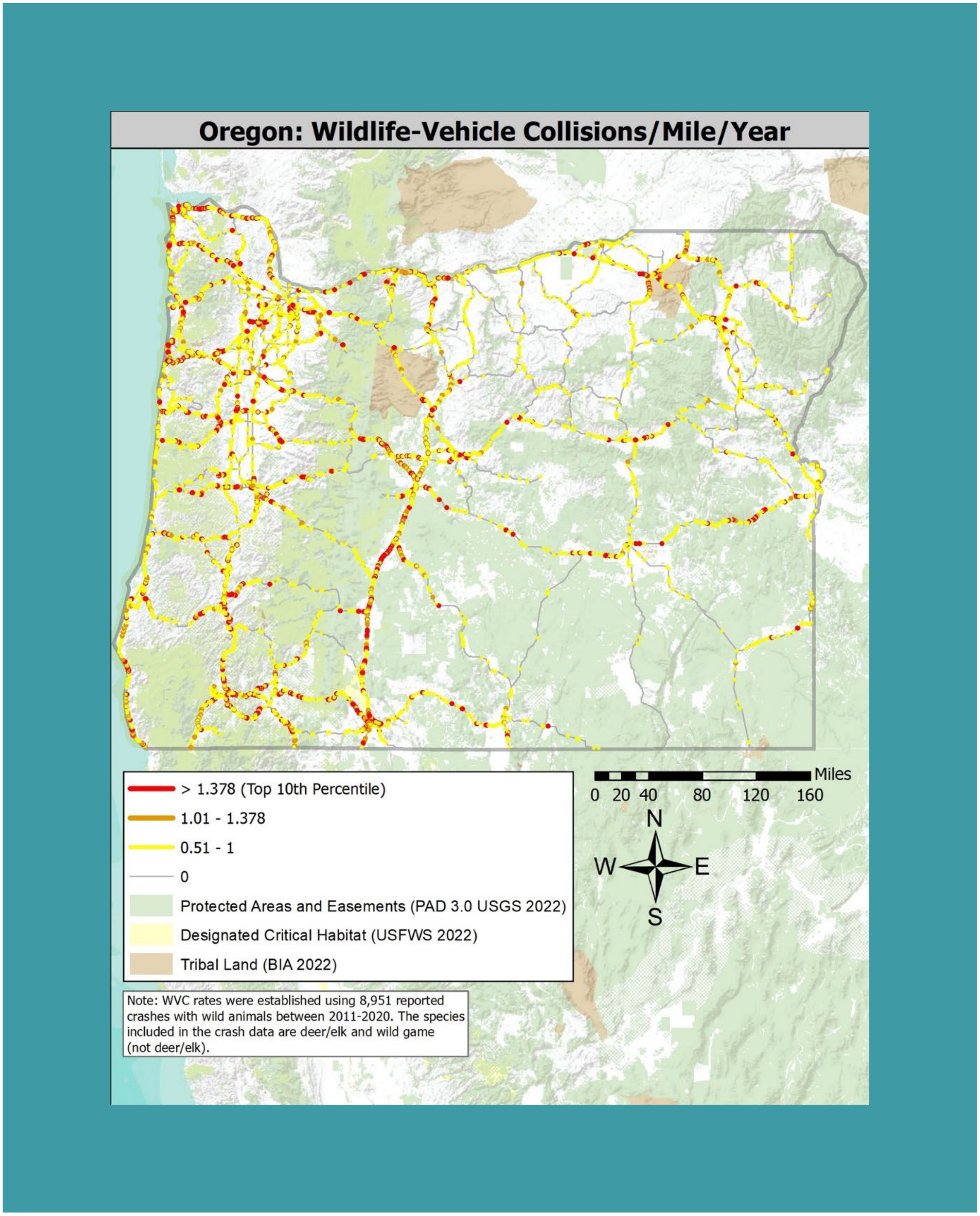

Figure 41. Average WVC rates for Oregon between 2010-2019.

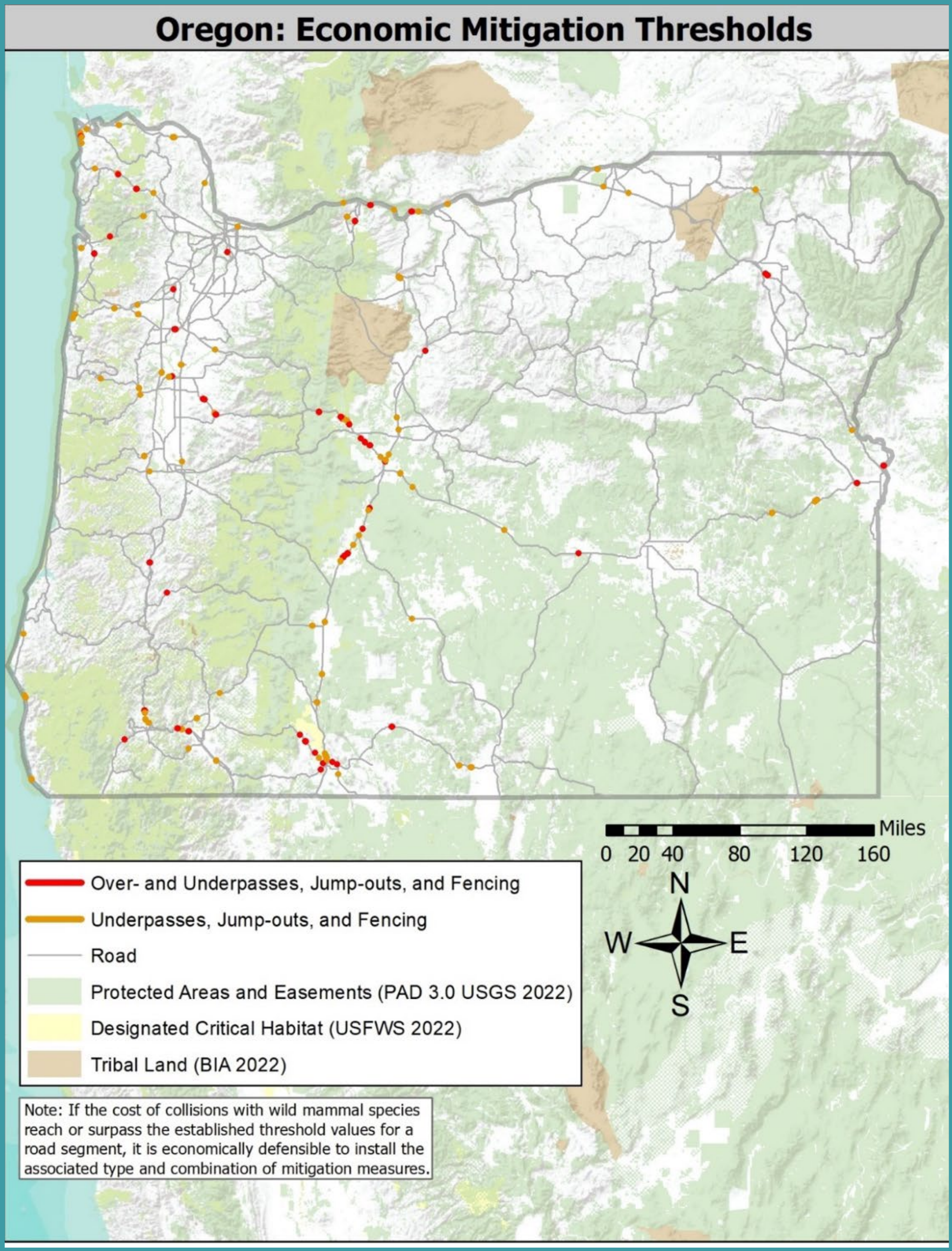

Figure 42. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

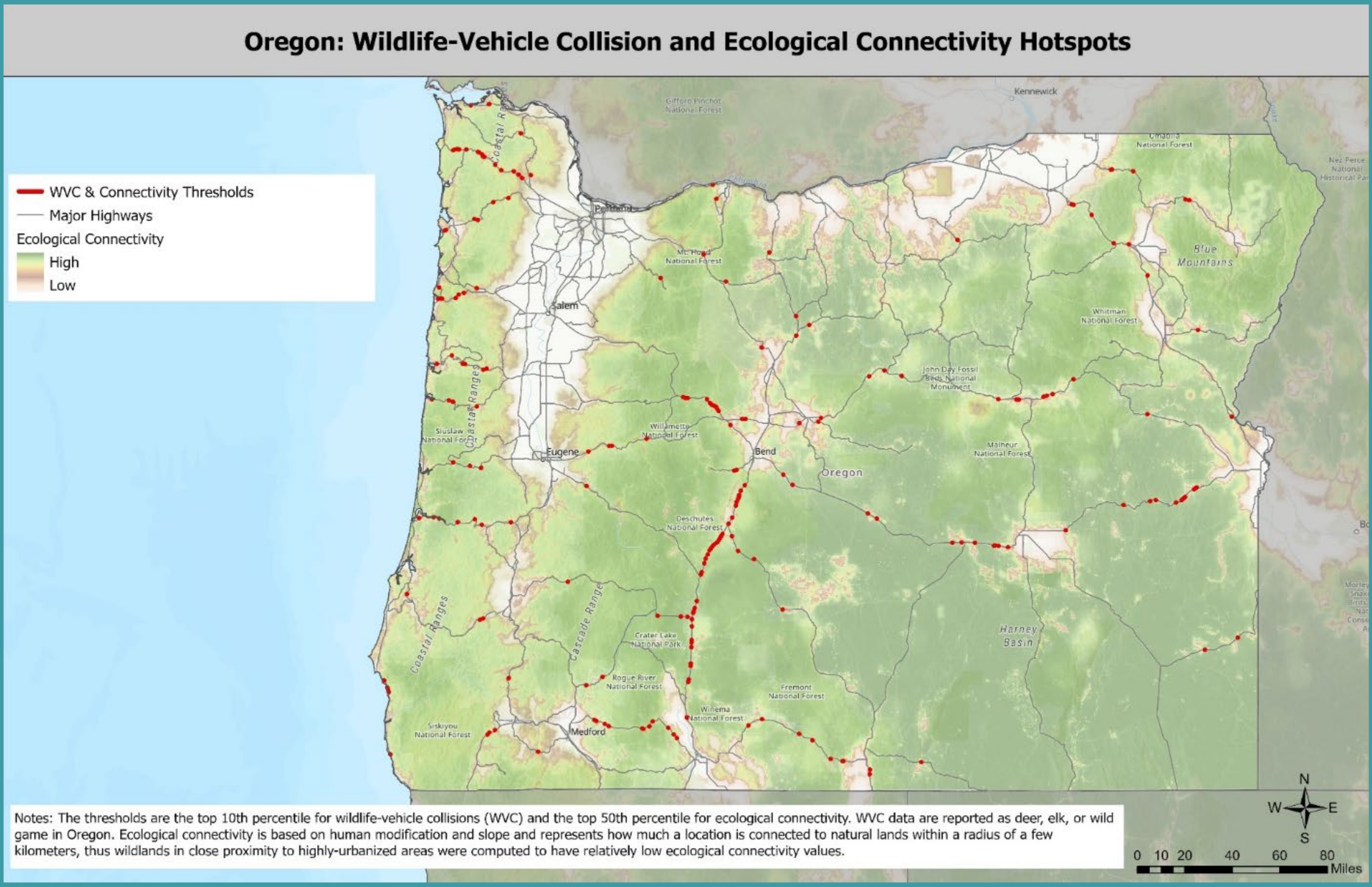

Figure 43. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

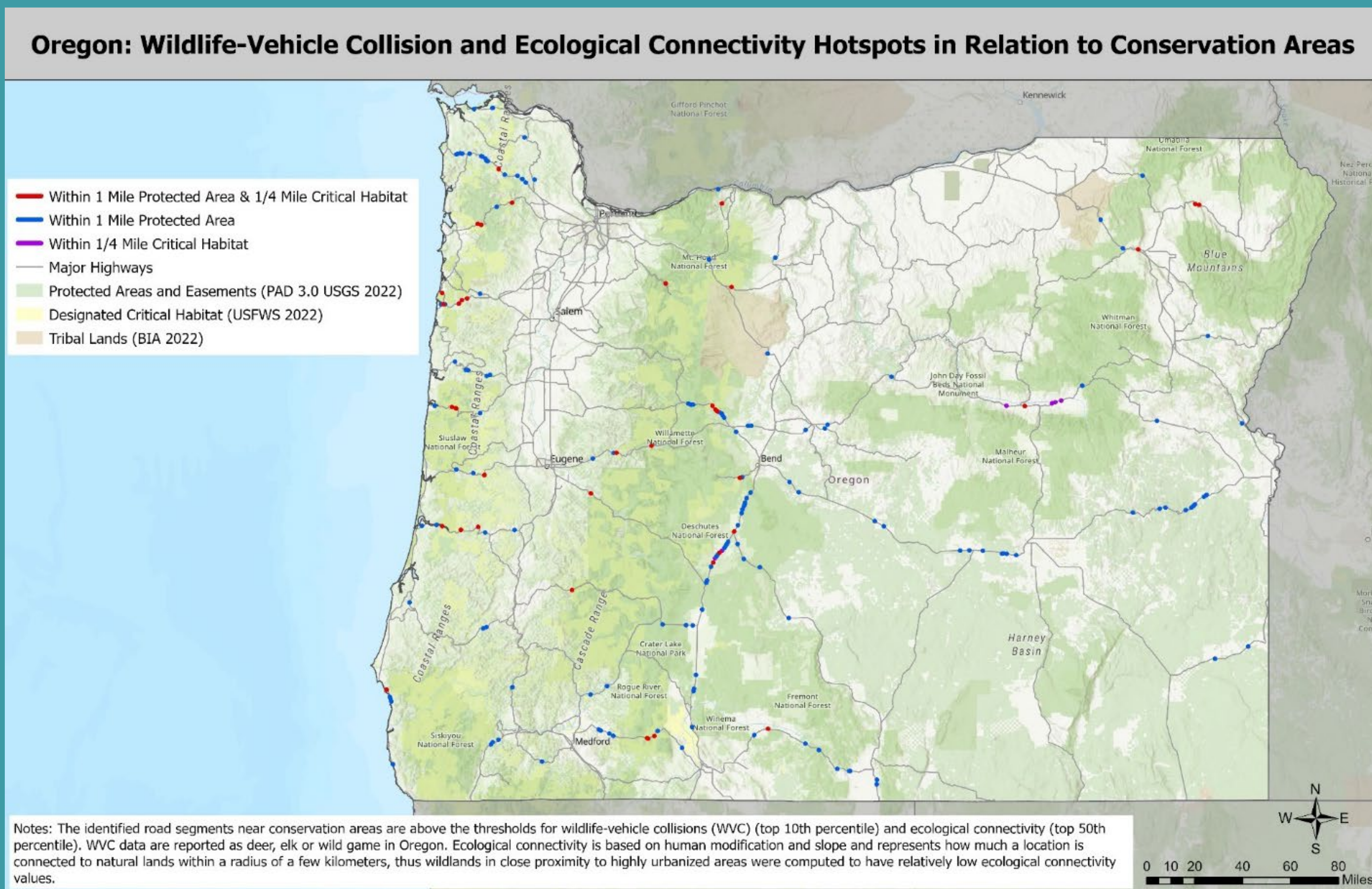

Figure 44. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

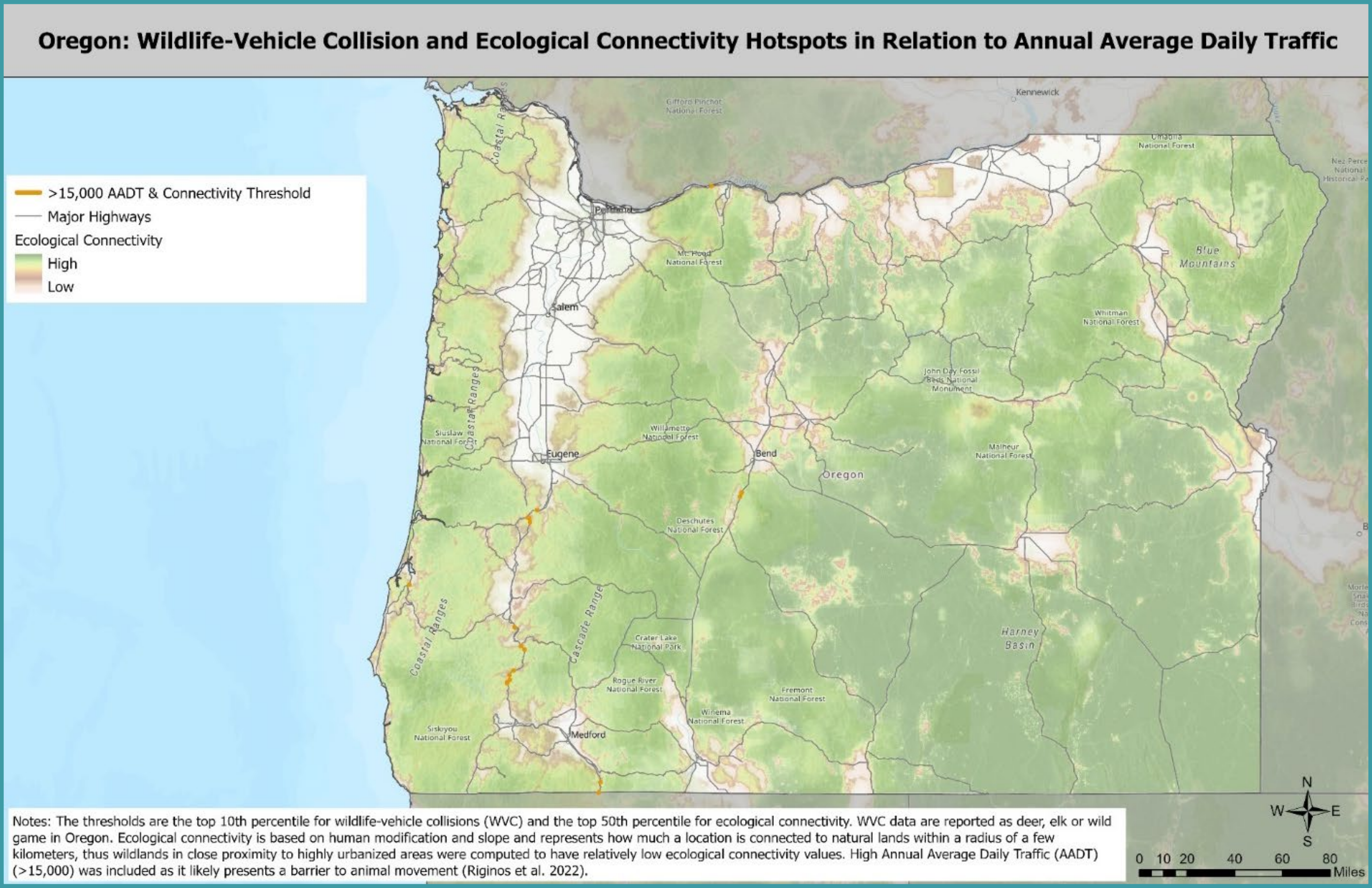

Figure 45. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

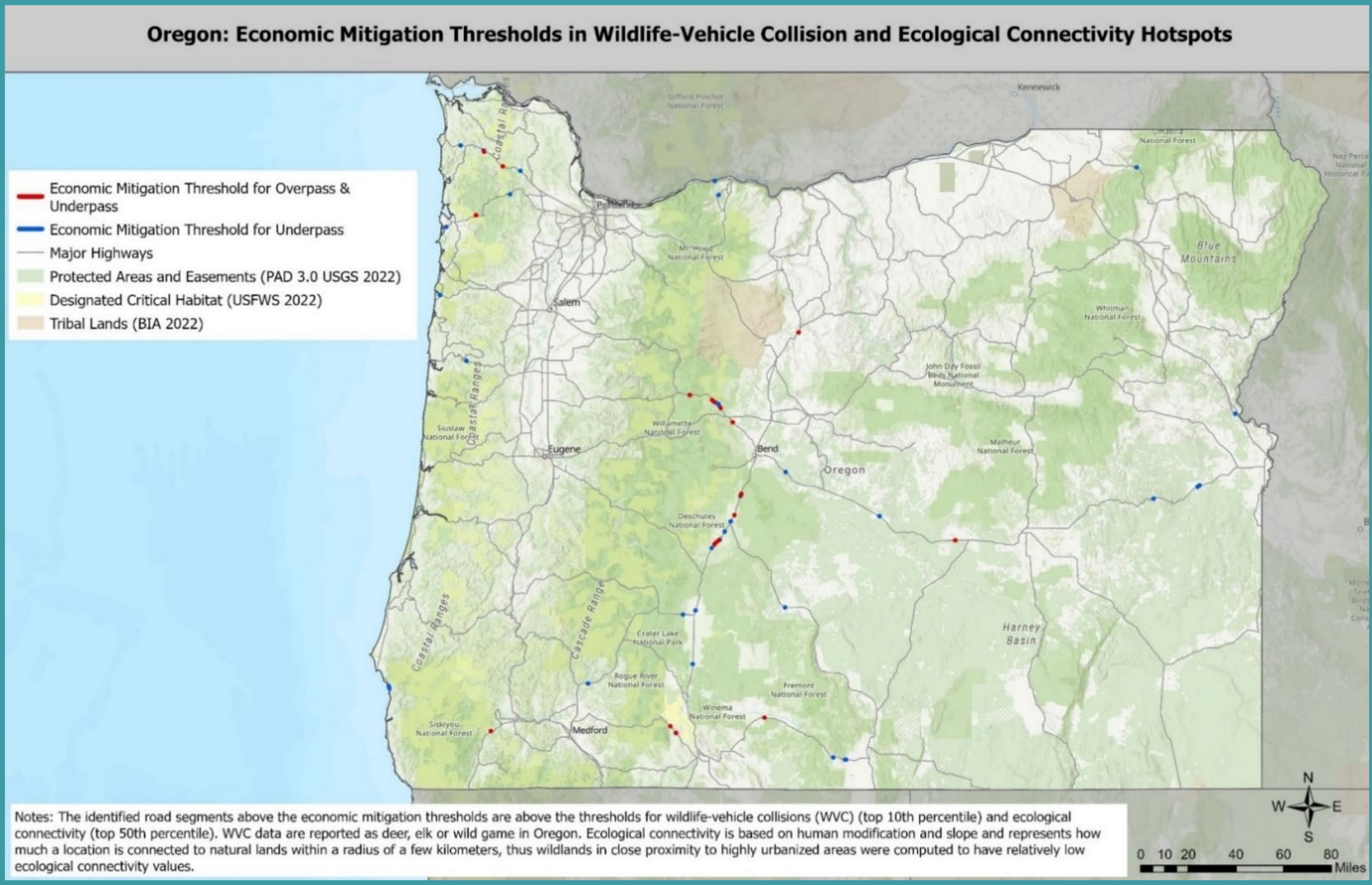

Figure 46. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

9. UTAH

9.1 Safety and Economics

There was a total of 23,600 reported collisions with large wildlife over 10 years (2011-2020) in Utah (Table 4 of report). The reported WVC crash data shows that crash rates ranged from 0 to 24.11 WVC/mi/yr (Table 7 of report). There are 24% of the road segments that have a WVC rate (> zero WVCs), and the top 10th percentile of identified segments has 2.03 WVC/mi/yr and higher (Table 8 of report, Figure 47).

Based on costs and number of collisions, Utah's average cost of WVCs per year is $247,531,772 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 436 road segments (79 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective, and 693 segments (125 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 48).

9.2 Collisions and Connectivity

Utah's road segment lengths were on average 0.18 mi in length (Table 3 of report). There are 1,207 road segments (217 mi) within the top 10th percentile for WVC and 25,139 road segments (4,525 mi) within the top 50th percentile for connectivity (Table 1). There are 264 road segments (48 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 49).

9.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 264 (48 mi) CC road segments, 234 (42 mi) are within one mile of a protected area, 22 (4 mi) are within a quarter mile of critical habitat, and 13 (2 mi) are near both protected areas and critical habitat (Table 1, Figure 50).

9.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 766 road segments that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 51). Of the 264 CC road segments, no road segments experience high traffic volume (AADT ≥ 15,000 vehicles per day).

9.5 Collisions, Connectivity, and Costs

Of the CC road segments, 238 (43 mi) meet the economic mitigation threshold where underpasses (with fencing with an apron and jump-outs) are cost-effective (Table 1). There are 139 road segments (25 mi) that meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Figure 52).

9.6 Other Resources to Examine

Cramer, P., E. Vasquez, and A. Jones. 2019. Identification of wildlife-vehicle conflict priority hotspots in Utah. Final Report to Utah Department of Transportation. https://rosap.ntl.bts.gov/view/dot/56388

West, P. 2007. Wildlife connectivity across Utah's highways. No. UT-06.09. Utah. Dept. of Transportation. https://rosap.ntl.bts.gov/view/dot/39791

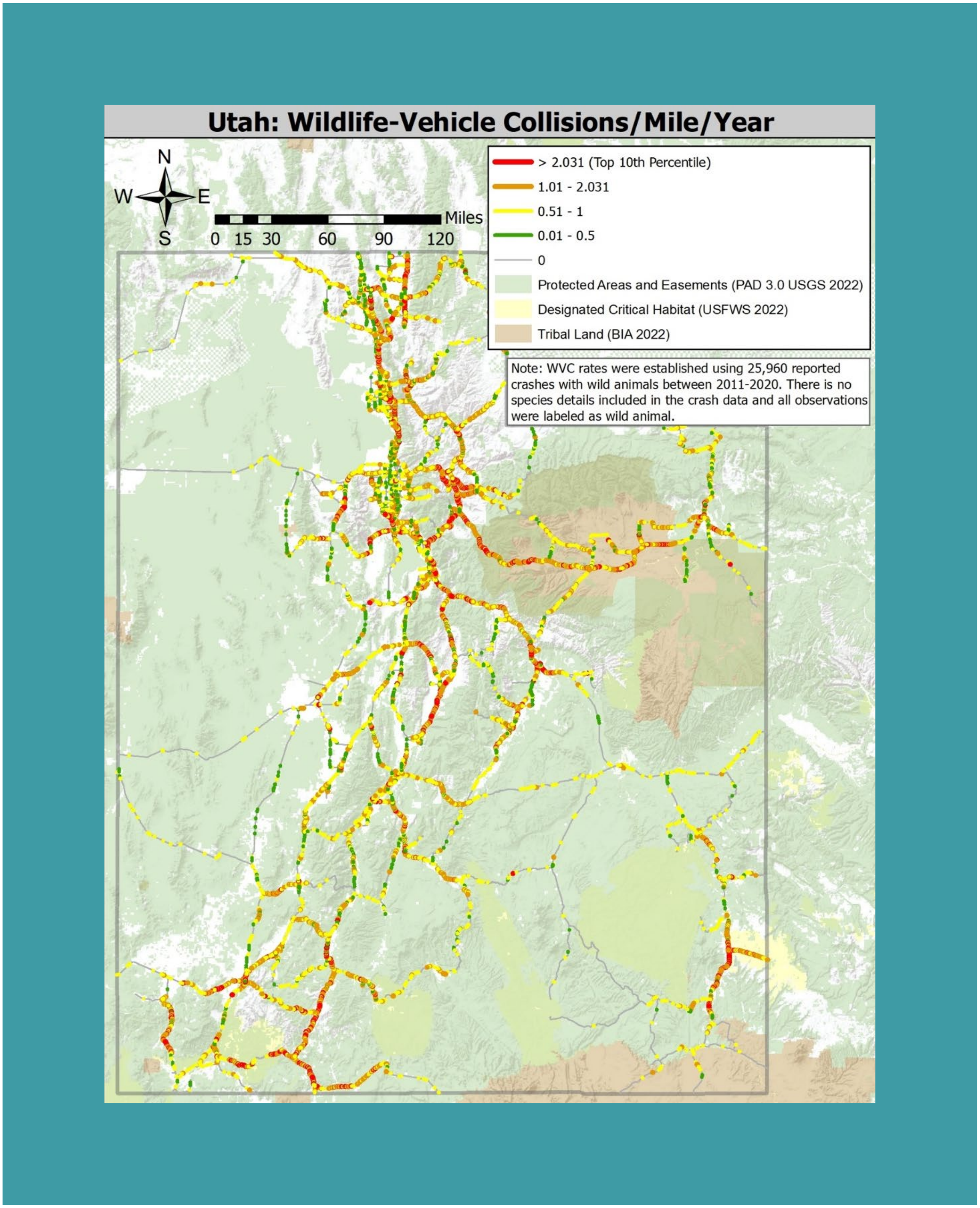

Figure 47. Average WVC rates for Utah between 2011-2020.

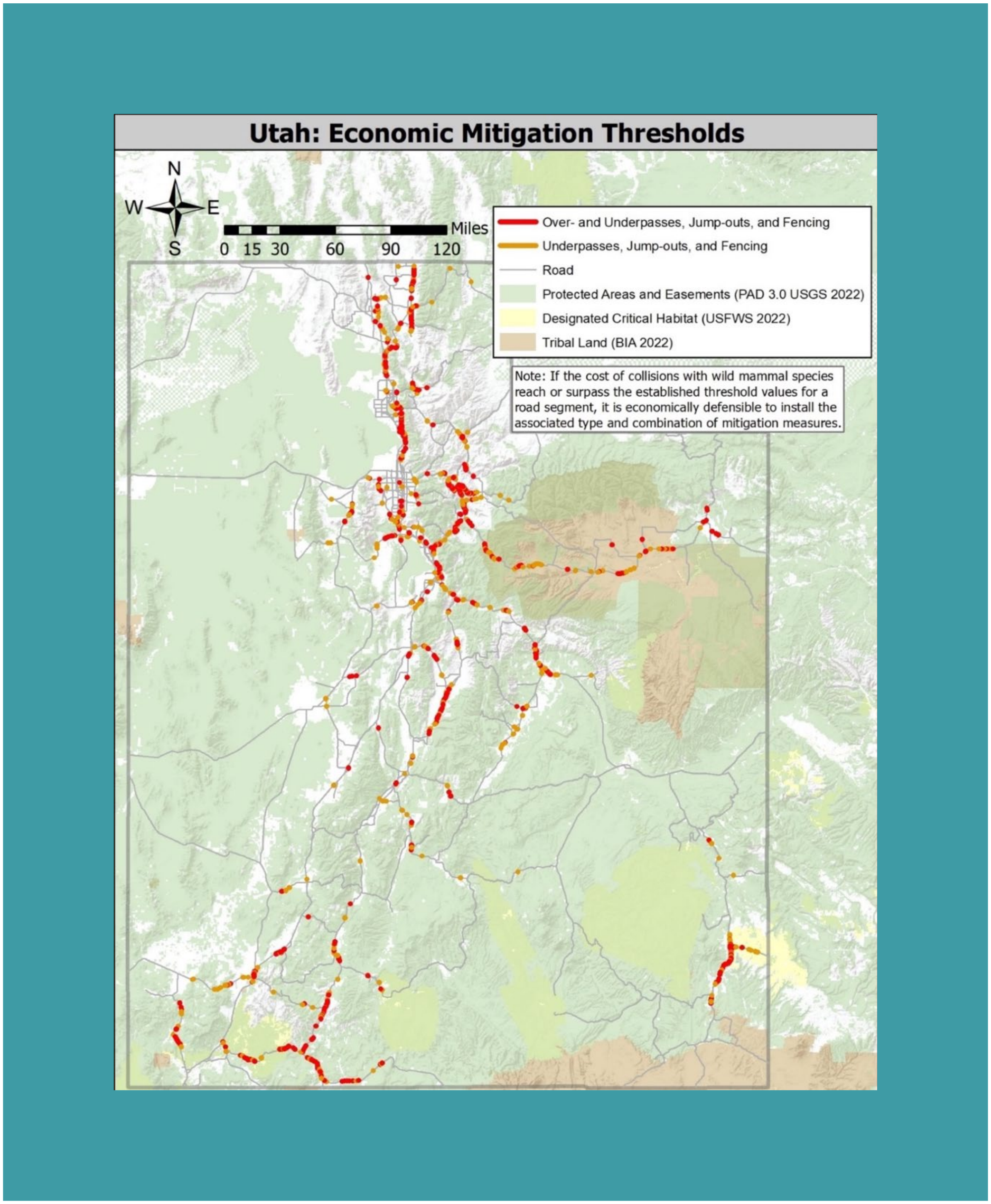

Figure 48. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

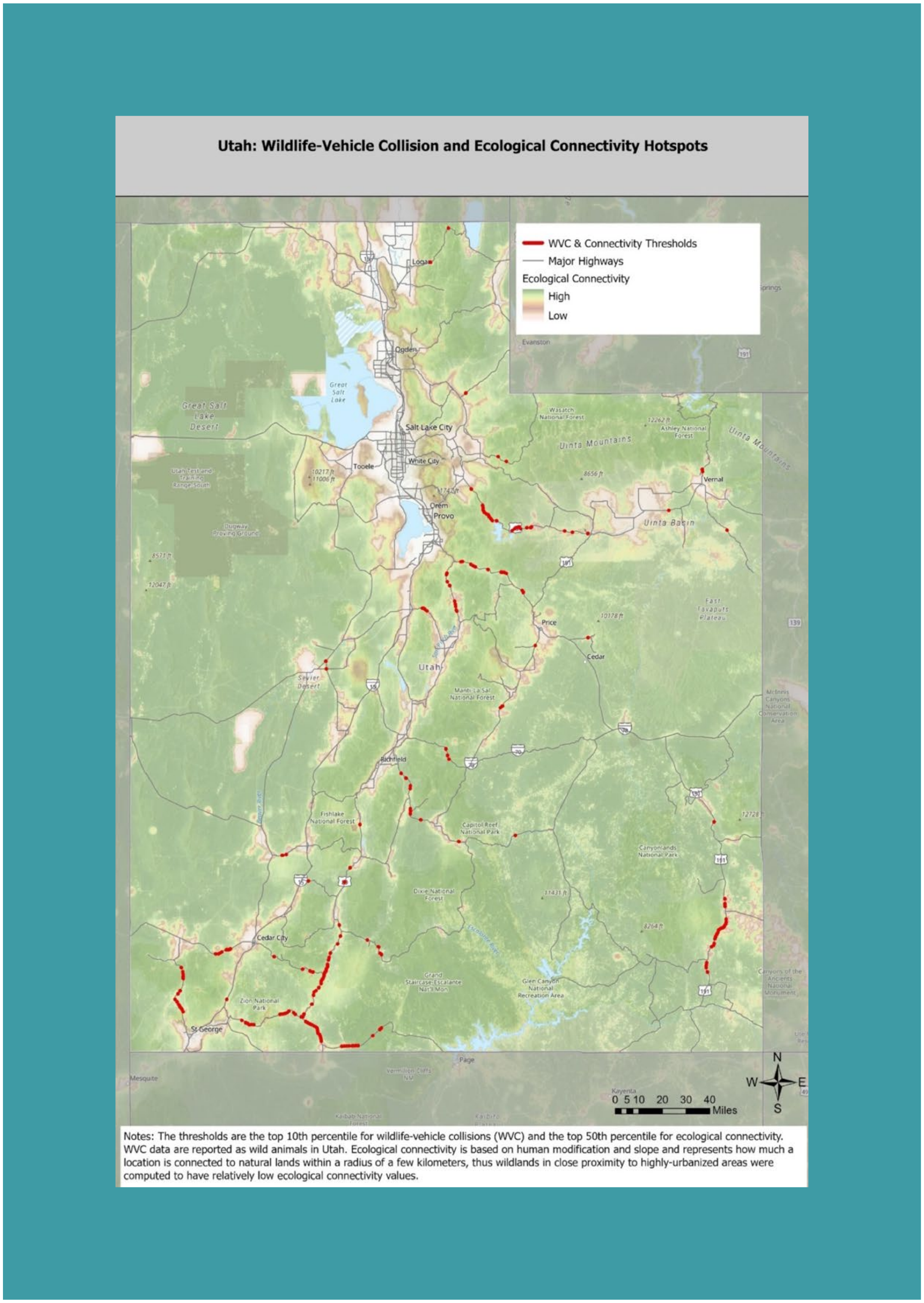

Figure 49. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

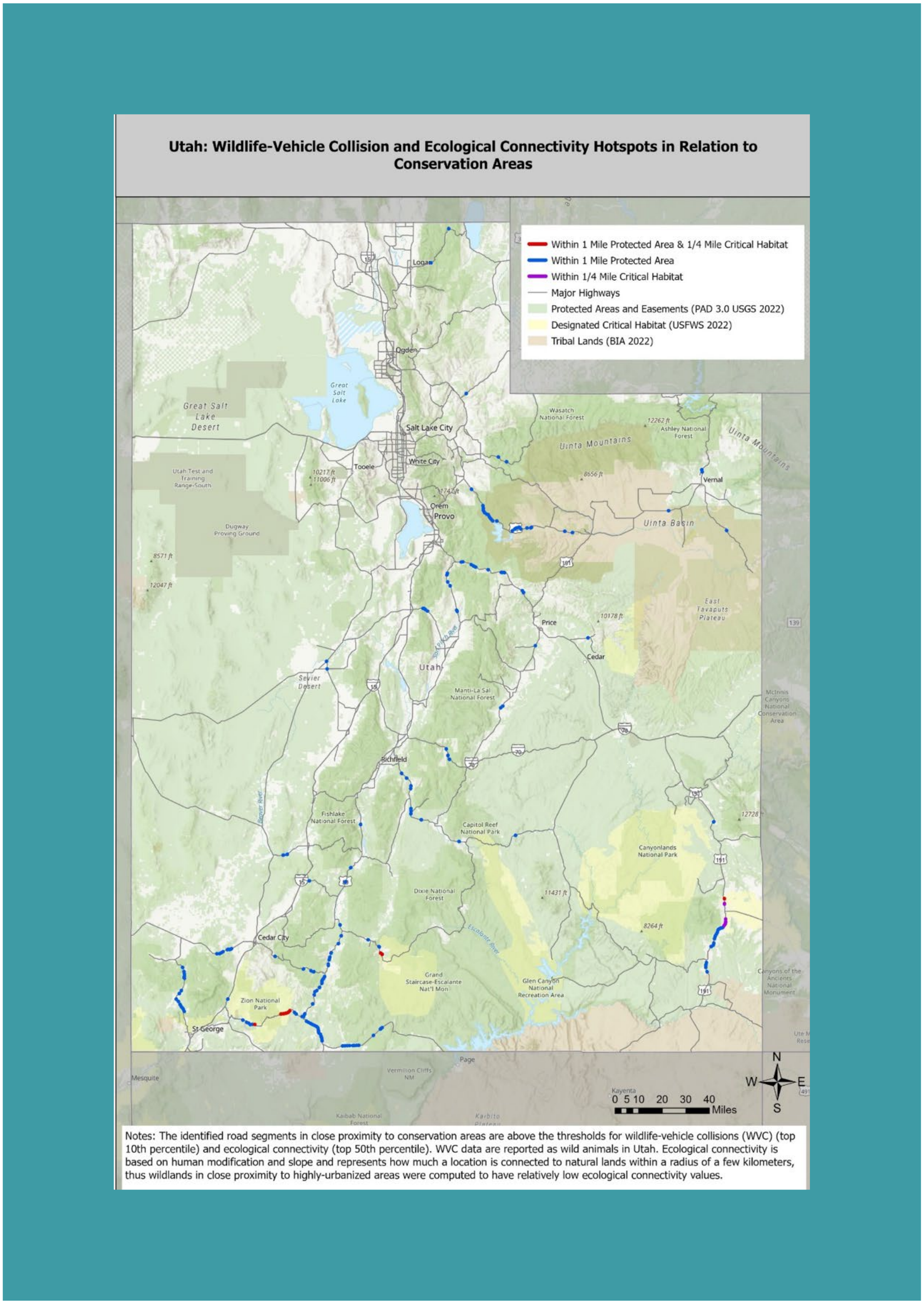

Figure 50. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

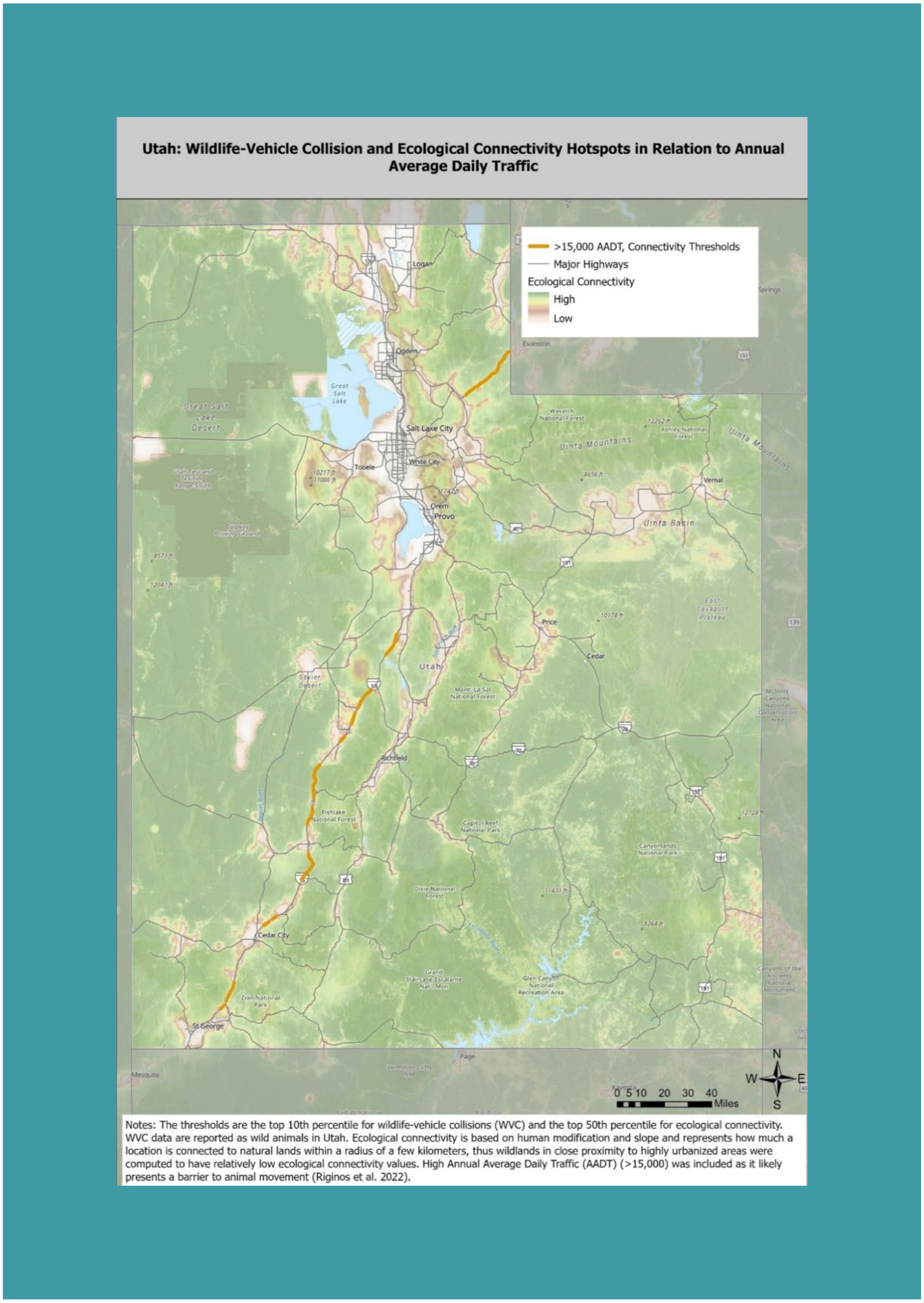

Figure 51. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

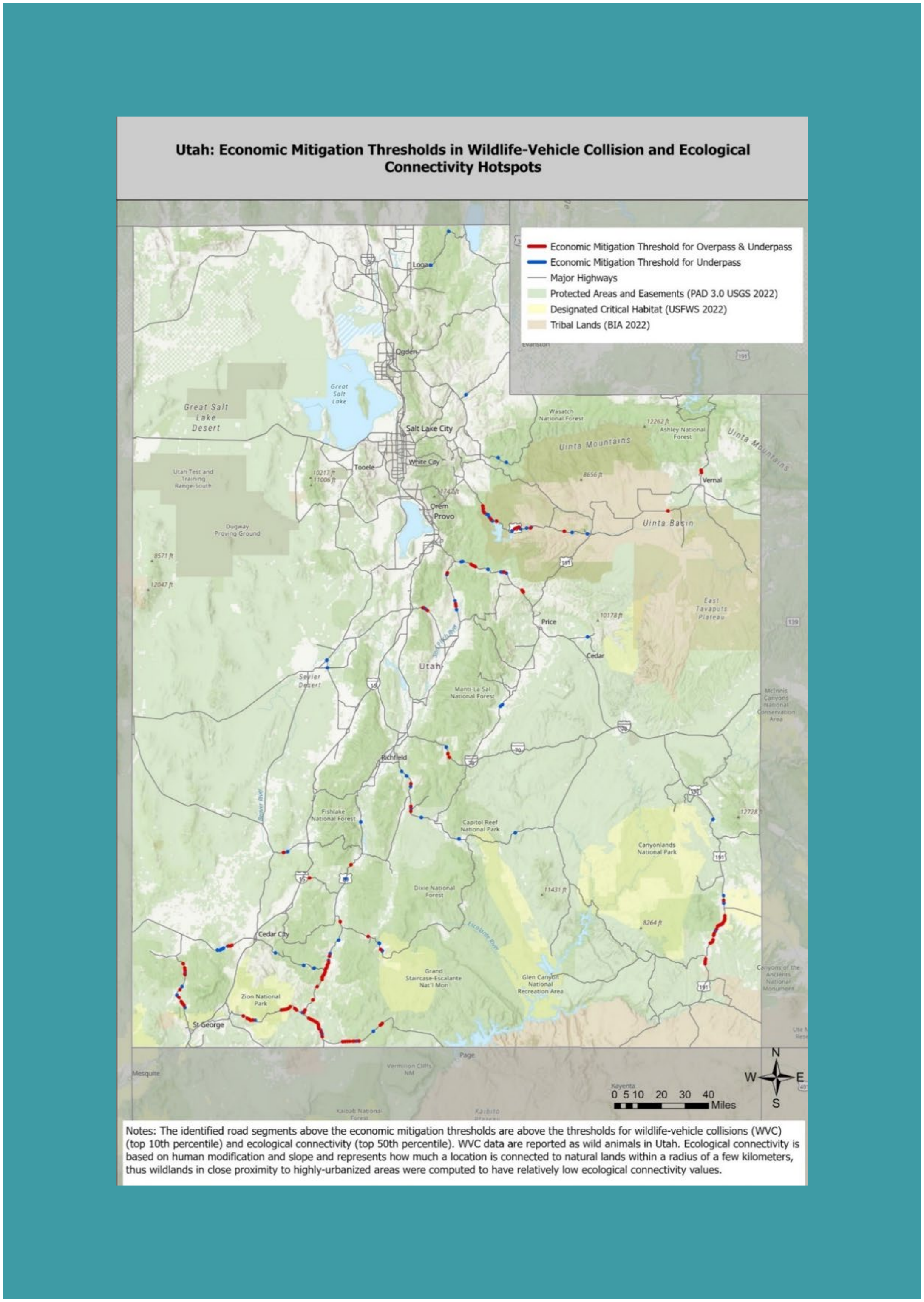

Figure 52. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

10. WASHINGTON

10.1 Safety and Economics

There was a total of 15,743 reported collisions with large wildlife over 11 years (2010-2020) in Washington (Table 4 of report). These collisions consisted of 14,426 with deer and 1,317 with elk. The reported WVC crash data shows that crash rates ranged from 0 to 7.06 WVC/mi/yr (Table 7 of report). There are 11.8% of the road segments that have a WVC rate (> zero WVCs), and the top 10th percentile of identified segments have 1.23 WVC/mi/yr and higher (Table 8 of report, Figure 53).

Based on costs and number of collisions, Washington's average cost of WVCs per year is $150,943,442 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 358 segments (62 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective, and 295 segments (51 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 9 of report, Figure 54).

10.2 Collisions and Connectivity

Washington's road segment lengths were on average 0.17 mi in length (Table 3 of report). There are 847 road segments (147 mi) within the top 10th percentile for WVC and 35,734 road segments (6,182 mi) within the top 50th percentile for connectivity (Table 1). There are 494 road segments (85 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 55).

10.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 494 (85 mi) CC road segments, 439 are within one mile of a protected area, 153 are within a quarter mile of critical habitat, and each of the 153 road segments near critical habitat are also within one mile to a protected area (Figure 56).

10.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 2,777 road segments (480 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 57). Of the 494 CC road segments, 109 (19 mi) experience high traffic volume (AADT ≥ 15,000 vehicles per day).

10.5 Collisions, Connectivity, and Costs

Of the 494 CC road segments, 200 (35 mi) meet the economic mitigation threshold where underpasses (with fencing with an apron and jump-outs) are cost-effective. There are 151 road segments (26 mi) meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Figure 58).

10.6 Other Resources to Examine

Cascades to Coast Landscape Collaborative. 2022. Coastal Northwest Landscape Conservation Mapper. https://www.ctoclc.org/conservationresources and https://fws.maps.arcgis.com/apps/webappviewer/index.html?id=a3c518e00ccf488db8cc0c8cd4646bce

McRae, B., K. Popper, A. Jones, M. Schinde, S. Buttrick., K. Hall, R. Unnasch, and J. Platt. 2016. Conserving Nature's Stage: Mapping Omnidirectional Connectivity for Resilient Terrestrial Landscapes in the Pacific Northwest. https://doi.org/10.13140/RG.2.1.4158.6166

Myers, W.L., W.Y. Chang, S.S. Germaine, W.M. VanderHaegen, and T.E. Owens. 2008. An analysis of deer and elk-vehicle collision sites along state highways in Washington State. Olympia, Wash., Washington Department of Fish and Wildlife. https://wdfw.wa.gov/sites/default/files/publications/01551/wdfw01551.pdf

Washington Wildlife Habitat Connectivity Working Group. 2022. Washington Connected Landscapes Project: Cascades to Coast Analysis. Washington Department of Fish and Wildlife, and Washington State Department of Transportation, Olympia, WA. https://waconnected.org/wp-content/uploads/2022/07/DRAFTReport_20220719.pdf

Washington Wildlife Habitat Connectivity Working Group. 2010. Washington connected landscapes project: Statewide analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. https://wdfw.wa.gov/publications/01324

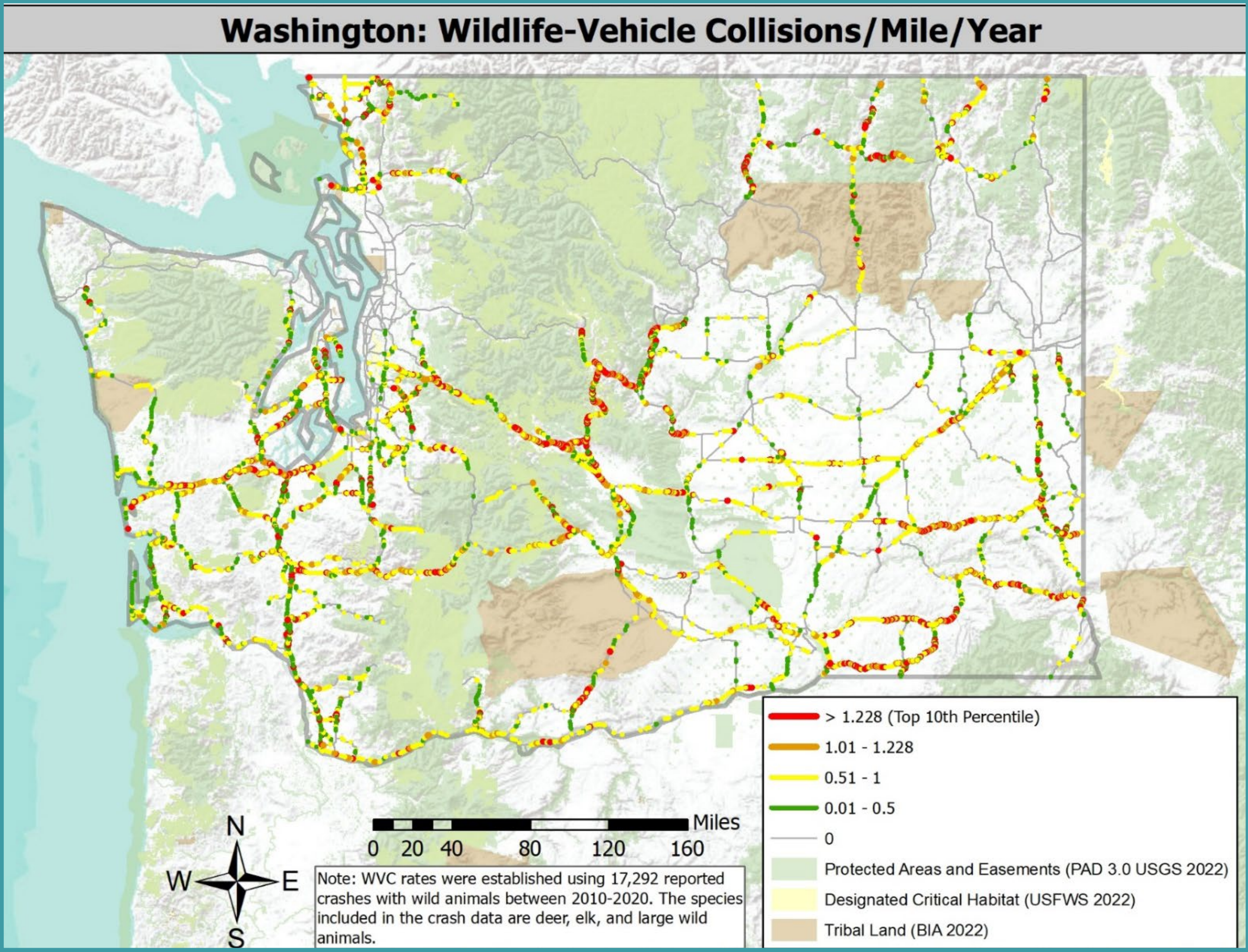

Figure 53. Average WVC rates for Washington state between 2010-2020.

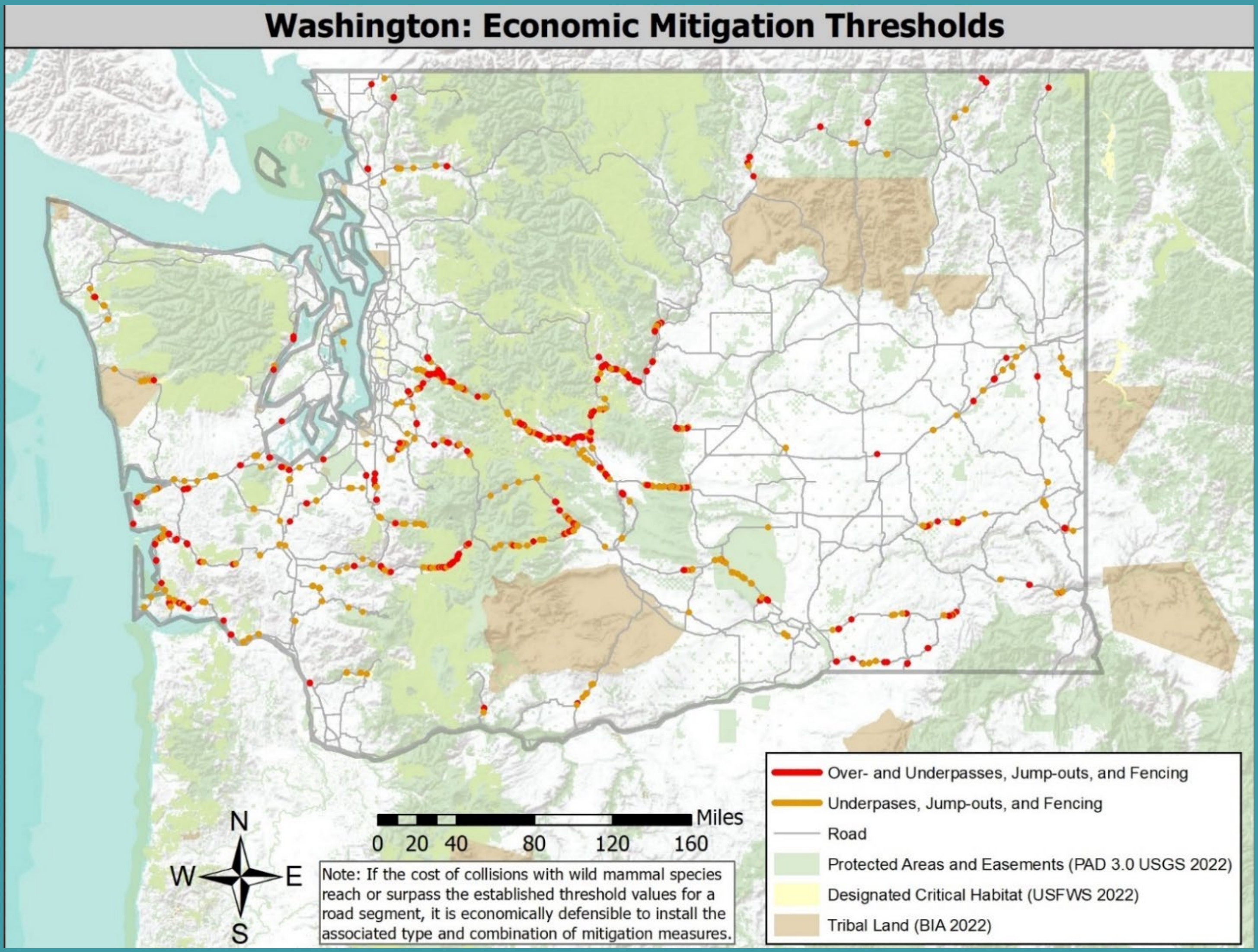

Figure 54. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

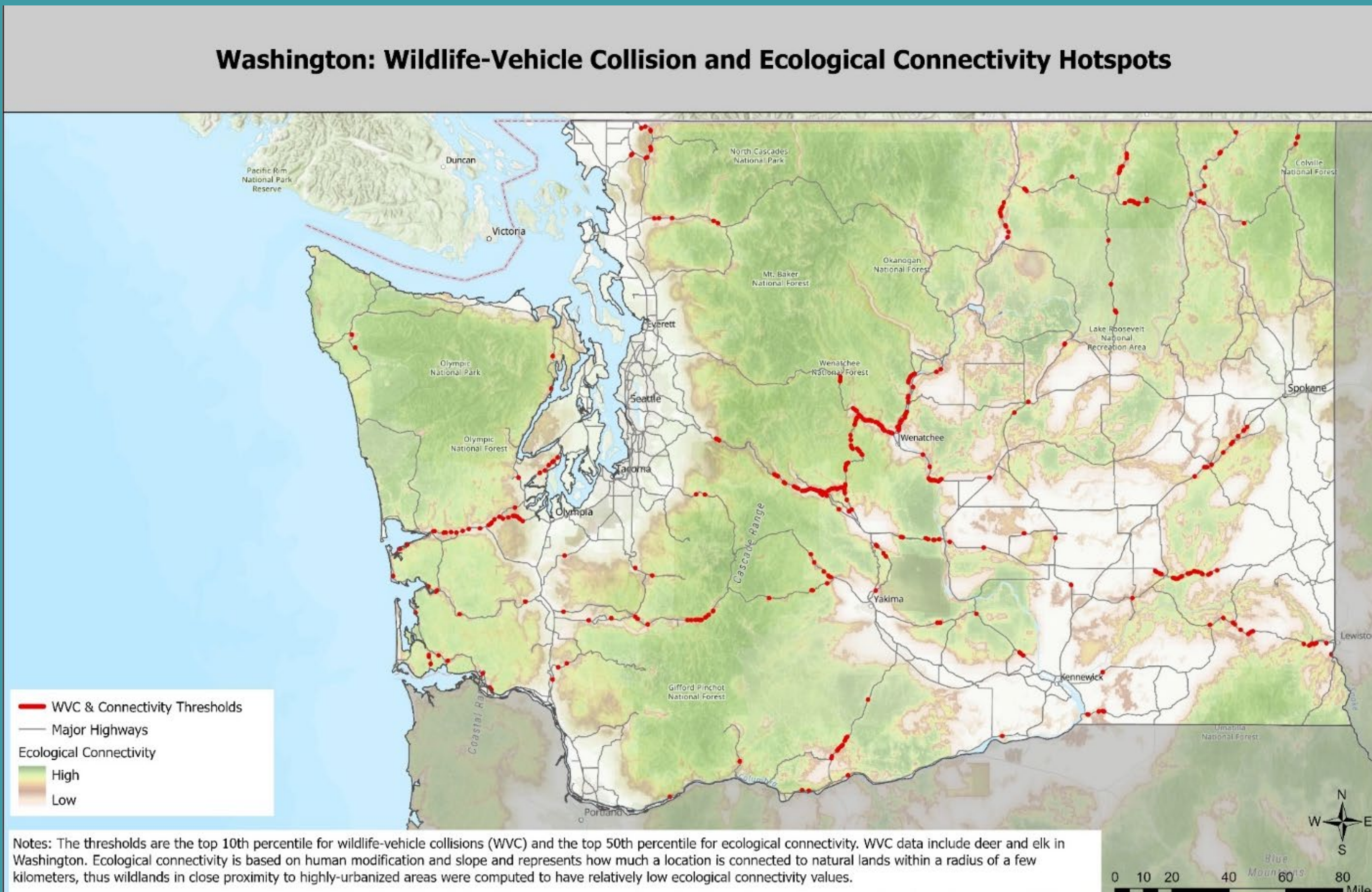

Figure 55. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

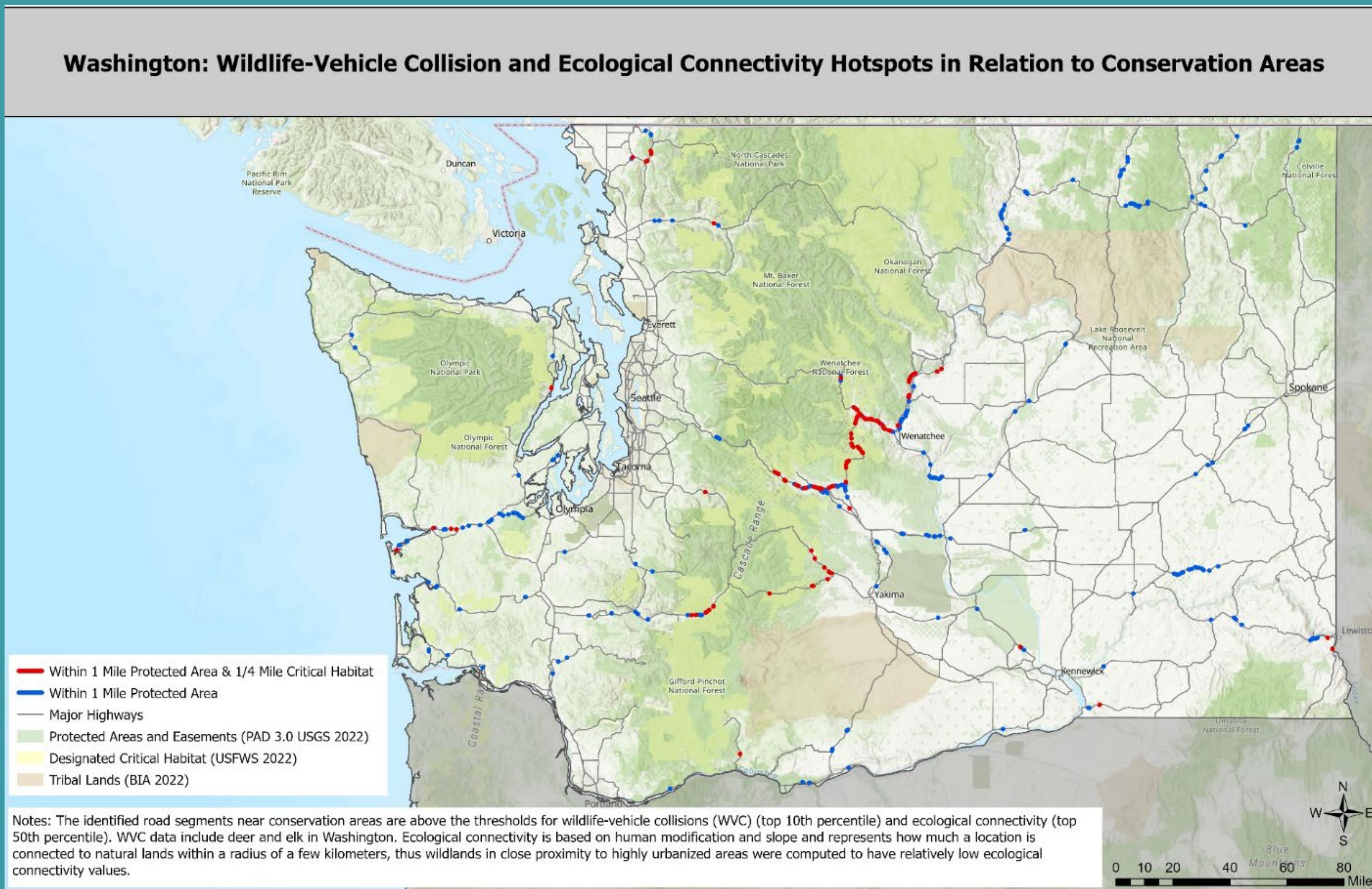

Figure 56. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

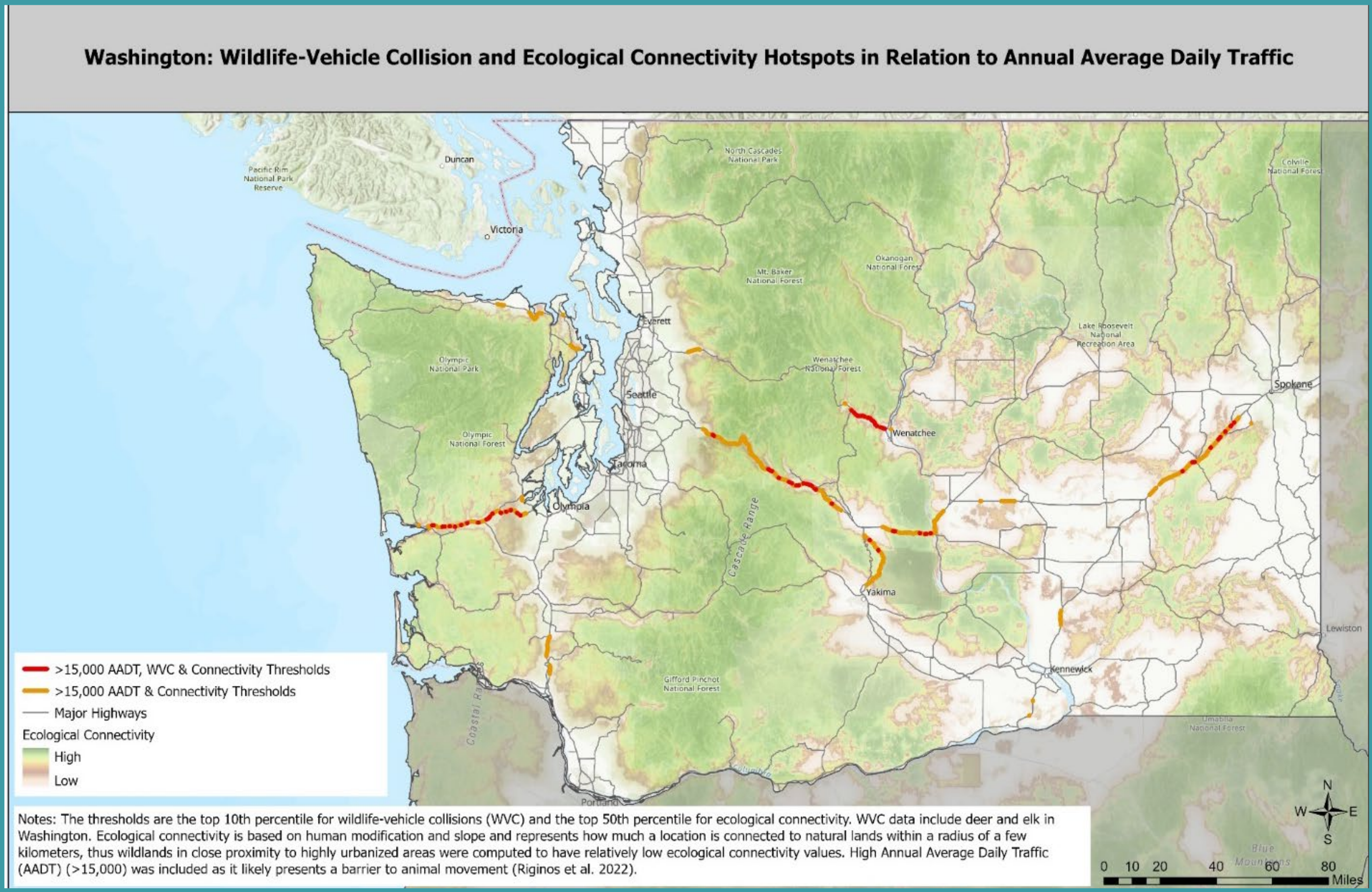

Figure 57. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

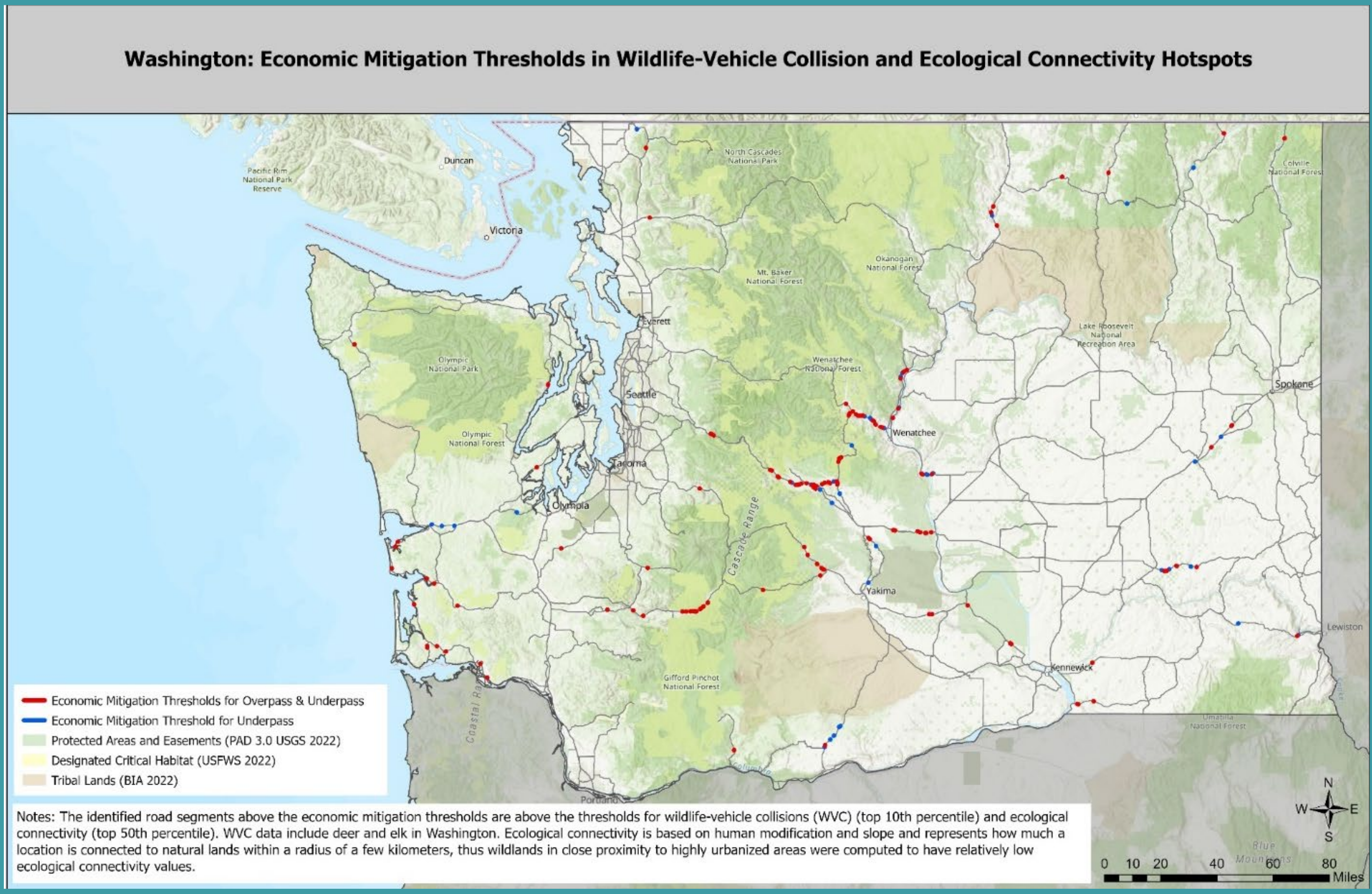

Figure 58. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).

11. WYOMING

11.1 Safety and Economics

There was a total of 23,766 reported collisions with large wildlife over 10 years (2011-2020) in Wyoming. These collisions consisted of 20,272 with deer, 1,141 with elk, 386 with moose, and 1,572 with antelope. The remaining 395 WVC locations were unidentified large wildlife. The reported WVC crash data shows that crash rates ranged from 0 to 11.65 WVC/mi/yr. There are 29.3% of the road segments that have a WVC rate (> zero WVCs), and the top 10th percentile of the identified segments have 1.54 WVC/mi/yr and higher (Figure 59).

Based on costs and number of collisions, Wyoming's average cost of WVCs per year is $204,039,048 (Table 9 of report). Across the state and without consideration of the 50th percentile connectivity threshold, there are 365 segments (97 mi) where underpasses (with fencing with apron and jump-outs) are most cost-effective, and 565 segments (150 mi) where under- and overpasses (with fencing with apron and jump-outs) are most cost-effective and should be considered from an economic perspective alone (Table 1, Figure 60).

11.2 Collisions and Connectivity

Wyoming's road segment lengths were on average 0.27 mi in length (Table 4 of report). There are 1,166 road segments (310 mi) within the top 10th percentile for WVC and 19,906 road segments (5,295 mi) within the top 50th percentile for connectivity (Table 1). There are 238 road segments (63 mi) that exceed both the WVC and connectivity thresholds (called CC road segments) (Figure 61).

11.3 Collisions, Connectivity, and Conservation – Protected Areas and Critical Habitat

Of the 238 (63 mi) CC road segments, 225 (60 mi) are within one mile of a protected area, 22 (6 mi) are within a quarter mile of critical habitat, and each of the 22 road segments near critical habitat are also within one mile to a protected area (Table 1, Figure 62).

11.4 Collisions, Connectivity, and Conservation – High Traffic Volume

There are 16 road segments (4 mi) that exceed the connectivity threshold and experience high traffic volume (Table 1, Figure 63). Of the 238 CC road segments, no segment experiences high traffic volume (AADT ≥ 15,000 vehicles per day).

11.5 Collisions, Connectivity, and Costs

Of the CC road segments, 113 (30 mi) meet the economic mitigation threshold where underpasses (with fencing with an apron and jump-outs) are cost-effective, and 87 road segments (23 mi) that meet the economic threshold for where under- and overpasses (with fencing with apron and jump-outs) are cost-effective (Table 1, Figure 64).

11.6 Other Resources to Consider

Huijser, M.P., C. Riginos, M. Blank, R. Ament, J.S. Begley, and E.R. Jenne. 2018. Teton County wildlife master plan. Western Transportation Institute, Montana State University, Bozeman, Montana, USA. https://westerntransportationinstitute.org/wp-content/uploads/2016/10/4W6376-Huijser-et-al-Report-Teton-County-20180531-LR.pdf

Riginos C. 2022. Impact of roadways on wildlife in Wyoming: long-term and recent trends. The Nature Conservancy, Lander, WY.

Riginos, C., C. Smith, E.R. Fairbank, E. Hansen, and P. Hallsten. 2018. Traffic thresholds in deer road-crossing behavior. No. WY-1807F. Northern Rockies Conservation Cooperative for Wyoming Department of Transportation. https://rosap.ntl.bts.gov/view/dot/58648

Riginos, C., H. Copeland, C. Smith, H. Sawyer, K. Krasnow, and T. Hart. 2016. Planning-support for mitigation of wildlife–vehicle collisions and highway impacts on migration routes in Wyoming. FHWA-WY-16/10F. Wyoming Department of Transportation, Cheyenne, WY.

Wyoming Wildlife and Roadways Initiative Implementation Team. 2019. A Framework for Prioritizing Projects to Reduce Negative Wildlife-Roadway Interactions. Wyoming Game and Fish Department and Wyoming Department of Transportation. https://wgfd.maps.arcgis.com/apps/MapSeries/index.html?appid=ef666ba292b74c56a339efc10fca5332

Wyoming Wildlife and Roadways Initiative website. https://wgfd.maps.arcgis.com/apps/MapSeries/index.html?appid=ef666ba292b74c56a339efc10fca5332

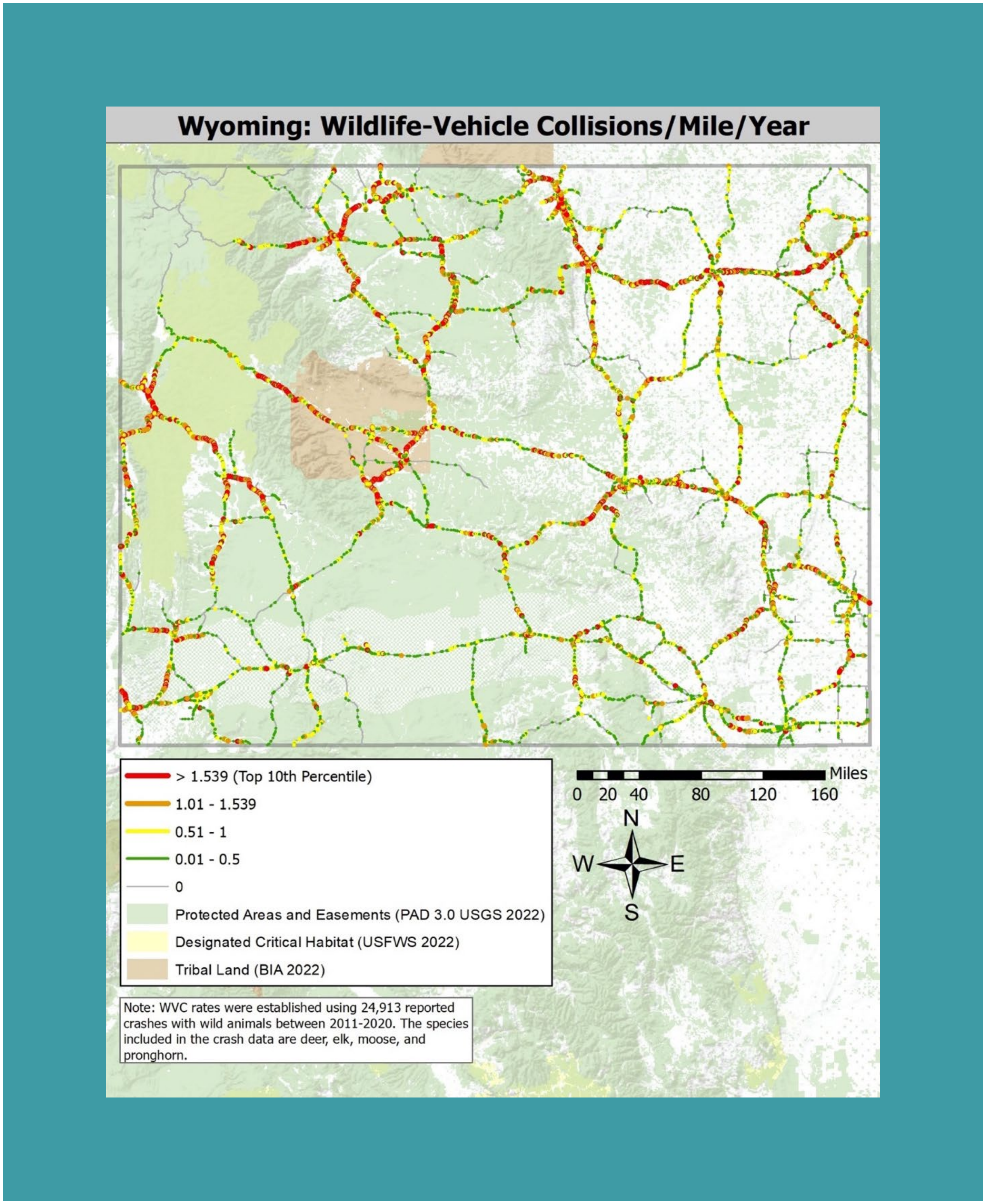

Figure 59. Average WVC rates for Wyoming between 2011-2020.

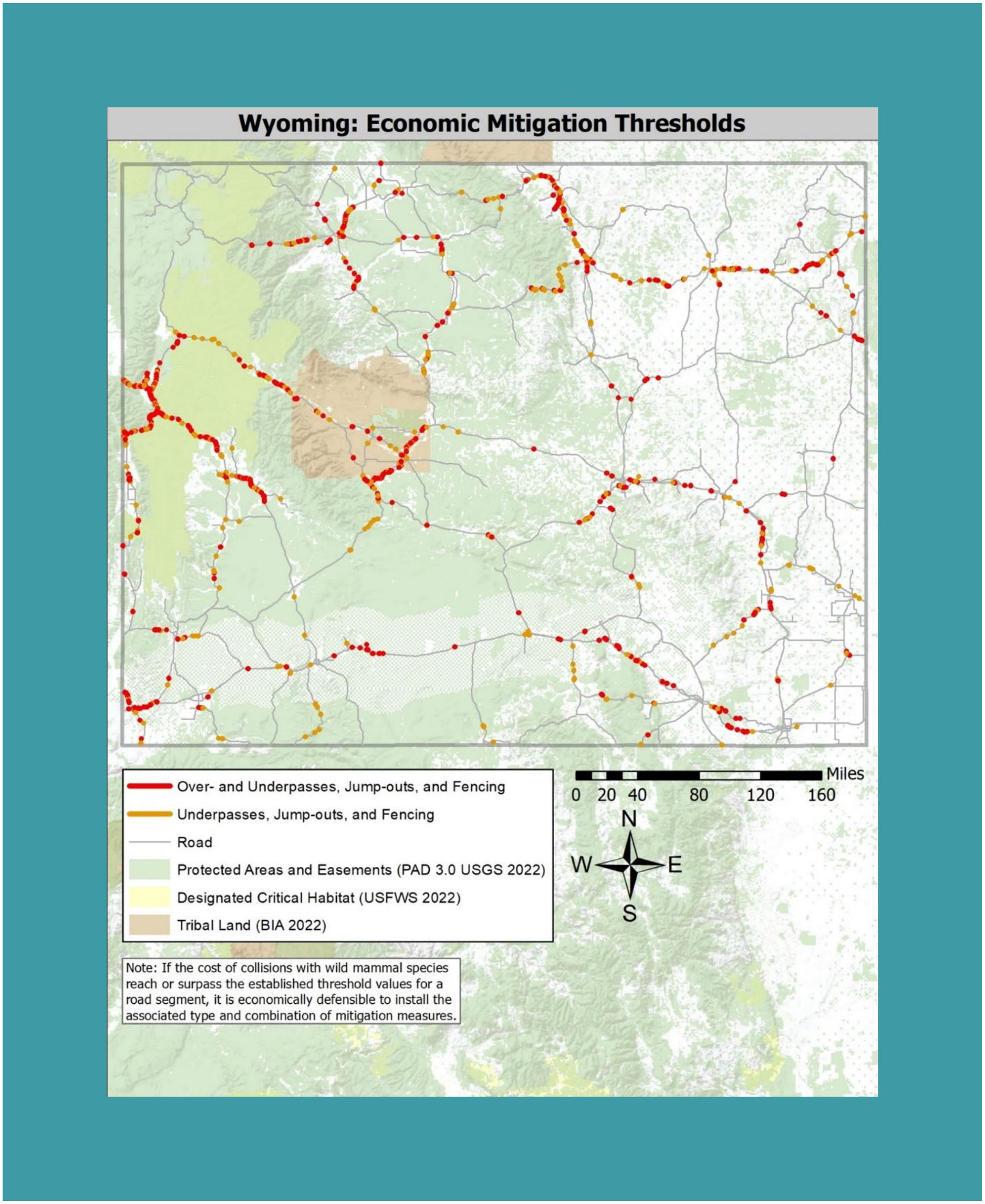

Figure 60. Road segments that meet the economic threshold for underpasses (with wildlife fencing, apron, and jump-outs) and the threshold for under- and overpasses (with wildlife fencing with apron, and jump-outs) without consideration of collision/connectivity thresholds. These are all road segments, not just the CC road segments.

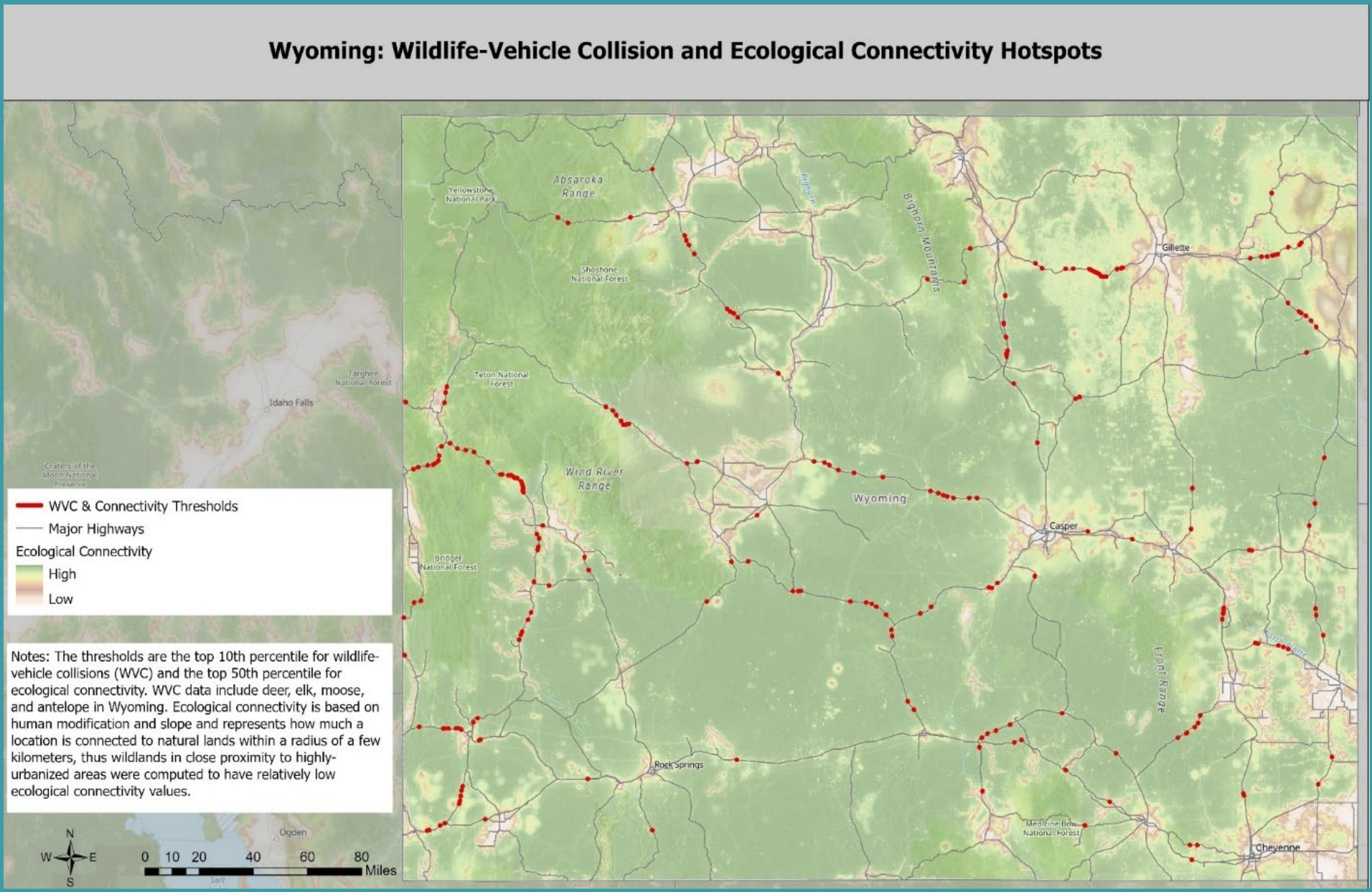

Figure 61. Road segments above the top 10th percentile for wildlife-vehicle collisions and above the 50th percentile for ecological connectivity (called CC road segments).

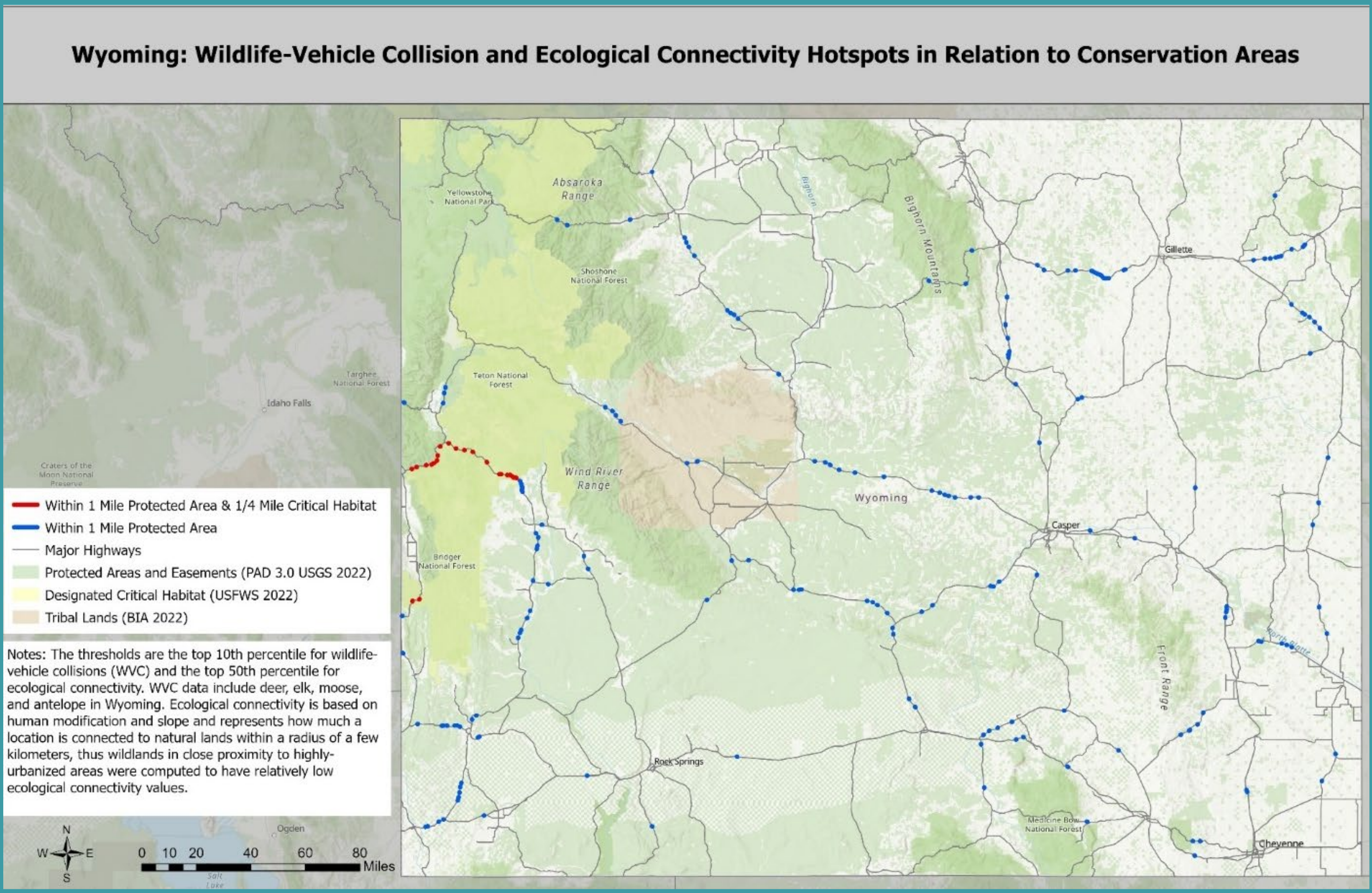

Figure 62. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, and that are a) within one mile of protected areas (blue), b) within ¼ mile of critical habitat purple), or c) within these distances of both types of conservation areas (red).

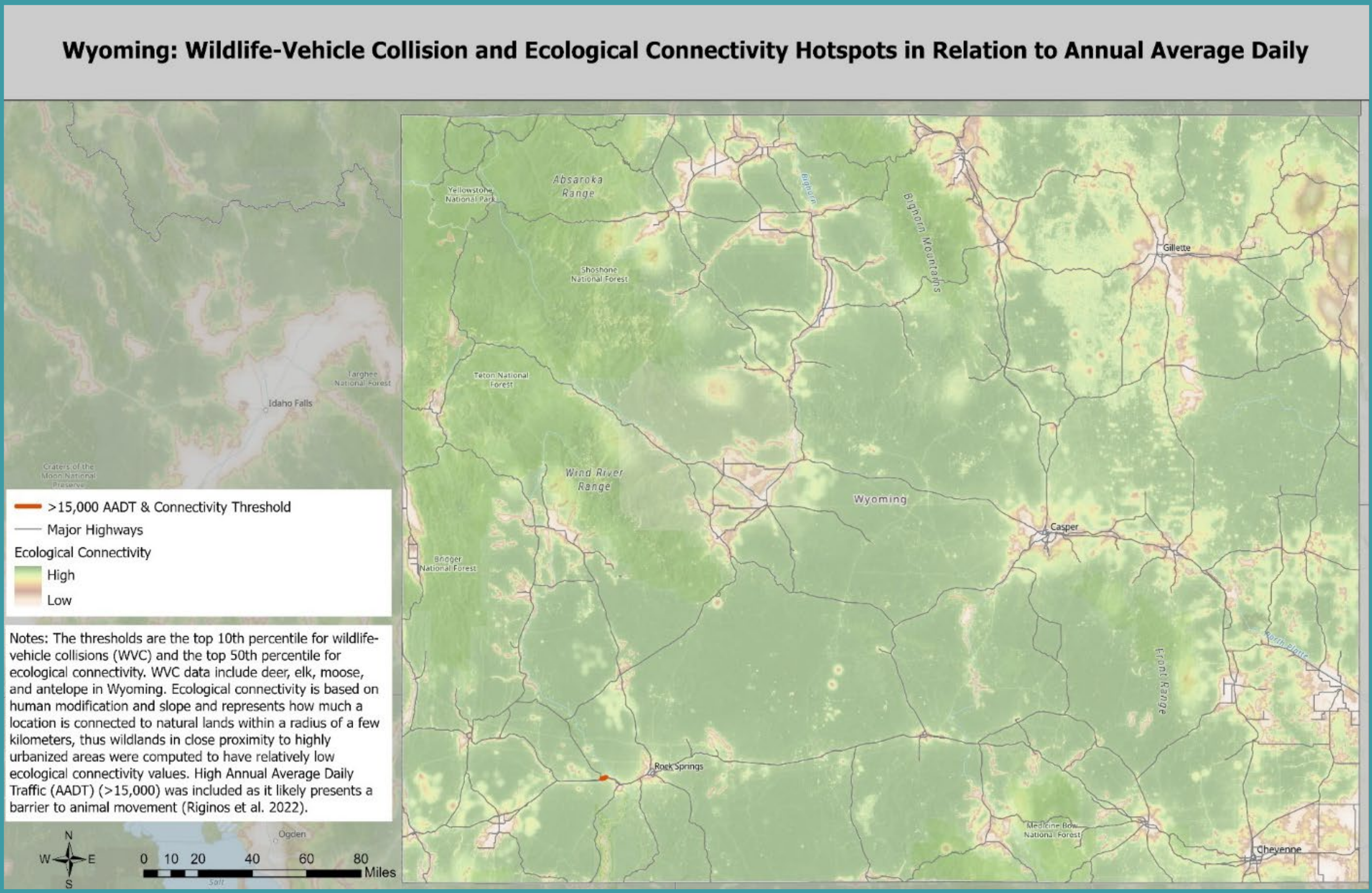

Figure 63. Road segments i) above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity, with high traffic volume of AADT ≥ 15,000 (red), and ii) above the 50th percentile for ecological connectivity with high traffic volume of AADT ≥ 15,000 (orange).

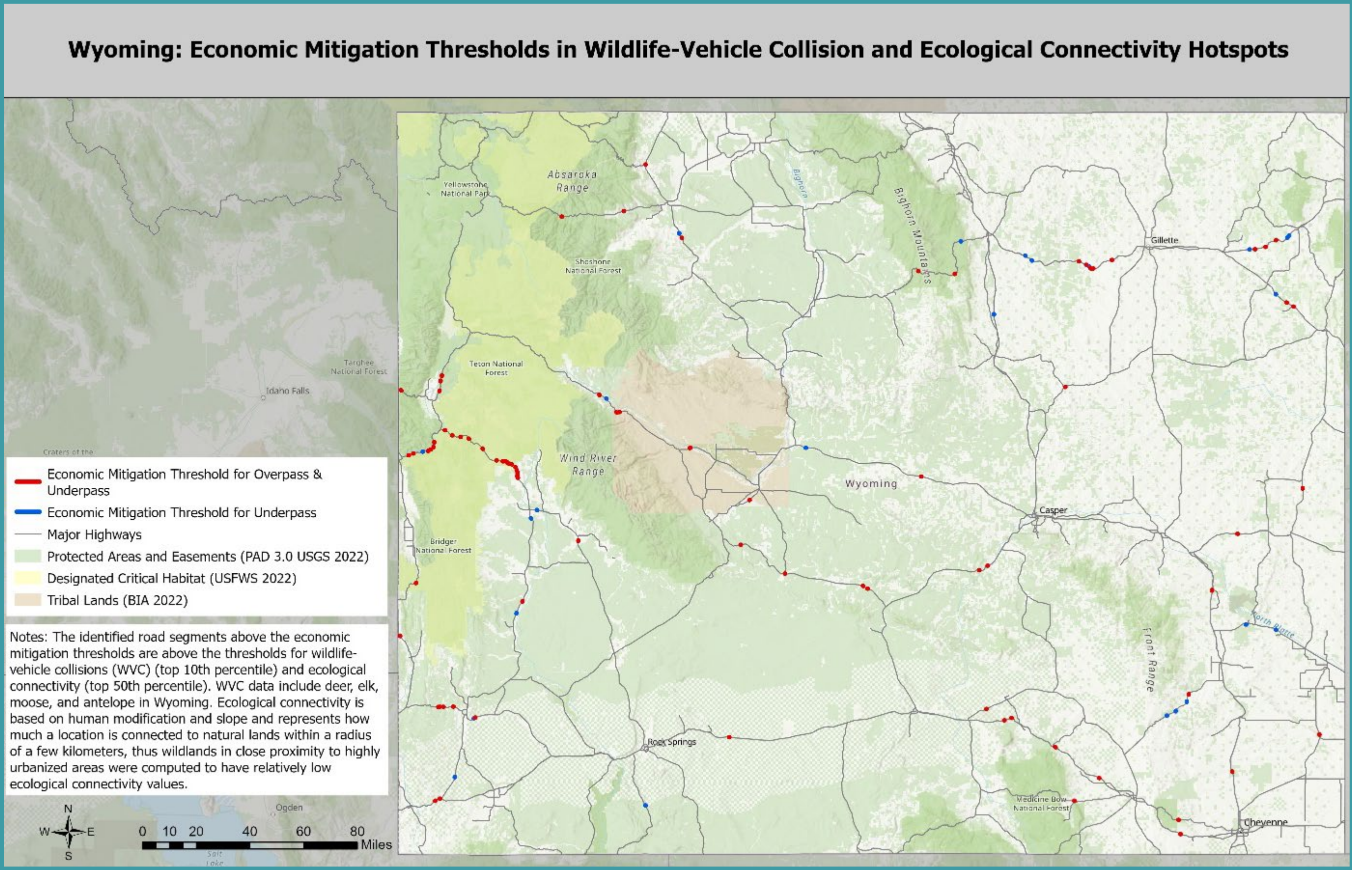

Figure 64. Road segments above the top 10th percentile for WVCs and the 50th percentile for ecological connectivity that meet the economic mitigation thresholds. Economic mitigation considers building an overpass and underpass (with fencing with an apron and jump-outs) (red), or underpass (with fencing with an apron and jump-outs) (blue).