WASHINGTON CONNECTED LANDSCAPES PROJECT:

ANALYSIS OF THE COLUMBIA PLATEAU ECOREGION

WASHINGTON WILDLIFE HABITAT CONNECTIVITY WORKING GROUP

FEBRUARY 2012

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Washington Connected Landscapes Project:
Analysis of the Columbia Plateau Ecoregion

Washington Wildlife Habitat
Connectivity Working Group

February 2012

Mission Statement of the
Washington Wildlife Habitat Connectivity Working Group

Promoting the long-term viability of wildlife populations in Washington State through a science-based, collaborative approach that identifies opportunities and priorities to conserve and restore habitat connectivity

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Executive Summary

Sonia A. Hall (TNC) and Joanne Schuett-Hames (WDFW)

Introduction

In the early 1800s, it took Lewis and Clark the better part of three years to travel from the Atlantic seaboard to the Pacific Ocean and back. Today, the same trip takes less than a day. People benefit in many ways from living in such a connected world. Being connected improves our lives by giving us access to new places, resources, partners, and ideas. However, the essential features of our modern and connected world—roads, railroads, transmission lines, irrigation canals, reservoirs, agricultural fields, mines, and houses—tend to fragment the natural world and affect animal movement. Like us, animals benefit from connectivity, and are harmed by isolation. When connected, even small patches of habitat function more like large patches, supporting more abundant, diverse, and resilient wildlife populations. For our world to continue enjoying healthy and diverse wildlife populations and the resources and values that wildlife represent, it is not only people who need to be connected; we also need to provide natural connections for animals.

The Washington Wildlife Habitat Connectivity Working Group (WHCWG) was formed to address issues of wildlife habitat connectivity within Washington and surrounding lands. Our mission is to "*promote the long-term viability of wildlife populations in Washington State through a science-based, collaborative approach that identifies opportunities to conserve and restore habitat connectivity*." The analysis described in this Executive Summary and the full report provides a vision for a connected landscape in the Columbia Plateau Ecoregion in Washington, and synthesizes the information that organizations need to incorporate connectivity into conservation efforts while meeting their own organizational goals and priorities.

Connectivity Analysis of the Columbia Plateau Ecoregion

The *Washington Connected Landscapes Project: Statewide Analysis* produced in 2010 (WHCWG 2010) was an important first step for connectivity conservation. It described broad connectivity patterns for Washington State and neighboring areas in British Columbia, Idaho, and Oregon and highlighted the Columbia Plateau as an ecoregion where native vegetation communities are severely fragmented, limiting movement potential for animals. We then focused on this more detailed and comprehensive connectivity analysis of the Columbia Plateau Ecoregion in the United States[1] (Fig. ES.1), with the **goal of identifying the most important areas for maintaining and enhancing wildlife habitat connectivity across this ecoregion**. This analysis bridges the broad patterns of connectivity we observed in the statewide analysis to local scale and project-level conservation efforts.

[1] Our study area includes the Columbia Plateau Ecoregion and those lands within a 25 km buffer around the ecoregion boundary. Because of modeling constraints we do not include in our analysis the portion of the Columbia Plateau Ecoregion that extends into British Columbia, Canada.

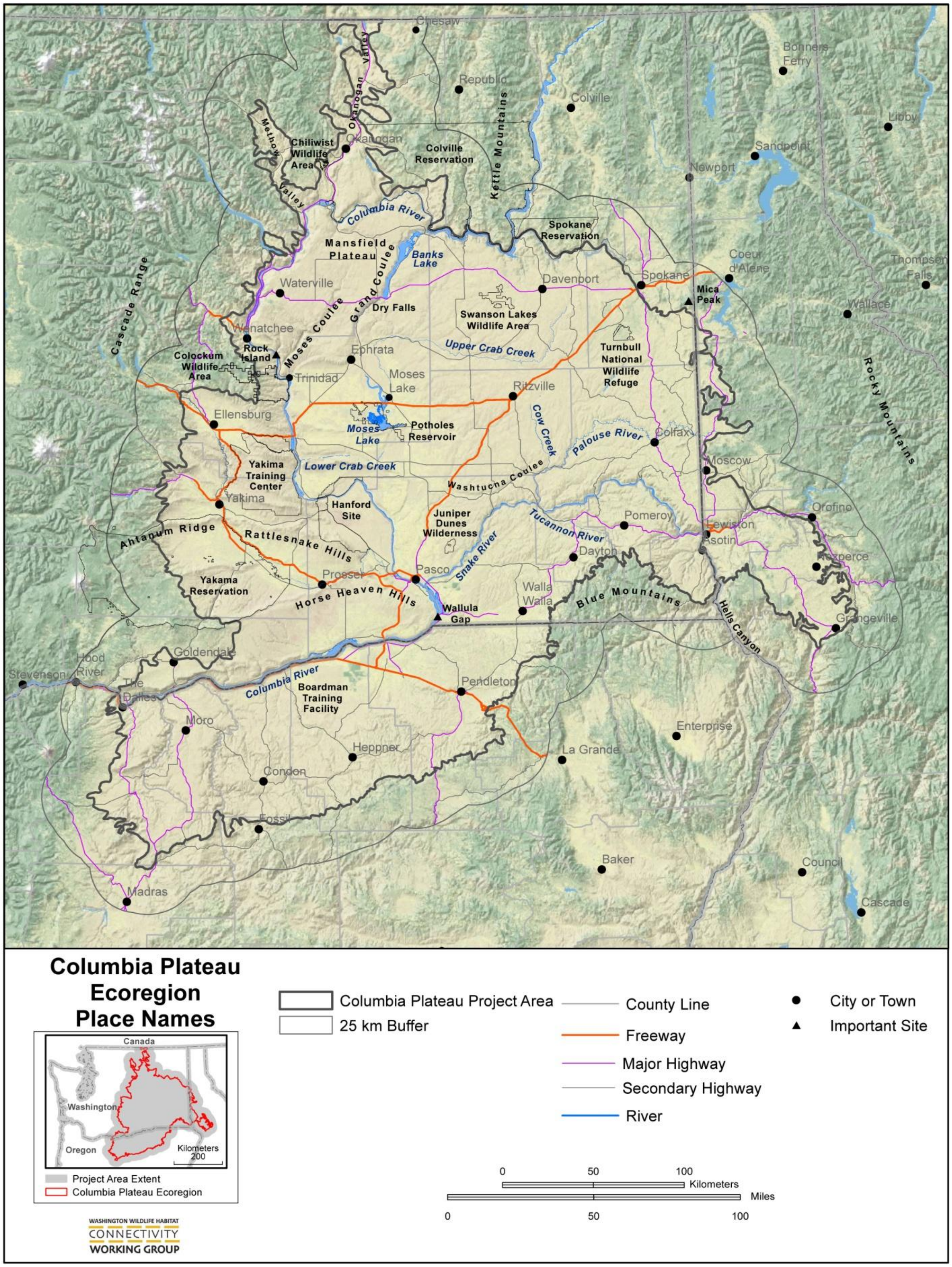

Figure ES.1. The Columbia Plateau Ecoregion showing common geographic features and place names.

The main products of our analysis are maps that depict linkage networks and the data and models used to create them. A linkage network includes areas of suitable habitat (called habitat concentration areas, or core areas) and the linkages connecting them. Sometimes the linkages include stepping stones of good habitat, though they are not contiguous enough to be characterized as habitat concentration or core areas. Other times the linkages follow the best, albeit marginal, movement routes through poor or degraded habitat, if there is nothing else available. The pathways that linkages take are influenced by both natural and man-made features across the landscape that may impede movement. For example, a linkage pathway may trace around cliffs, large lakes, or other natural impediments to animal movement, as well as developed areas, highways, or extensive agricultural areas.

The linkage network maps we present in this report are derived from two modeling approaches: focal species and landscape integrity. Our focal species approach produced linkage networks for 11 focal species selected to represent the connectivity needs of a broader assemblage of wildlife (See example in Fig. ES.2). Our landscape integrity approach identified cores of relatively intact natural areas with low levels of human modification, and linkages tracing the least-modified routes between them (Fig. ES.3). These two different approaches identified broadly similar patterns of habitat connectivity, giving us confidence that this modeling effort effectively represents the connectivity needs of our study area.

This Executive Summary describes the two main outcomes of the connectivity analysis of the Columbia Plateau Ecoregion: (1) a vision for a connected Columbia Plateau in Washington, and (2) recommendations for maintaining and restoring connectivity to achieve this vision.

(continued on page 6)

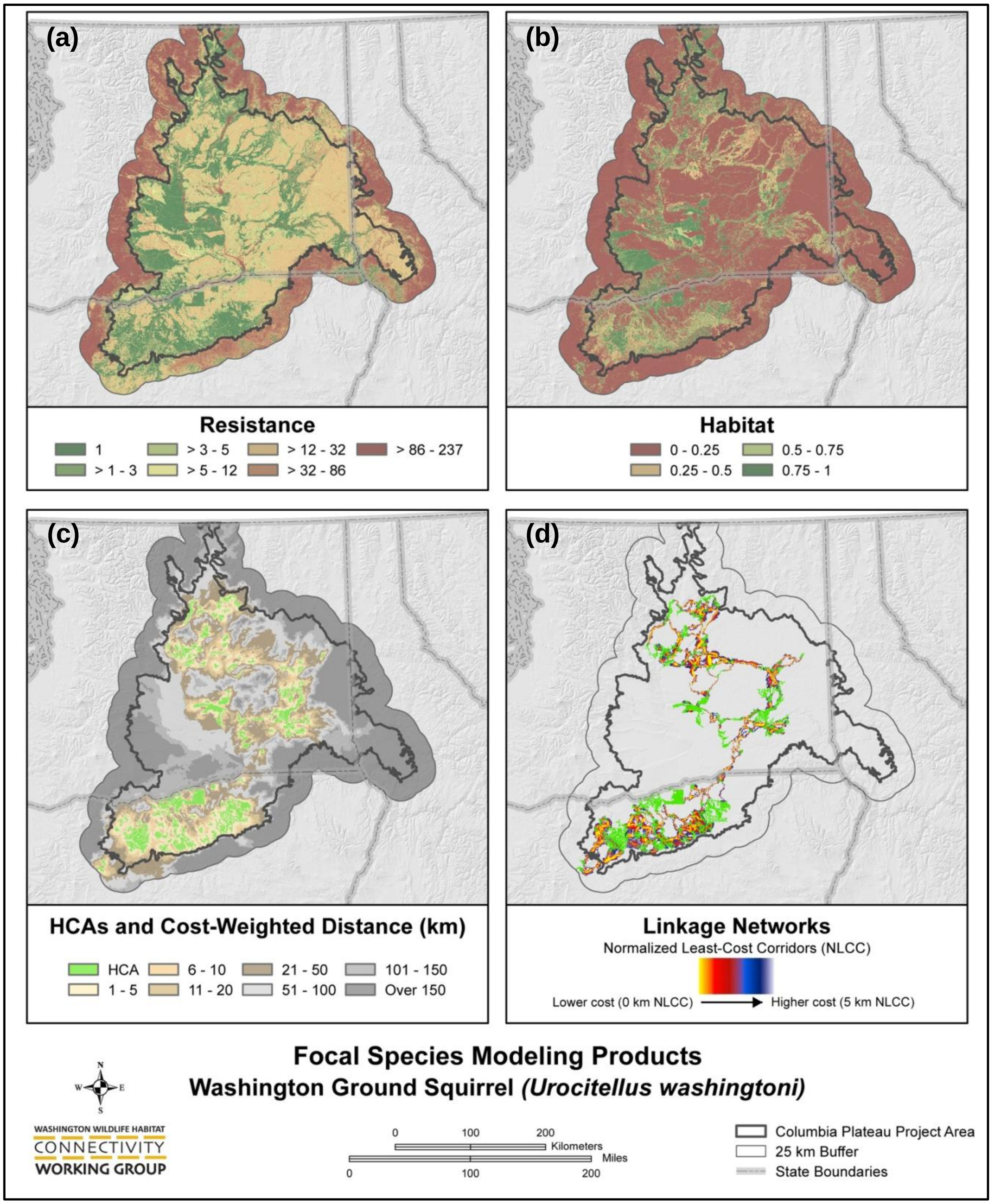

Figure ES.2. Main products of the focal species modeling approach. (a) Resistance, depicting how hard it is for the species to move across the landscape. (b) Habitat value, reflecting habitat suitability for the species across the landscape. (c) Habitat concentration areas (HCAs), where suitable habitat for the species is most dense; and cost-weighted distance, which provides a measure of the accumulated cost of movement as the species moves away from a HCA. This measure considers both the actual distance from the habitat area and the resistance to movement of the intervening landscape. (d) Linkage networks, which include the habitat concentration areas and the linkages connecting them, follow the path of least resistance for the species between neighboring habitat areas.

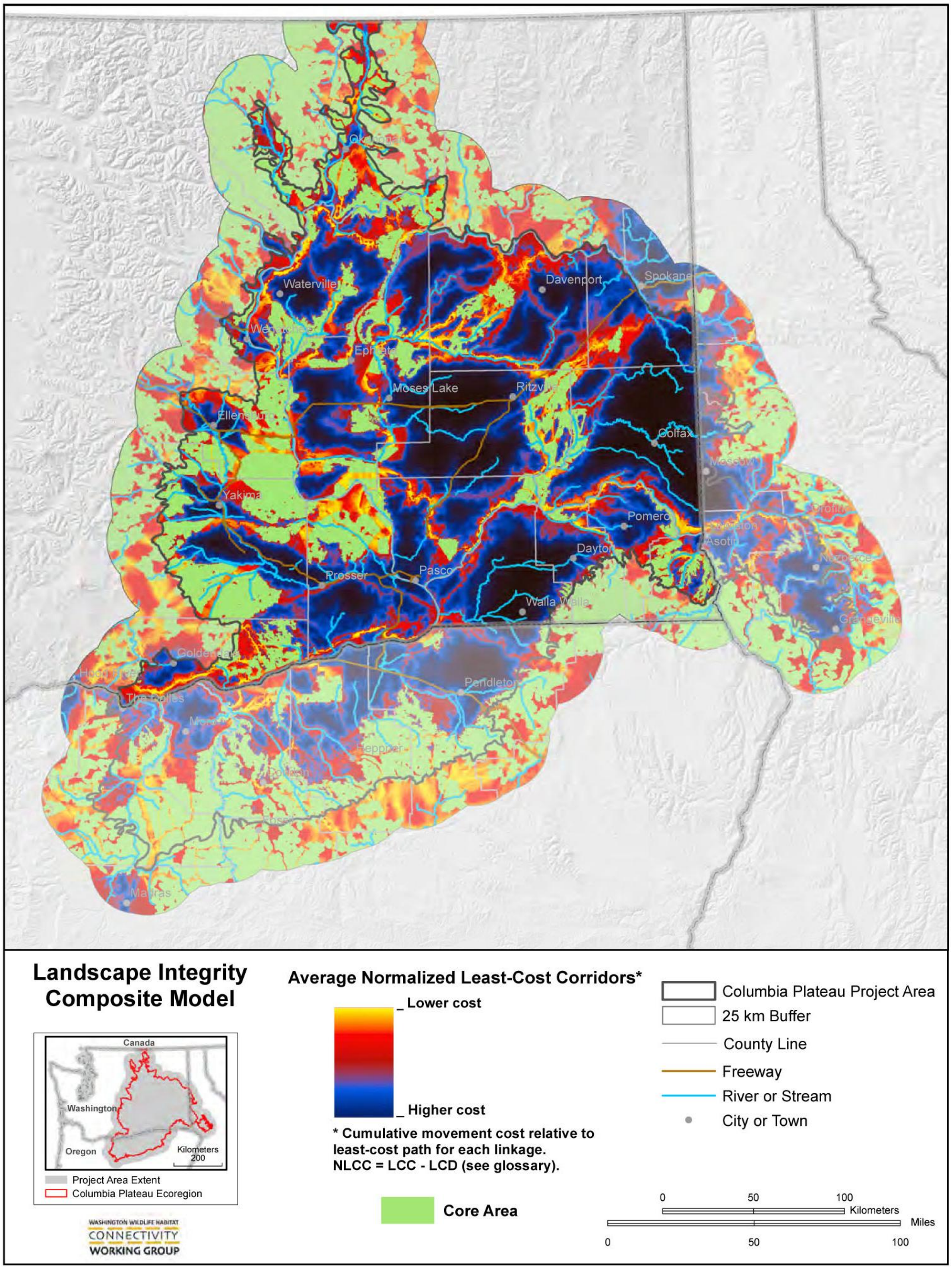

Figure ES.3. Landscape integrity composite model map. This map indicates the results from the combined linear, minimum, medium, and maximum linkage models (See full document for details of these models).

A Vision for a Connected Columbia Plateau Ecoregion in Washington

We have identified two broad regions and two critical sets of complex linkage zones—each containing multiple individual core areas and linkages—that together provide a vision for a connected Columbia Plateau landscape in Washington and beyond. These are:

- Central Washington's **Connected Backbone**, from the Horse Heaven Hills through to the Okanogan Valley (Fig. ES.4)—This series of loosely linked core areas has been identified as important in all the analyses carried out so far as part of the *Washington Connected Landscapes Project*. This result reinforces the conclusion of the statewide analysis that conversion and development in the Columbia Plateau has constrained potential movement routes for wildlife to fewer and fewer portions of the landscape (WHCWG 2010).
- The **Braided Scablands Swath**, from Spokane to the confluence of the Snake and Columbia rivers (Fig. ES.4)—In the eastern portion of the Columbia Plateau, movement routes are even more constrained, and generally follow lands still dominated by native habitat, mostly the lands scoured by the Missoula Floods, where soils are too shallow or rocky or the land too rugged to be used for agriculture. A well-connected system of Washington's arid lands will not be achieved with a sole focus on the north–south Connected Backbone in central Washington; it should also link to this Braided Scablands Swath and beyond.
- Complex east–west linkage zones between the Connected Backbone and the Braided Scablands Swath—The **Upper Crab Creek** and the **Lower Crab Creek Linkage Zones** encompass the main pathways that would allow for east–west movement (Fig. ES.4). These pathways are a critical component of a connected landscape. Like rungs of a ladder, these linkage zones connect two mostly parallel bands of habitat running approximately north to south, transforming them into a network of habitat that spans the majority of Washington's arid lands.
- Complex linkage zones beyond Washington, connecting the Washington network to surrounding areas (Fig. ES.4)—A connected landscape within Washington State that is isolated from the surrounding ecoregions and neighboring jurisdictions may not be sufficient to support species' long-term persistence under the continuing pressures of population growth, development, and the projected impacts of climate change. Complex linkage zones that can maintain connections to areas outside of Washington are therefore essential to the vision of a connected landscape we propose here. Our results highlight the most important areas as: (1) the **Northern Linkage Zone** along the Okanogan Valley, which contains potentially critical areas for the movement of shrubsteppe species to higher latitudes as temperatures increase in the region; (2) the **Southern Linkage Zone**, which includes the braided linkages south of the Horse Heaven Hills, providing a pathway to the Columbia River and across it to the uplands in north-central Oregon, and the tenuous linkage just east of Wallula Gap, establishing connectivity into north-central Oregon without needing to cross the Columbia River; (3) the broad and numerous linkages between the Connected Backbone and the forested areas in the **Cascade Range**; and (4) the diverging, narrow linkages that follow the Snake and Tucannon river valleys,

from the Braided Scablands Swath towards the **Blue Mountains** in northeastern Oregon and western Idaho.

The broad regions as well as the complex linkage zones arise from recurring patterns observed in the results obtained using the focal species and landscape integrity modeling approaches. These regions and linkage zones also reflect the current land use and the patterns of infrastructure and development across the ecoregion. This observed pattern supports the conclusion that our vision for the Columbia Plateau, though based on a landscape modeling project with intrinsic limitations, reliably represents connectivity at the ecoregional scale. Results of this connectivity analysis provide a solid foundation from which entities interested in connectivity conservation can design strategies to achieve their specific goals and priorities.

Achieving the Vision of a Connected Columbia Plateau

The vision for a connected Columbia Plateau we articulate here and in the full report has yet to be achieved. A guiding principle as our team was making the multiple decisions that went into the development of each model was to err on the side of including as many opportunities for connectivity conservation as was reasonable. For example, linkages for some species were allowed to be longer than the species' documented movement distances to help ensure that the best opportunities for linkages between important areas were identified, even if they might not currently function as connections (Appendix A). Additionally, this analysis did not include information on the condition of the vegetation: all areas where there is abundant shrubsteppe are treated equally, whether the vegetation is in excellent condition or highly degraded. Realistically, degraded lands provide lower habitat value and may well pose greater resistance to animal movement.

Even given this generous approach, many linkages in the region are tenuous and narrow, at best, suggesting that they may not persist under future environmental and land use changes. We raise these points to emphasize that connectivity in the future will depend not just on maintaining what is currently connected. It will also depend on restoration and enhancement efforts to increase the size and improve the condition of the broad connected regions and the complex linkage zones that comprise this vision for wildlife connectivity in the Columbia Plateau.

Grounded in this perspective, we provide some recommendations to those interested in conserving and restoring habitat connectivity in the Columbia Plateau and contributing to this vision. These recommendations are concrete examples of how to use the insights gained through this analysis—detailed below each recommendation—to inform decisions. They are not meant to be all-inclusive nor are they meant to be prescriptive. We recognize that each entity and organization has its own goals and priorities, and we consider that one of the greatest values of the Columbia Plateau connectivity analysis is the depth and breadth of results, which lend themselves to multiple uses and opportunities for informing decisions.

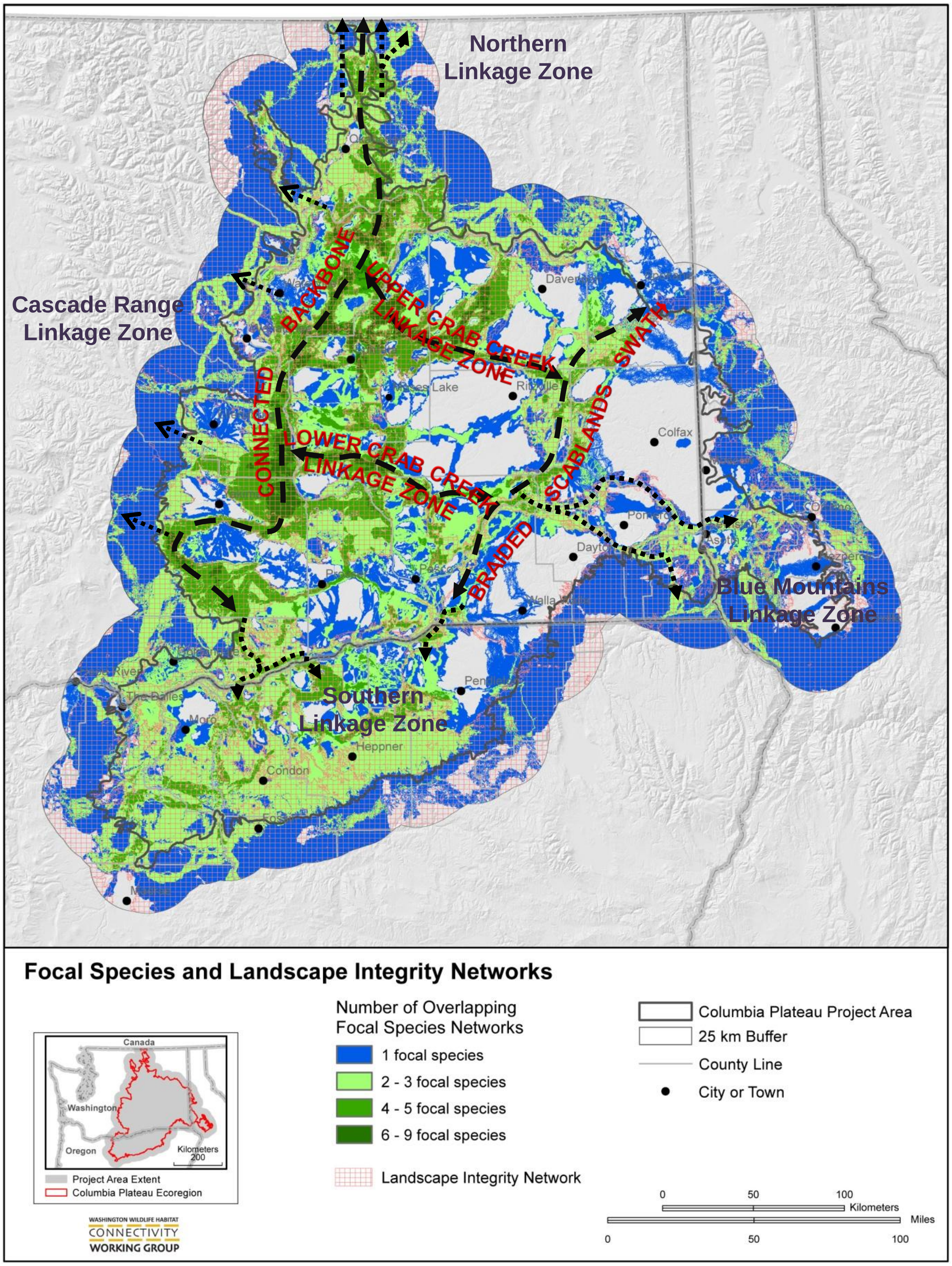

Figure ES.4. Vision for a connected Columbia Plateau Ecoregion in Washington. Solid colors reflect the number of focal species' networks particular areas belong to. The hatching represents the landscape integrity composite network. Dashed arrows highlight important areas for connectivity in Washington, and dotted arrows highlight important linkage zones to neighboring ecoregions and states.

Maintain and restore the integrity of the Connected Backbone. The larger blocks of remaining native habitat and the generally broad linkages between them along this Backbone are essential to connectivity conservation in the Columbia Plateau. Future land use changes and infrastructure development projects (wind farms for example) warrant appropriate consideration of connectivity effects in this area.

- The linkages along the Backbone in central Washington vary in their current capacity to function as true connections. Our ecoregional-scale results emphasize locations within the Backbone where particular attention is needed to either maintain or, most likely, restore linkages, such as the narrow or otherwise tenuous connections between the Horse Heaven Hills and the Hanford Site, across the Yakima Valley (Ahtanum Ridge to Rattlesnake Hills), and across the Columbia River between Rock Island and Trinidad.

Maintain and restore the integrity of the Braided Scablands Swath. A well-connected system of Washington's arid lands would be incomplete without the core areas and linkages in the eastern portion of the Columbia Plateau, contained in the Braided Scablands Swath. The emphasis in this portion of the ecoregion, where networks are less consistent and more tenuous, may need to be on restoration, particularly of deep-soiled plant communities around narrow linkages where the habitat characteristics differ from those of the scabland communities.

- Connectivity in the easternmost portion of Washington is less robust than further west (Figs. ES.3 and ES.4). This pattern is consistent with the level of agricultural conversion of the deep, tillable soils in the Palouse Prairie. Much of the remaining native habitat is associated with surface geology dominated by exposed volcanic rocks, either due to uplift of mountains or to the scouring of the Missoula Floods.

Restore and expand the complex linkage zones that transform bands of connected habitat into a comprehensive network spanning the Columbia Plateau in Washington and beyond. Apparently robust linkage zones extend from the Connected Backbone westward to the Cascade Range, and northward to British Columbia. Linkages are more tenuous, however, in the eastern and southern portions of the ecoregion. Linkages between the Connected Backbone and the Braided Scablands Swath, linkages that extend beyond the ecoregion in Washington, and linkages that provide opportunities to increase the number of linkage zones—thereby increasing the robustness of this habitat network—would benefit from particular attention to connectivity effects.

- The networks for the seven species most closely associated with upland systems in the Columbia Plateau tend to be contained within the ecoregional boundary (Fig. ES.5), indicating the likelihood of limited interaction with populations in adjoining ecoregions. However, there are prominent linkages with the potential for connecting the Backbone to the Cascade Range in the mule deer and landscape integrity networks (Fig. ES.6), as well as to British Columbia and north-central Oregon for these and the upland species (Figs. ES.5 and ES.6).
- Multiple narrower areas run approximately perpendicular to the Braided Scablands Swath, potentially linking it to the Connected Backbone. In addition to the Upper and Lower Crab Creek linkages, a less robust connector in the northern portion follows a

route along Lake Roosevelt, and another minor connector extends from Cow Creek across to the Potholes vicinity. Native habitats are confined to coulees and shallow rocky soils that have not been converted to agriculture.

- The species that represent drainages, aquatic, and canyon landscapes in the ecoregion—particularly Western rattlesnake and beaver—have networks that extend into the buffer, particularly along drainages and riverine corridors (Fig. ES.7).

Restore and expand key linkages that may be degraded or unlikely to be resilient to environmental change. It is important to recognize that this analysis is a reflection of the existing distribution of native habitat, which is not representative of the types of habitat that historically dominated the ecoregion. Areas with deep soils, particularly in areas with higher rainfall or with access to water, were selectively converted to other land uses, mainly agriculture. As a result, our vision for a connected landscape may fall short for species that are particularly dependent upon these under-represented systems, such as the endangered Columbia Basin pygmy rabbit (*Brachylagus idahoensis*). As a consequence, habitat restoration may be an important tool for connectivity conservation.

Test innovative approaches to simultaneously achieve production and conservation objectives. Better understanding the connectivity value of a matrix of native habitat and agricultural lands may provide a way to achieve agricultural production and connectivity conservation objectives that can be effectively replicated elsewhere.

- Multiple species' networks cross the Mansfield Plateau (Fig. ES.8, oval), in the northern part of the Connected Backbone, which has a mix of native remnant patches, active farm fields, and agricultural lands enrolled in the Conservation Reserve Program[2]. The landscape integrity network, however, traces the edge of the plateau (Fig. ES.8, dashed arrow), following a narrow strip of land dominated by cliffs along the western shore of Banks Lake that, although it is not as extensively modified by human activities, may pose a significant natural barrier to movement of many species.

Integrate conservation of connectivity for terrestrial vertebrates with conservation of aquatic systems. Water—the quantity, quality, and timing of its availability—is an important economic driver in the region, with agriculture being the dominant use of this resource. Linkages associated with the main rivers in the ecoregion provide an opportunity for investing in better ways to integrate conservation efforts focused on riverine systems (many associated with salmonid species recovery) with efforts focused on connectivity conservation.

- Key components of the networks of species that are associated with drainages, aquatic systems, and canyons follow the main river systems in an open ring around the Columbia Plateau in Washington (Fig. ES.7). This ring starts in the northeast, follows the Spokane River westward to its mouth, and from there follows the Columbia River west, south, and back east to the mouth of the Snake River, and further east following the Snake River upriver.

[2] The Conservation Reserve Program is a voluntary federal program through which landowners receive annual rental payments and cost-share assistance to establish long-term, resource-conserving vegetation cover on eligible farmland.

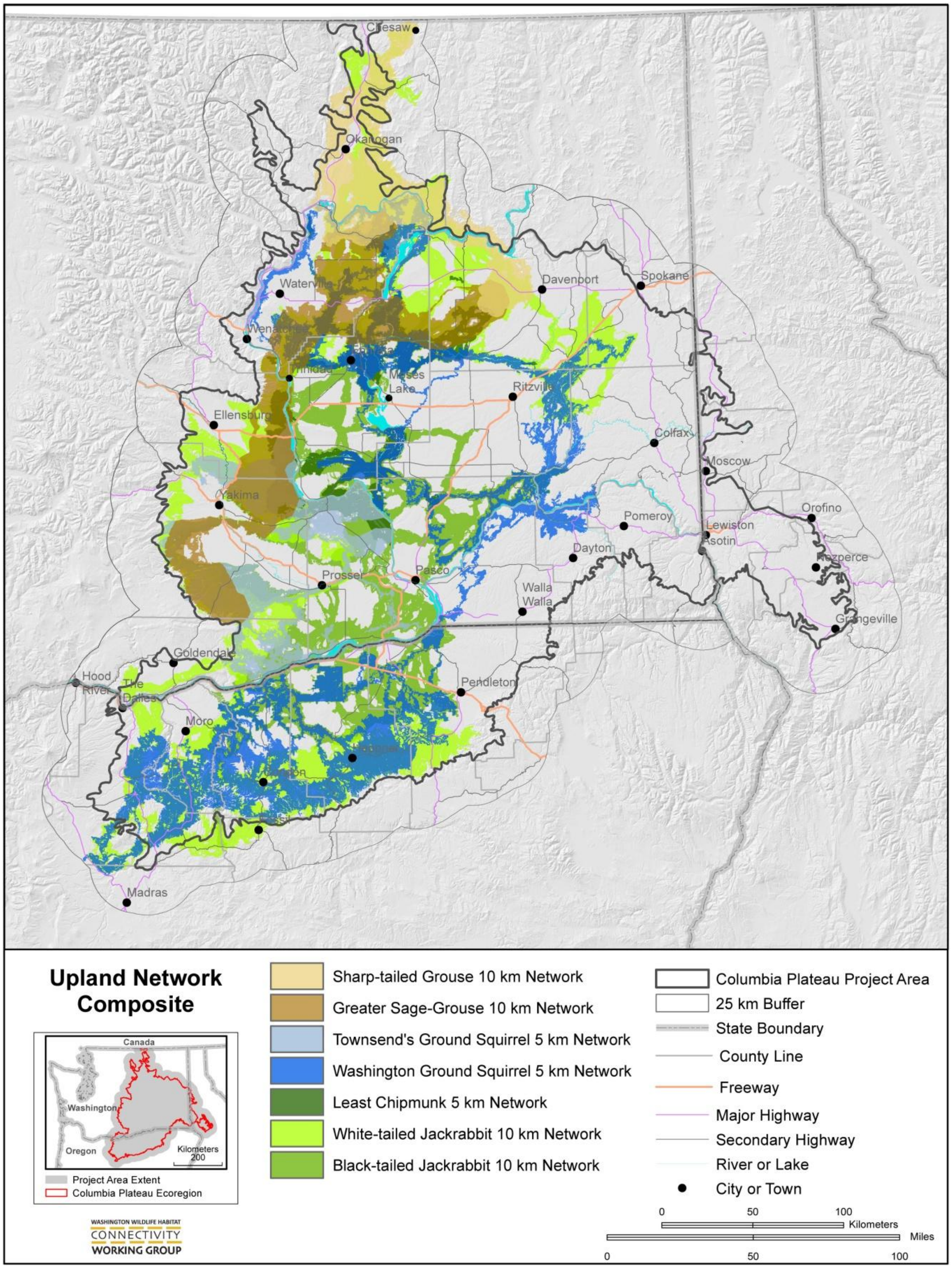

Figure ES.5. Upland Network composite map. This map is based on seven species closely associated with upland shrubsteppe habitat.

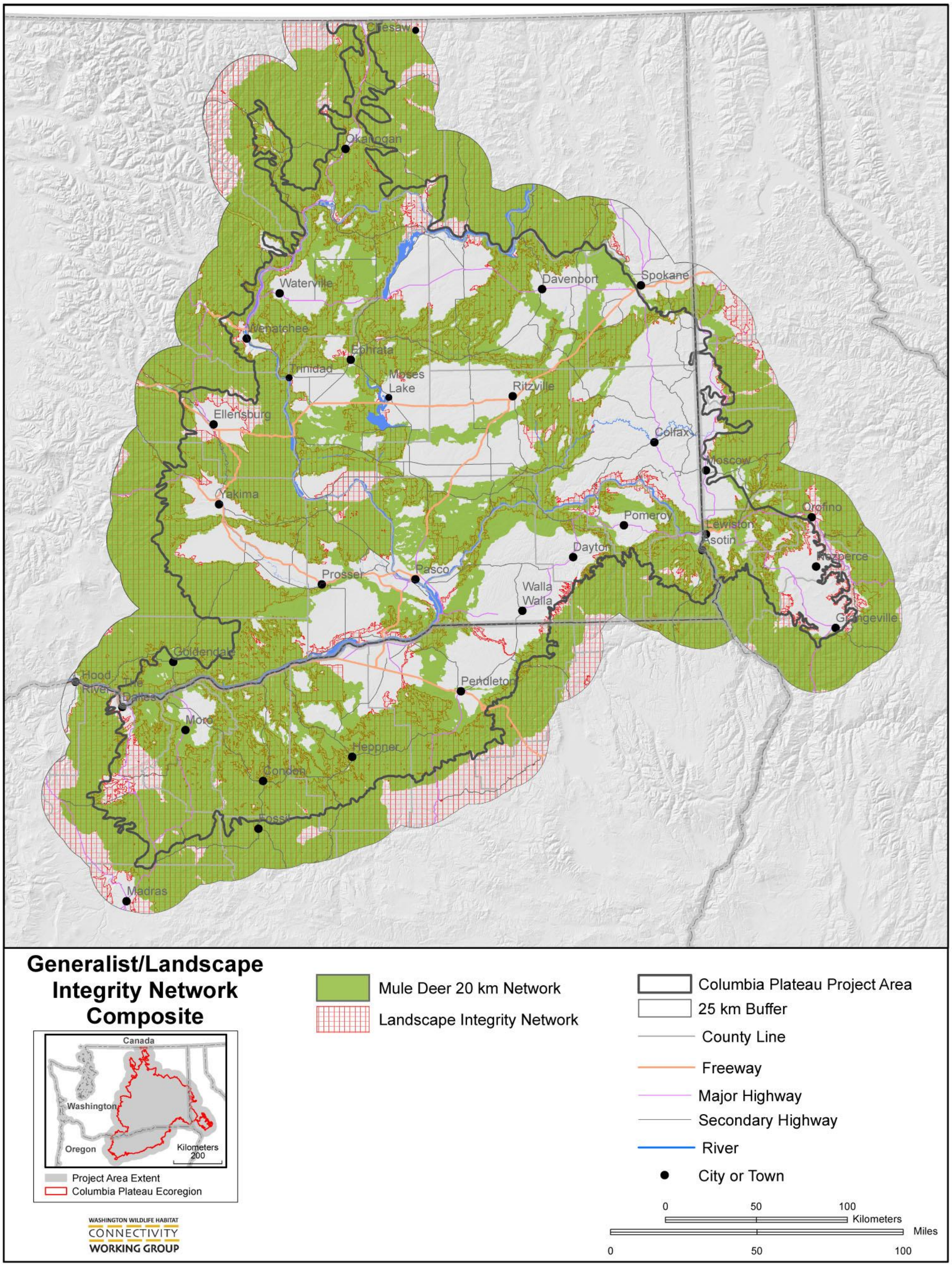

Figure ES.6. Generalist/Landscape Integrity Network composite map. Shown are mule deer and landscape integrity networks.

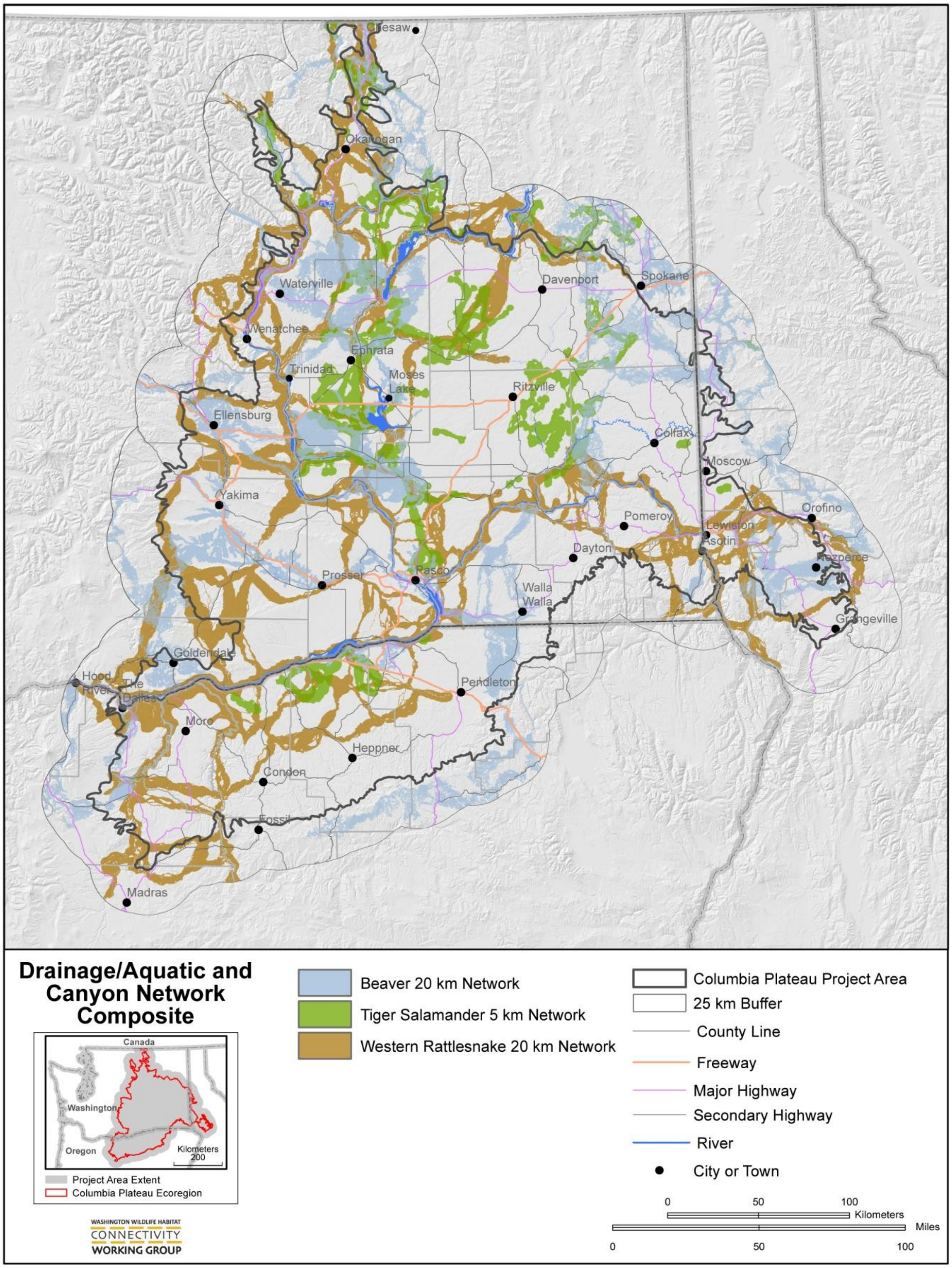

Figure ES.7. Drainage/Aquatic and Canyon Network composite map. This map includes beaver and tiger salamander, species selected to ensure inclusion of aquatic and riparian environments in the Columbia Plateau connectivity analysis; as well as Western rattlesnake, chosen to represent cliffs, canyons, and talus.

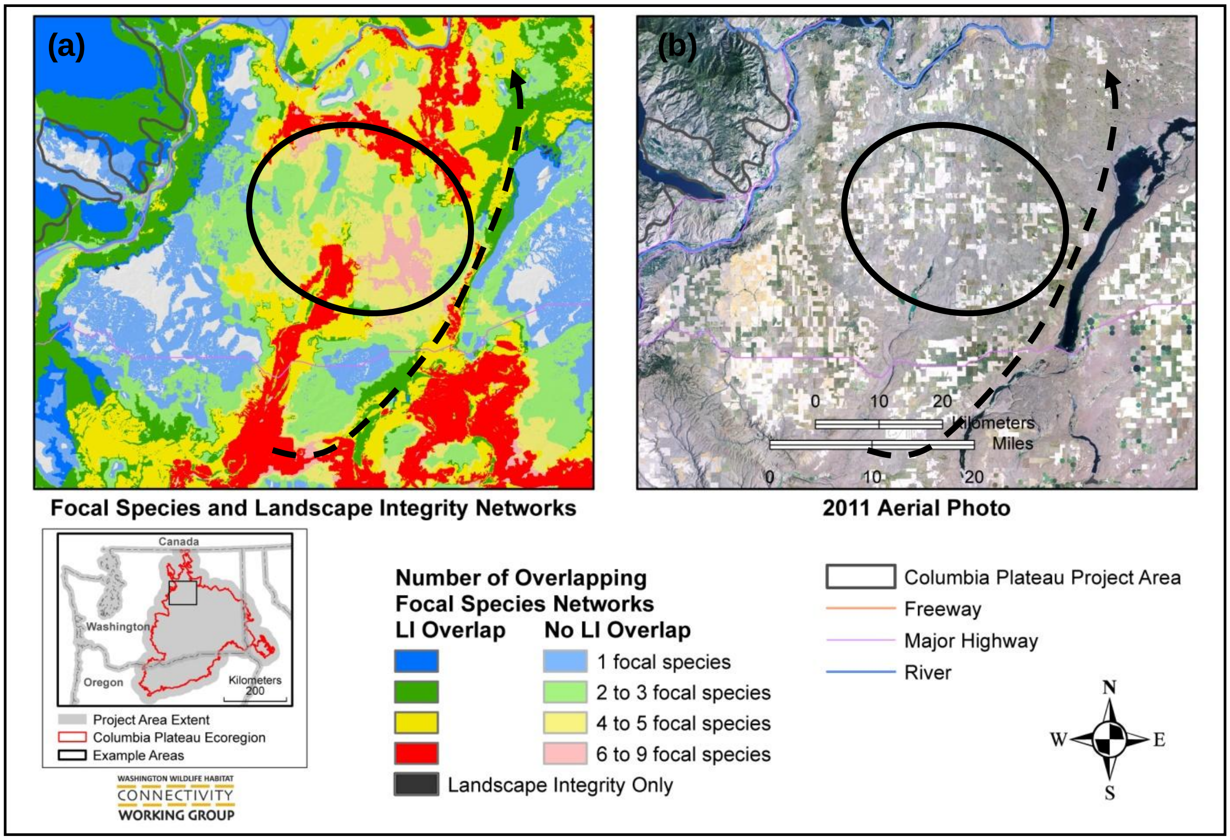

Figure ES.8. Mansfield Plateau, an area where the differences in results between the focal species and landscape integrity approaches are particularly noteworthy. (a) Overlap of focal species and landscape integrity networks. (b) 2011 aerial photo. Bold colors reflect the number of focal species' networks particular areas belong to, where they overlap with the landscape integrity network. Variants in soft colors occur where these focal species networks do not overlap with the landscape integrity network. Arrows and shapes highlight areas that exemplify how the networks for focal species (oval) and landscape integrity (dashed arrow) diverge.

Future Work and Conclusions

There are multiple opportunities for future work to test, validate, and apply the results from this analysis of the Columbia Plateau Ecoregion to individual species as well as a broader landscape perspective. With our partners, we are already planning or engaged in projects that will apply these results, including:

- ***Linkage Model Validation***—Two projects are underway, under the leadership of the Washington Department of Fish and Wildlife, to validate the Greater Sage-Grouse and mule deer connectivity models using radio-telemetry and genetic data collected from populations in the Columbia Plateau Ecoregion. An additional project led by Northern Arizona University will evaluate the effectiveness of linkages across the Mansfield Plateau as part of a worldwide study to test the efficacy of corridors.

- ***Future Analyses***—Led by The Nature Conservancy, we are developing tools that will identify: (1) critical barriers to wildlife movement that can inform restoration priorities, (2) core areas and linkages whose loss could disconnect large portions of the network, and (3) "pinch points" within individual linkages whose loss could sever an existing connection between core areas. The Washington Wildlife Habitat Connectivity Working Group (WHCWG) will use these tools to run analyses most useful to entities working on connectivity conservation in the Columbia Plateau. In addition, the WHCWG is working to identify linkages intended to facilitate species' adaptation to climate change (led by the University of Washington).
- ***Implementation***—The Arid Lands Initiative[3] will use our results to inform priority areas for implementing conservation strategies directed at "*conserving and restoring a viable, well-connected system of eastern Washington's arid lands and related freshwater habitats, sustaining native plant and animal communities, and supporting compatible local economies and communities*."

We are already moving forward with further work based on the results of the Columbia Plateau analysis to validate the models, and providing these results to inform the conservation decisions that different entities are making across this landscape. We also support and encourage current and future efforts to (1) improve our understanding of the value agricultural landscapes provide for connectivity and (2) develop linkage designs where needed to guide local collaborations and action. Our over-arching goal is to provide the information needed to effectively conserve habitat connectivity so that Washingtonians can continue enjoying healthy and diverse wildlife populations in this modern world and into an ever-changing future. We expect this analysis to support the development and implementation of innovative strategies and efficient and effective efforts to help fulfill the vision of a connected Columbia Plateau in Washington.

[3] The Arid Lands Initiative is a public-private partnership working to develop and cooperatively implement a coordinated strategy for the conservation of Washington's arid lands.

Chapter 1. Introduction to the Columbia Plateau Ecoregion Analysis

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Contributing authors: Sonia A. Hall (TNC), Karl Halupka (USFWS), Kelly McAllister (WSDOT), Brad McRae (TNC), Michael A. Schroeder (WDFW), Joanne Schuett-Hames (WDFW)

Human beings live in an increasingly connected world. In the early 1800s, it took Lewis and Clark the better part of three years to travel overland from the Atlantic to the Pacific and back. Today, the same trip takes less than a day. Yet the same infrastructure that now connects and provides resources for an increasing number of people often disconnects the natural world. Our ability to move hinders the connectivity and success of wildlife. Highways, transmission lines, and cityscapes add to the movement barriers already posed by natural features. Unconnected, wildlife are relegated to smaller and smaller islands of suitable habitat with each island increasingly separated from the next occupied island. This fragmentation and lack of connected habitat isolates wildlife populations, increases mortality, lowers genetic heterogeneity, and, ultimately, increases rates of species extirpation and extinction. A well-connected landscape for wildlife is key to supporting more resilient wildlife populations as they face future changes in land use practices, human population growth, and potential effects of a changing climate.

The Washington Wildlife Habitat Connectivity Working Group (WHCWG) was formed with the mission to identify "*opportunities and priorities to conserve and restore habitat connectivity*" for our region's wildlife. To address issues of wildlife habitat connectivity within Washington and adjacent lands, the WHCWG adapted a three-tiered approach focused at statewide, ecoregional, and local scales (Fig. 1.1). The first tier, a broad-scale assessment, was addressed by the *Washington Connected Landscapes Project: Statewide Analysis* (WHCWG 2010). The statewide analysis revealed the Columbia Plateau as an ecoregion where natural vegetation communities were severely fragmented, limiting movement potential for wildlife.

The analysis of habitat connectivity across the Columbia Plateau Ecoregion presented in this report is a second-tier assessment conducted at a finer resolution than the statewide analysis. It bridges broad, statewide connectivity patterns to local and project-level conservation efforts and helps identify where these efforts are warranted. In this ecoregional analysis we describe the current patterns of wildlife habitat connectivity in the Columbia Plateau Ecoregion. We also identify areas important for maintaining these patterns, and highlight opportunities for maintaining and enhancing connectivity in this region into the future—furnishing a vision for a connected Columbia Plateau. We foresee this analysis serving as a template for future analyses of other ecoregions, and providing a foundation for assessment and management efforts for wildlife connectivity at the third tier, the local level.

1.1. The Columbia Plateau Ecoregion

Our project area for connectivity analysis includes the Columbia Plateau Ecoregion and those lands within a 25 km buffer around the ecoregion boundary. Because of modeling and data constraints, we do not include in our analysis that portion of the Columbia Plateau extending into

British Columbia, Canada. Although we model habitat concentration areas (important habitat areas for wildlife) and linkages (pathways between these areas) in parts of northern Oregon and western Idaho, here we focus our assessment and interpretation of connectivity on that portion of the Columbia Plateau Ecoregion and buffer within the state of Washington (Fig. 1.2).

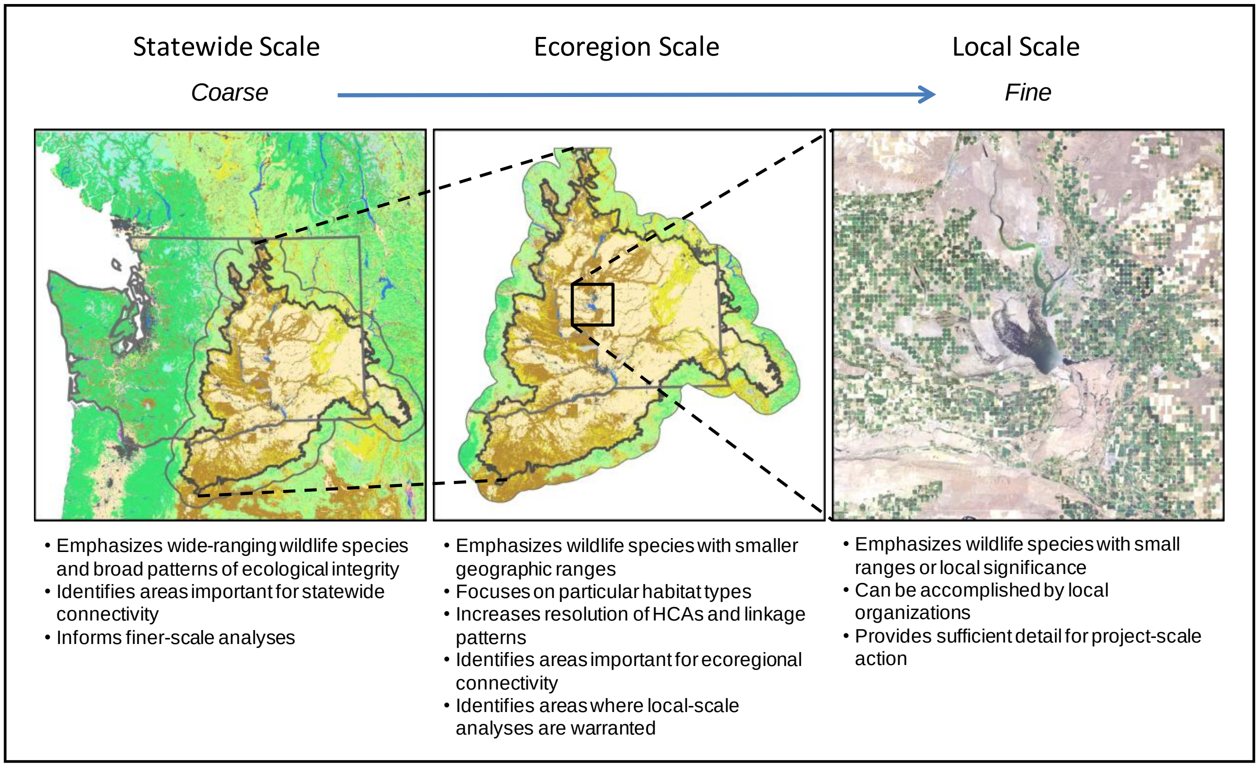

Figure 1.1. Scales of wildlife habitat connectivity analyses in Washington.

The Columbia Plateau is the largest ecoregion in Washington and occupies nearly one-third of the state. It is dominated by the Columbia River and its tributaries and bordered by the Cascade Range and the Rocky and Blue mountains. A complex geologic history of volcanic activity, glaciation, and glacial floods has created a landscape of glacial deposits, coulees, channeled scablands, and rolling areas of deep soil. The semi-arid climate of the Columbia Plateau supports native shrubsteppe vegetation as well as other drought-tolerant plant communities. The impact of human activity is high here: more than half of the shrubsteppe has been converted to agriculture, primarily dryland wheat, with some irrigated crops, while other areas have been altered by development and infrastructure. The remaining native habitat is often fragmented and on shallow soils less amenable to agriculture. Hydroelectric energy production is important to the area's economy, and in recent years wind energy production has become more common, especially in southern portions of the ecoregion. The imprint of development and agriculture is reflected in the substantial number of Washington's Species of Greatest Conservation Need found here. While this landscape may still provide connectivity for many species of wildlife, future changes in land use practices, human population growth, and potential effects of a changing climate underscore the need for a better-connected landscape—one that allows for continued and future movement of wildlife throughout the Columbia Plateau.

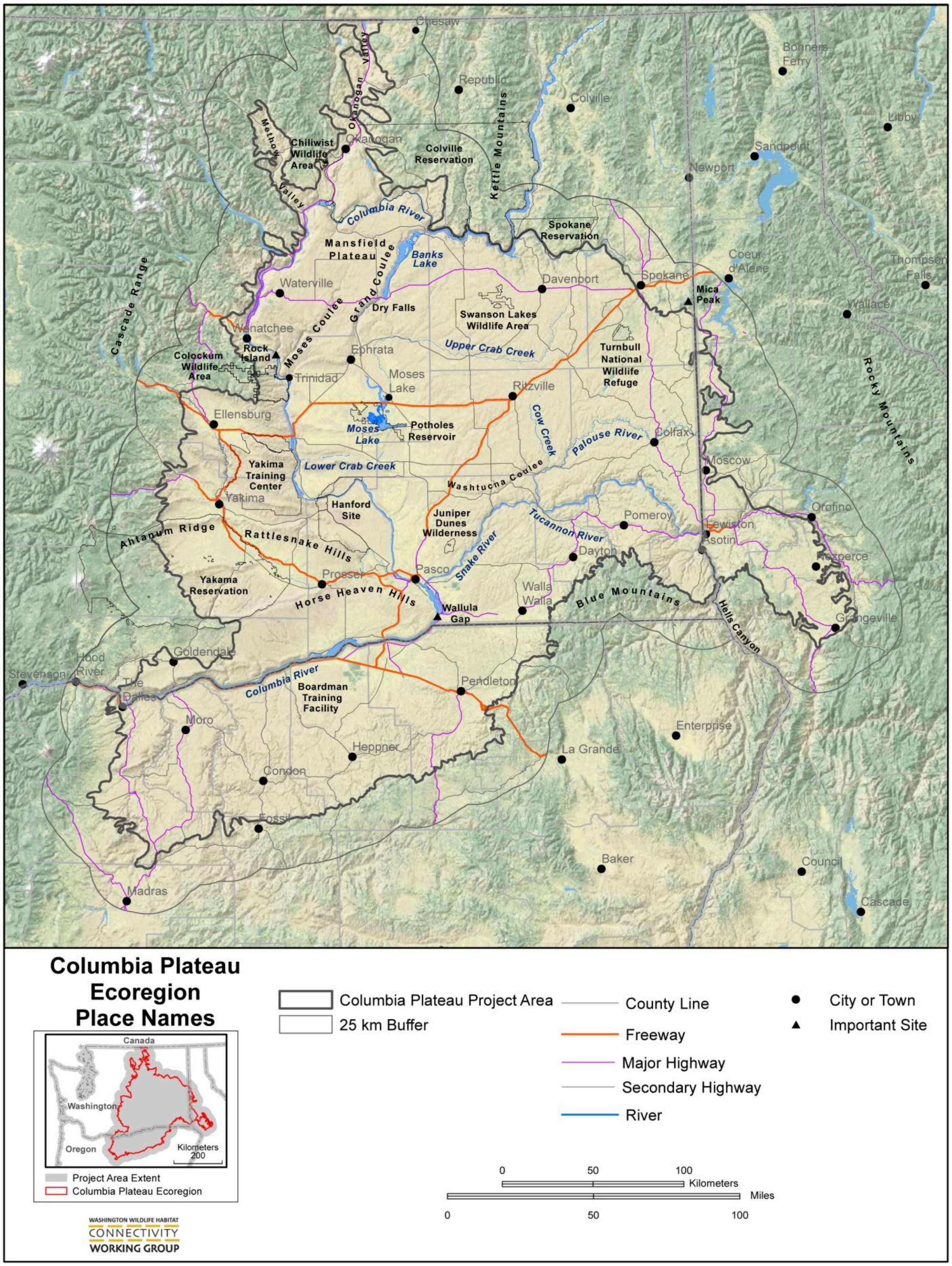

Figure 1.2. The Columbia Plateau Ecoregion showing common geographic features and place names.

1.2. Goal

Our goal for this connectivity analysis of the Columbia Plateau Ecoregion is to identify the most important areas for maintaining and enhancing wildlife habitat connectivity across the ecoregion. We anticipate that this analysis will provide a strong foundation for prioritizing conservation efforts, guiding development of detailed linkage design at the local scale, and encouraging future validation of connectivity models.

1.3. Analysis Approach

This ecoregional analysis follows the organizational structure, methodology, and approach outlined in the *Washington Connected Landscapes Project: Statewide Analysis* (2010). We urge readers who are unfamiliar with our methods, or who need to refresh their understanding of connectivity analyses, to consult the statewide analysis (available from http://www.waconnected.org). As suggested above, the statewide analysis provides context and technical details that will enhance the interpretation and application of the products, such as maps, produced through this analysis and described in this document.

As in the statewide analysis, the ecoregional analysis applies focal species and landscape integrity approaches to model patterns of habitat connectivity. The focal species approach is closely related to functional connectivity for particular species; its strength lies in the consideration given to the ways that each species contributes to our understanding of connectivity. The challenge for this approach lies in integrating results across focal species. Also, modeling is labor intensive, and connectivity patterns may not adequately represent needs of some non-focal species. The landscape integrity approach seeks to identify the best available routes to maintain movement for wildlife and ecological processes across the landscape by modeling connectivity across large, contiguous areas that retain high levels of naturalness (limited human impact). However, its results do not assess specific ecological functions, can be difficult to validate, and are more challenging to communicate. By taking a two-pronged strategy to model connectivity, we gain the advantages associated with both approaches while addressing shortcomings associated with using each approach alone.

Many of the data layers mapped in the statewide analysis were updated and used in this ecoregional analysis (See Chapter 2 and Appendix D). In addition, we compiled and mapped data layers that were not available or not feasible to include in the statewide analysis such as soils, topographic complexity measures, railroads, transmission lines, wind turbines, and irrigation canals.

1.3.1. Focal Species Modeling

We selected 11 species to represent the connectivity needs of a broader assemblage of wildlife, as well as the major vegetation classes, and threats to wildlife connectivity and persistence in the Columbia Plateau Ecoregion (See Appendix E). During the selection process we considered species' sensitivity to landscape features such as development, agriculture, and roads, as well as to energy development, fire impacts, and climate change. We chose species with different movement capabilities, such as mule deer (*Odocoileus hemionus*) and Washington ground squirrel (*Urocitellus washingtoni*), as well as those with diverse habitat needs, like tiger salamander (*Ambystoma tigrinum*) and Greater Sage-Grouse (*Centrocercus urophasianus*). Five of the focal species we selected for connectivity modeling at the ecoregional scale were also included in the statewide analysis: mule deer, Greater Sage-Grouse, Sharp-tailed Grouse (*Tympanuchus phasianellus*), white-tailed jackrabbit (*Lepus townsendii*), and black-tailed jackrabbit (*L. californicus*). Inclusion of these five species in the connectivity modeling for the Columbia Plateau allowed us to examine how closely complementary the coarse-scale statewide analysis and the finer-scale ecoregional analysis might be.

For each focal species, we prepared a detailed account (See Appendix A) of the connectivity modeling analysis. These accounts discuss the biology and ecology of the focal species in the context of their movement and connectivity across the landscape and provide the rationale for specific modeling decisions. The accounts also include connectivity modeling results and maps, accompanied by interpretation and insights drawn from the connectivity patterns. Modeling products—connectivity maps—for the focal species include: (1) landscape resistance to movement, (2) habitat value—relative habitat suitability of the landscape, (3) habitat concentration areas (HCAs)—important habitat areas to connect, (4) cost-weighted distance (CWD)—cumulative cost of resistance as species move outward from HCAs, and (5) modeled linkages—movement pathways between HCAs. We provide linkage statistics, such as linkage length and quality metrics (See Appendix B) for users to evaluate the linkage quality and degree of connectivity between specific HCA pairs.

1.3.2. Landscape Integrity Modeling

Landscape integrity can provide a measure of the relative degree of human disturbance on the landscape. We followed the landscape integrity approach outlined in the statewide analysis (WHCWG 2010), modified to include additional data layers. We produced alternative landscape integrity resistance models to reflect different sensitivities to human modifications, such as roads. Landscape integrity modeling products include maps of (1) landscape resistance for alternative models, (2) landscape integrity core areas, and (3) linkages among core areas for alternative resistance models.

1.3.3. Linkage Networks

The focal species and landscape integrity approaches identify habitat concentration areas and core habitats, respectively, and areas of the landscape important for connecting them. A linkage network consists of the combination of all the habitat concentration areas and the linkages modeled for focal species, or core areas and modeled linkages for landscape integrity (WHCWG 2010; see also Glossary). We have organized the species and landscape integrity networks into three composite networks:

1) *Upland Network*—Species most closely associated with upland shrubsteppe habitat (these are Sharp-tailed Grouse; Greater Sage-Grouse; Townsend's ground squirrel, *Urocitellus townsendii*; Washington ground squirrel; black-tailed jackrabbit; white-tailed jackrabbit; and least chipmunk, *Neotamias minimus*).
2) *Drainage/Aquatic and Canyon Network*—Species closely associated with aquatic, riparian, cliff, canyon, and talus habitats (beaver, *Castor canadensis*; tiger salamander; and Western rattlesnake, *Crotalus oreganus*).
3) *Generalist/Landscape Integrity Network*—Species that have broad coverage across the Columbia Plateau and the buffer (mule deer) and the landscape integrity network.

1.4. Interpretation

By modeling habitats and linkages important for an array of wildlife species, we have created a vision for a connected landscape across the Columbia Plateau. These ecoregional level results, following up on a connectivity analysis that began at the statewide scale (WHCWG 2010; see Fig. 1.1), are intended to help prioritize connectivity conservation both ecoregionally and locally. The Columbia Plateau connectivity results, based on spatially explicit connectivity data, lend themselves to multiple uses, including essential decision making for conservation-based wildlife planning.

It is important for users to understand the strengths and limitations of this ecoregional analysis so that the results can be interpreted correctly and used effectively. We identify some of the strengths and weaknesses here and encourage the reader to refer to the statewide report (WHCWG 2010) for a more in-depth discussion. The analysis: (1) creates a vision of a connected landscape by modeling habitats and linkages for an array of wildlife species and landscape integrity, (2) provides information to help organizations incorporate connectivity into conservation efforts while meeting organizational goals and priorities, (3) delivers the foundation for linkage design analyses that can guide actions to enhance connectivity, and (4) affords opportunities for validation of model assumptions and predictions. There are limitations to the analysis which may include: (1) errors and limitations in spatial data, (2) reduced applicability outside the Columbia Plateau project area, (3) incomplete assessment of important habitats or linkages, (4) insufficient detail to prioritize habitats or linkages at a finer scale, and (5) lack of adequate field data to validate all model assumptions. Despite these limitations, this analysis is a powerful tool that provides a solid foundation for interpretation of connected landscapes as well as opportunities for future work.

1.5. Application

This analysis is a landscape modeling effort that reflects our best estimate of modeled pathways for potential movement in the Columbia Plateau Ecoregion. We provide a great deal of information in this analysis and rely on readers to select from this array the information that is most pertinent to their specific interests and applications. We encourage users to delve into the focal species and landscape integrity resistance models most relevant to their questions and objectives. Likewise, the landscape integrity resistance models and connectivity products for each focal species each provide singular information about movement opportunities available in the Columbia Plateau Ecoregion. There are a great many ways to use these species and analysis products to address a wide variety of potential applications. Our composite network analysis is one way of integrating different types of information. Other approaches to integration are possible, and we hope readers will develop and share new ideas about how to synthesize the information we provide to promote practical connectivity conservation.

1.6. Document Organization

Our analysis results may be viewed from different perspectives, from broad patterns of connectivity across the entire ecoregion (See Chapters 3 and 4) to species-specific linkages between individual HCAs (See Appendices A and B). This complexity and breadth provides a wealth of opportunities for application to multiple uses, but presents challenges for full discussion and consideration within a single document. Thus, we have synthesized our focal species and landscape integrity results to highlight important patterns of connectivity across the ecoregion. This approach is intended to help prioritize areas important for the conservation of connectivity in the Columbia Plateau, and give direction for validation and more detailed linkage design. We provide examples of these patterns to illustrate ways in which users can apply our results to inform their own decision making. Our examples are not intended to be all-inclusive and users should explore other considerations. We stress the importance of the document's Appendices as they provide additional detail and insight to our analysis.

We have organized the Columbia Plateau Ecoregion analysis into five chapters, followed by a glossary of terms and five Appendices. In Chapter 2 we provide a detailed account of the methods used including: analysis area, focal species selection, data development, habitat modeling, resistance modeling, habitat concentration areas, and linkage modeling for focal species and for landscape integrity. In Chapter 3 we present the results of our analysis and in Chapter 4, an assessment of the key patterns and insights. We pose the larger patterns of landscape connectivity across the landscape that are illustrated by the focal species and landscape integrity modeling, and consider the recurrent patterns of connectivity in the Columbia Plateau Ecoregion. We provide examples of opportunities for conserving connectivity in the ecoregion. Chapter 5 outlines future work and tenders conclusions and next steps.

The Appendices provide supporting information and substantiate in greater detail the aspects of this analysis. Appendix A is partitioned into individual connectivity modeling accounts, providing natural histories, modeling overviews, connectivity mapping products, and interpretations for each of the focal species. In Appendix B we provide modeling statistics, such as habitat concentration and core area values, and linkage length and quality. Appendix C is a file of focal species and landscape integrity resistance and habitat values, and other parameter values used during the model runs.

Chapter 2. Methods

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We based our methods on those of the WHCWG (2010) statewide connectivity analysis, modifying them as appropriate to (1) accommodate additional and finer-scale data available for the Columbia Plateau Ecoregion, and (2) provide products tailored specifically to guide connectivity conservation at the ecoregional scale. We avoid repeating material from the statewide report here, so readers should refer to Chapter 2 in WHCWG (2010) as a companion document to this one.

As with the statewide analysis, we modeled connectivity both for focal species and for areas of high landscape integrity, i.e., areas that have low levels of human modification and are in relatively natural condition (Fig. 2.1). We selected focal species using criteria designed to identify species with geographic ranges, habitat associations, and vulnerabilities to human-created barriers that make them good representatives of the connectivity needs of many species and important ecological processes. Wildlife biologists with intimate knowledge of the Columbia Plateau Ecoregion led development of individual species habitat and resistance models. We used cost-weighted distance methods to map least-cost corridors and identify continuous swaths of land expected to encompass the best routes for species to travel between habitat blocks.

Building upon the statewide analysis, we modified our methods in important ways: (1) we selected focal species to represent major vegetation types within the Columbia Plateau Ecoregion; (2) we refined species selection criteria to include vulnerability to threats not considered in the statewide analysis, such as climate change and wind energy development; (3) we conducted habitat modeling separately from resistance modeling; (4) we included additional data layers that were unavailable or infeasible to include at the statewide scale; and (5) base layer compilation and resistance and habitat calculations were calculated at a smaller grid cell size. We focus on these and other differences in the following sections, and refer the reader to our statewide report (WHCWG 2010) for supporting details and background on methods common to the two projects.

2.1. Analysis Area

The WHCWG chose the Columbia Plateau Ecoregion for its first ecoregional analysis for three reasons. First, the group's statewide connectivity analysis (WHCWG 2010) identified the Columbia Plateau as one of the two most fragmented ecoregions in Washington. Yet despite the high level of habitat loss and fragmentation in the ecoregion, our analysis identified previously undocumented patterns and opportunities for multiple-species connectivity conservation there. Second, several climate models suggest that the Columbia Plateau Ecoregion in Washington may become one of the few climatically suitable areas for shrubsteppe ecosystems under future climate change. These findings highlighted the need to refine analyses for the region and prioritize among areas needed to maintain connectivity, particularly with increasing pressure from human population growth, agricultural conversion, and energy development. Lastly, there were pressing needs for data to assist in conservation prioritization by the Arid Lands Initiative (ALI), a multiple-partner effort working to develop and cooperatively implement a coordinated strategy for the conservation of Washington's arid lands. The ALI intends to use the results of this analysis to identify shared priority areas for the implementation of strategic actions such as grazing management, habitat protection, and restoration, and to work with agencies and local governments to evaluate management and development alternatives to minimize impact of development, climate change, and other factors on conservation goals.

To delineate the analysis area, the WHCWG selected the Columbia Plateau ecoregional boundary as defined by the U.S. Environmental Protection Agency (2003). This boundary (Fig. 1.2) encompasses common patterns of geology, physiography, vegetation, climate, soils, land use, wildlife, water quality, and hydrology. We added a 25 km buffer around the ecoregion to allow for habitat concentration areas and linkages up to and beyond the ecoregional boundary, without artificial or arbitrary breaks due to boundary selection. Because of time and capacity limitations, we excluded the portion of the ecoregion that extends north through the Okanogan Valley into British Columbia, Canada. Although study participants recognized the importance the valley holds in providing connectivity between Washington's arid lands and key areas in south-central B.C., compiling and "stitching" together disparate data sources across the international boundary would have consumed a disproportionate share of resources available for the project, and since this area covered a very small portion of the ecoregion, we decided to omit the B.C. portion. Our final analysis area encompassed 132,190 km^2.

2.2. Focal Species Selection

The focal species we selected were intended to represent both the needs of wildlife species for which ecoregional-scale planning was relevant and the habitat and connectivity value provided by the main vegetation types across the Columbia Plateau. The selection process gave particular consideration to species that are sensitive to landscape features of interest to conservation planners, such as transportation or energy infrastructure and urban development, and those species sensitive to factors that may not yet be comprehensively addressed in conservation status rankings, such as climate change.

The focal species selection process followed multiple steps and was carried out with significant input from 29 ecologists and wildlife biologists working in the Columbia Plateau Ecoregion (See Appendix E). For selecting focal species, we applied the criteria used in our statewide analysis (WHCWG 2010) with several modifications. First, the database of vertebrate species assembled as an initial step included not only species of conservation concern as identified based on their NatureServe (2009) ranks but also: (1) species of particular interest and concern to entities involved in planning or management in the Columbia Plateau, and (2) species considered particularly vulnerable to the effects of wind energy development.

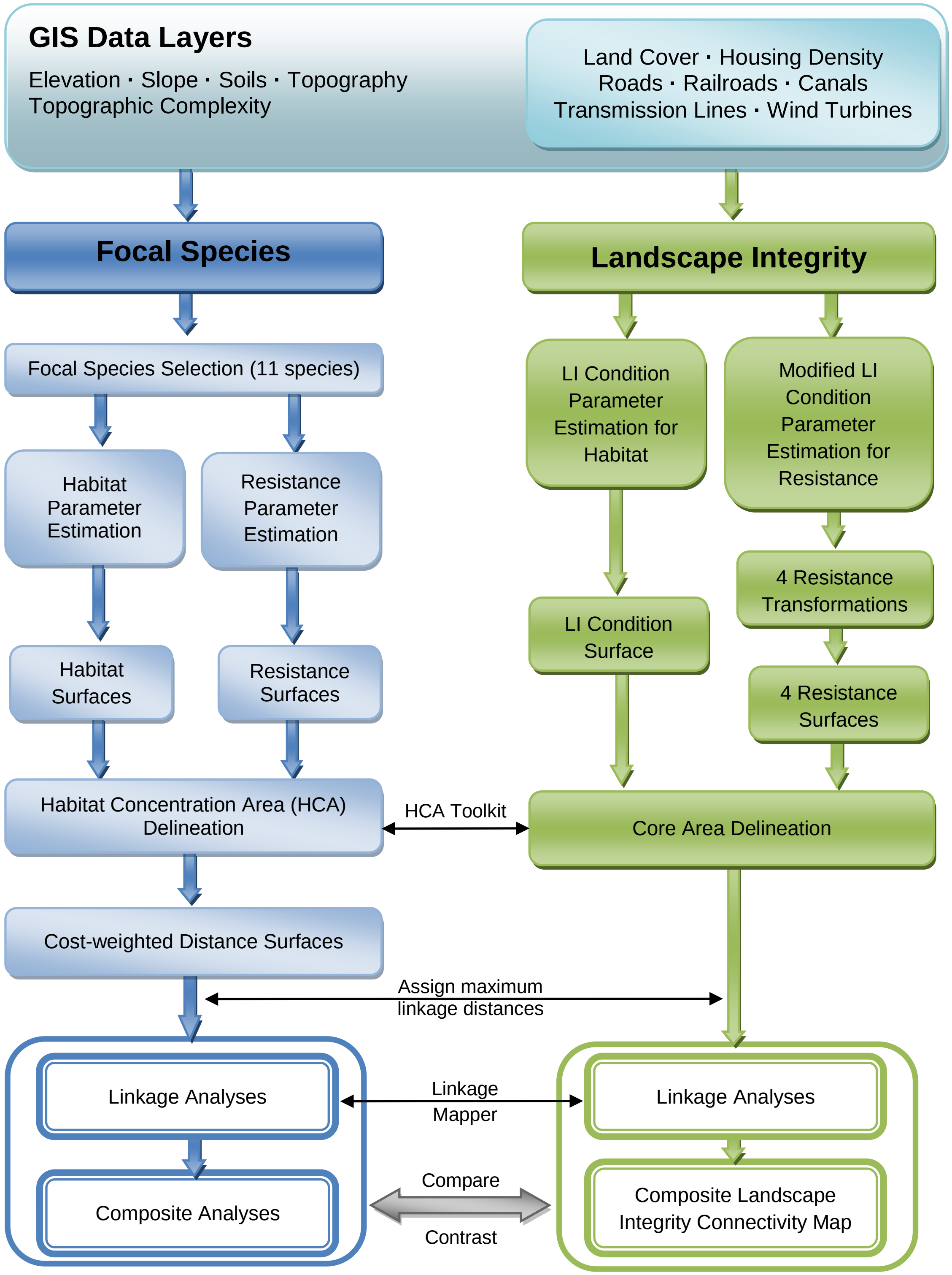

Figure 2.1. Flow of the Columbia Plateau Connectivity analysis.

Second, the vegetation types the focal species were meant to represent were identified and described so as to be compatible with the Arid Lands Initiative's conservation targets. These groupings of ecological systems were developed to be compatible with standard vegetation classification hierarchy (e.g., the National Vegetation Classification System), while simultaneously representing conservation priorities in eastern Washington's arid lands.

Lastly, when prioritizing species for selection we considered additional threat categories. The first four categories were the same as those used in the statewide analysis, and included: land clearing/vegetation removal, development, roads/traffic, and presence of people or domestic animals. Specific examples of how each of these categories affect connectivity can be found in WHCWG (2010). In addition, we evaluated species for sensitivity to the following:

- *Wind turbines/transmission lines*—Species were ranked based on their vulnerability to wind development (and based on the confidence biologists had in their assessment of species vulnerability), using available wind farm mortality data from the ecoregion. This category limits connectivity through:
    - Direct mortality (e.g., from wind turbine blades)
    - Barotrauma (the drop in air pressure caused by wind turbine rotation that has been found to cause mortality in bats)
    - Disturbance (e.g., from vertical structures, noise, ground vibrations, potentially affecting Greater Sage-Grouse and other wildlife)
- *Fire impacts*—Species were ranked based on their sensitivity to fire and habitat changes and losses caused by fire. In the Columbia Plateau, frequent fires primarily affect connectivity by:
    - Changing shrubsteppe to annual grasslands dominated by invasive species. This limits movement of wildlife species that need fire-sensitive plant species (e.g., *Artemisia tridentata*).
- *Climate change*—The top 20 candidate species for the different vegetation types were evaluated for sensitivity to climate change following criteria similar to those developed by the University of Washington, the USGS, and other partners for the Pacific Northwest Climate Change Sensitivity Database (http://esp.cr.usgs.gov/info/nccwsc/vulnerability/products.html). We considered characteristics that are intrinsic to certain species and habitats which make them particularly vulnerable to changing climate. For example, species that scored high included those that:
    - Specialize on one or a few habitats or food sources
    - Are sensitive to temperature or precipitation changes
    - Reproduce rarely and have few young
    - Depend on a sensitive habitat type (e.g., vernal pools)
    - Have a latitudinal range limit within the Columbia Plateau
    - Are endemic to the Columbia Plateau

The above process led to a suite of 11 focal species representing major vegetation types in our study area (See Table 3.1). More details about the process can be found in Appendix E.

2.3. Data Development

Following focal species selection, we assembled 22 GIS data layers suitable for characterizing wildlife habitat quality and landscape resistance in the Columbia Plateau Ecoregion (Appendix D). In addition to the features mapped at the statewide scale, we compiled new layers representing soils (depth and texture), railroads (active and inactive), topographical complexity measures (ruggedness, landform, insolation, and other topographical indices), transmission lines, wind turbines, and major irrigation canals (Table 2.1). Our development of GIS base layers was limited by the need to maintain consistency across the entire analysis area and in some cases required modifying existing spatial information across jurisdictional boundaries.

Many of the GIS data layers used in the statewide analysis, such as roads data, were updated and refined for use at the ecoregional scale. We added new classes to the land cover/land use data layer, resulting in 14 classes of native vegetation, two classes of introduced vegetation, and nine classes of agriculture, including four classes of agricultural lands occurring within two different buffer distances from native habitat (Table 2.1; see also Appendix D).

For some types of base data, we buffered features so that the layers used for habitat and resistance modeling could incorporate not only effects of the physical features themselves but also effects that extend beyond those features. For example, each wind turbine point location was represented as a 45 m radius feature, based on the typical wind turbine blade-width in Washington facilities. We then mapped buffer zones of 0–500 m and 500–1000 m around turbines to allow species models to incorporate effects of maintenance traffic, visual impacts, turbine noise, or vibration. These buffer classes were also mapped for all roads, transmission lines, and railroads, in addition to grid cells representing the centerlines of these features. Lastly, we classified agricultural areas within 0–250 m and 250–500 m of large blocks of natural habitat to account for the accessibility, and potential foraging value, of agricultural lands adjacent to natural areas for focal species. Categories contained in each base layer are listed in Appendix C.

For low-use roads, we created two layers, one with centerlines and buffers (like other road classes), and another measuring road density. For the latter we scored, for each cell, the number of kilometers of low-use roads within a 4 km^2 circular moving window.

As with the statewide analysis, not all data layers were used for all focal species or landscape integrity models. Ancillary data sets, such as species distribution data, were used as necessary to support focal species modeling (See Appendix A for details on species models).

All base layers were compiled using an Albers Conical Equal Area map projection with a 30 m square grid cell size. More detail on the spatial data layers and associated classes, the rationale for data development decisions, and layer processing can be found in Appendix D.

Table 2.1. Summary of GIS spatial data layers used for habitat connectivity modeling for focal species and landscape integrity analyses in the Columbia Plateau Ecoregion.

Data layer	*Summary*
Land Cover/ Land Use	Our primary data source for land cover was Northwest Gap Analysis Program (GAP) data. We augmented these data with additional information on agricultural types, representing four classes of agriculture, and identifying agricultural areas in close proximity to native habitat. These were developed using the 2010 growing season Cropland Data Layer (CDL) raster obtained from U.S. Department of Agriculture's National Agricultural Statistical Service (USDA-NASS). This allowed us to further break agricultural uses into four categories: pasture/hay, non-irrigated cropland, irrigated cropland, and highly structured agriculture. Lastly, we used Landfire's Existing Vegetation (EVT) raster and National Wetland Inventory data to improve the representation of recently burned areas and of wetlands and riparian areas.
Soils	We developed two categorical layers representing soil depth and soil texture, plus a continuous layer representing available water capacity (the latter was used for modeling Western rattlesnake habitat only). These layers were compiled using data from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) and, for areas within the Columbia Plateau where SSURGO data are not available, filled in with coarser-scale data from the U.S. General Soil Map (STATSGO).
Topography and Topographic Complexity	We assembled elevation data from the USGS 1 arc second, 30-meter National Elevation Dataset (NED). Additional variables derived from these data included slope, a vector ruggedness measure, a compound topographical index, a topographical position index, a landform index, and a solar radiation index.
Housing Density	We obtained a housing density raster layer based on U.S. Census 2000 data from http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=205305. These data were compiled using methods described by the U.S. Environmental Protection Agency (2009).
Roads	We used TIGER roads data provided by the U.S. Census Bureau based on 2010 Census data. This layer was used to represent freeways, major highways, and secondary highways. TIGER roads data do not distinguish paved or high-use local roads from low-use, non-paved roads in rural areas in ways that allowed us to effectively model the impacts of these different types of roads on movement and habitat. We therefore used data compiled by state Departments of Transportation (WA, ID, OR), which classify these local roads according to the Federal Functional Classification system, to distinguish high-use local roads from low-use roads across the study area.
Railroads	TIGER data provided by the U.S. Census Bureau based on 2010 Census data also includes railroads. We derived both active and inactive railroads from this layer.
Transmission Lines and Wind Turbines	We used transmission corridor data from Ventyx Corporation (November 2011 release), which include information on the number of lines and their voltages within each transmission corridor. We also used Ventyx data for wind turbine locations, mapping individual point locations of wind turbines that have been built (we did not include sites where turbines are proposed or potentially in construction, due to uncertainty about data quality).
Irrigation Canals	There was no consistent layer representing irrigation canals of different sizes and types across the Columbia Plateau. The considerable movement barriers that larger, cement-lined canals create for many species led to the decision to at least capture these larger features using the National Hydrography Dataset (NHD) Area layer. These data provided consistent coverage across each state, while excluding small ditches.

2.4. Habitat Modeling

To identify areas important to connect, we first needed to model suitable habitat for each species. Our approach to habitat modeling for focal species differed from that used in the statewide analysis. At the statewide scale the resistance surface generated for each focal species was used to model suitable habitat in a moving window analysis. In contrast, habitat maps for most focal species in this analysis were based on habitat models developed independently of resistance models. In other words, land cover types that do not contribute to foraging or breeding habitat can still have low resistance values, and vice versa.

Our landscape integrity modeling approach was similar to that used at the statewide scale. Model parameterization focused on landscape integrity condition values, and resistance values were subsequently calculated based on four transformations of modified landscape condition values, as described below.

2.4.1. Focal Species Habitat Parameters

For eight of the 11 focal species, focal species leads developed habitat models by assigning habitat values to each class of each relevant data layer (not all 22 layers were used for every species). These habitat values ranged from 0 (non-habitat) to 1 (the best possible habitat), and were selected based on information gleaned from the literature, expert opinion, and critical review of first-draft habitat maps.

We used this rating scale to estimate the habitat value score for categories in each data layer assuming that all other input layers are optimal (e.g., what would the habitat value be for a cell that includes a steep slope, if all other conditions were optimal?).

Once habitat scores were applied to base raster data, we multiplied scores across all input data layers to derive a composite score for each grid cell. For example, if a model included three layers, and a particular grid cell had values of 1.0, 0.5, and 0.5, respectively for the layers, the final model would have a value of 0.25 (1.0 x 0.5 x 0.5) in that cell. Thus, a feature in each data layer could only reduce the final habitat score or leave it unchanged. Species leads could parameterize features to force grid cells to be non-habitat by assigning them zero values. Likewise, assigning features a value of one meant that the remaining features in the grid cell would determine habitat values. See Appendix C for a master list of parameter values.

For the Western rattlesnake, Greater Sage-Grouse, and Sharp-tailed Grouse, sufficient data existed for species leads to consider different approaches to modeling habitat and the associated habitat concentration areas. In the case of the rattlesnake, occurrence data were used in combination with the input data layers to model habitat using the MAXENT habitat modeling tool (Philips et al. 2006; see also Appendix A.9). For the two grouse species, we used lek location data in combination with resistance layers to identify habitat concentration areas without using a habitat model (See Section 2.7.1 and Appendices A.1 and A.2).

2.4.2. Landscape Integrity Habitat Parameters

To model landscape integrity, we followed the approach described in WHCWG (2010), using additional data layers available for the study area that were relevant to scoring human modifications (e.g., transmission lines, wind turbines, and railroads). Landscape condition parameter values were based on input from other human footprint/modification modeling efforts (Sanderson et al. 2002; Leu et al. 2008; Theobald 2010; P. Comer, D. Theobald, and S. Trombulak, personal communication). As in the statewide analysis, we converted low-use road features to densities (using a 4 km^2 circular moving window for this analysis). Lands with low-use road densities above 6 km of roads per 4 km^2 were given a condition score of 0.05. We assigned landscape condition scores ranging from 0 to 1 to classes in each data layer, and grid cells were assigned a combined landscape condition score based on the minimum score across all input data layers. Only grid cells with a minimum condition score of 0.9 were considered for inclusion in landscape integrity core area calculations (See Section 2.7.2). Final parameter values are given in Appendix C.

2.5. Resistance Modeling

2.5.1. Focal Species Resistance Models

For each of the 11 focal species, we assigned relative resistance values to different landscape features, such as different types of roads or various land cover/land use classes. As in the statewide analysis (WHCWG 2010), we defined the resistance contributed by each landscape feature as the number of additional grid cells of "ideal" habitat a given species would move through to avoid one grid cell of the landscape feature under consideration. For each landscape feature, focal species leads and other species experts estimated the additional resistance to movement imposed by the feature relative to ideal movement habitat, ranging from zero for ideal habitat to 1000 for strong barriers. The final resistance layer for each species was then derived by summing the resistances from each input layer and adding 1.0 (to account for Euclidean distance). Note that this resulted in resistance grids where the lowest resistance a grid cell could have was 1.0. See WHCWG (2010) for further details on this approach and Appendix C for a master list of resistance parameters.

2.5.2. Landscape Integrity Resistance Models

As described in the statewide analysis (WHCWG 2010), we created four alternative landscape integrity resistance models. Landscape integrity resistance values were derived from transformations of the same landscape condition scores described in Section 2.4.2 with two modifications. First, we used low-use roads and associated buffers, rather than road densities, to calculate condition scores used in the resistance models. Second, we gave open water a condition score of 0.5 (compared with 0.9 used in habitat calculations) to represent the decreased permeability commonly associated with larger water bodies (e.g., Spencer et al. 2010). We then assigned a condition score to each grid cell equal to the minimum score taken across all layers. The first resistance model used a simple linear transformation of the resulting landscape integrity condition score assigned to each grid cell for all LI_C values <0.9:

$$R_{LI} = 100 * (1 - LI_C) - 0.9$$

Where R_{LI} is the resistance and LI_C is the landscape integrity condition value. The other three resistance models created were designed to reflect low, medium, and high sensitivities to human modification. We transformed the landscape integrity habitat values so that areas with greatest human alteration were 100, 1000, and 10,000 times less permeable to movement than the least human-altered areas (representing the low, medium, and high maximum resistance values, respectively) using the equation:

$$R_{SENS} = (10 - LI_C)^{P_{SENS}}$$

Where R_{SENS} is the resistance derived for each sensitivity model, and P_{SENS} is a constant chosen for each sensitivity model such that the maximum value of R_{SENS} equals 100, 1000, or 10,000 for the low, medium, and high sensitivity models respectively. The landscape condition and resulting resistance values used for landscape integrity modeling are provided in Appendix C.

2.6. Generalization of Habitat and Resistance Rasters

We converted habitat and resistance maps from 30 m to 90 m grid cell sizes by first assigning to each cell the average habitat value of that cell plus its eight immediate neighbors. We then aggregated 30 m cells to 90 m grid cells using the average habitat value of the nine 30 m cells contained within each 90 m grid cell.

Generalizing habitat and resistance maps in this way had several advantages. By averaging neighboring resistances, small holes in barriers and single-cell habitat patches have less of an effect on corridor locations. Such features can easily result from errors in classification of satellite data and are unlikely to provide biologically viable movement pathways. Experiments indicated that corridor locations appeared to be more biologically realistic at coarsened cell sizes, because the algorithms were less likely to find single-cell-wide holes in barriers or to move along small stepping-stones or habitat stringers that appeared to result from land cover misclassification. Additionally, subsequent processing was at least nine times faster, in some cases cutting time to create linkage maps from days to hours, resulting in maps that took up a fraction of the disk space and were easier to share. This allowed us to iteratively improve models by accelerating the communication of preliminary results between modelers and species experts. Though the larger grid cell size of 90 m made calculations much faster, the benefits of calculating habitat values and resistances at 30 m were largely retained. For example, we were less likely to double-count resistances of different features (like roads and transmission lines) unless the grid cells representing them exactly overlaid one another.

2.7. Delineating Areas Important to Connect

2.7.1. Focal Species Habitat Concentration Areas

Habitat concentration areas (HCAs) are defined as significant habitat areas that are expected or known to be important for focal species based on survey data or habitat association modeling. For most species, the steps we followed to delineate HCAs were similar to those used in the statewide analysis, with some modifications. Most importantly, here we used focal species habitat models, rather than resistance surfaces, to identify areas with enough high-quality habitat to warrant potential inclusion in an HCA. These habitat layers formed the basis of HCA modeling, which proceeded as follows:

1) For each species, we used a circular moving window with the area equal to an average home-range size to mask out portions of the landscape where the average habitat value within the home range was below a given threshold. Average habitat threshold values were initially set at 0.75, but were then modified as appropriate for individual species based on the expert opinion of the focal species lead scientists and their supporting teams.
2) After grid cells falling below the moving window threshold were masked out, we converted the remaining grid cells to a binary habitat/non-habitat map. We started with binary habitat threshold values of 0.75, modifying these as focal species leads deemed appropriate.

3) Remaining habitat cells were joined if they were within a home-range movement distance (measured in cost-weighted distance units) from one another. This was done in the same way as in the statewide analysis, using the resistance model and expanding designated habitat cells outwards up to a total cost-weighted distance equal to the species' home-range movement radius. This has the effect of joining nearby habitat cells together if the intervening landscape supports movements within home-range-scale distances.
4) Habitat concentration areas smaller than a specified threshold were then removed. Species were assigned one of three minimum HCA thresholds: 50 km^2 (large herbivores—mule deer); 25 km^2 (small herbivores—jackrabbits, grouse, and beaver); 12.5 km^2 (small rodents, reptiles, and amphibians—chipmunk, ground squirrels, rattlesnake, and tiger salamander).

We applied these rules to map HCAs using the HCA Toolkit (Shirk 2011). Home range areas and other parameters for each species were derived from literature review, occurrence data, and expert opinion, and are summarized in Table 2.2.

Table 2.2. Parameters used for habitat concentration area (HCA) and linkage modeling. See Appendix A for details regarding individual focal species models.

Species	*Home-range radius (m)*	*Moving window radius (m)*	*Average habitat threshold value*	*Binary habitat threshold value*	*Min HCA area (ha)*	*Max Euclidean distance (km)*	*Max cost-weighted distance (km)*	*Linkage width cutoff (km)*
Sharp-tailed Grouse	NA	NA	NA	NA	2500	60	-	10
Greater Sage-Grouse	NA	NA	NA	NA	2500	100	-	10
Black-tailed jackrabbit	500	500	0.80	0.80	2500	50	-	10
White-tailed jackrabbit	500	500	0.80	0.80	2500	50	-	10
Townsend's ground squirrel	250	250	0.85	0.85	1250	-	-	5
Washington ground squirrel	250	250	0.75	0.75	1250	-	-	5
Least chipmunk	600	600	0.95	0.95	1250	12	20	5
Mule deer	3500	3500	0.89	0.75	5000	100	-	20
Western rattlesnake	2500	2500	0.30	0.07	1250	50	-	20
Beaver	4000	4000	0.25	0.75	2500	60	-	20
Tiger salamander	8500	500	0.67	0.75	1250	10	-	5
Landscape integrity	1000	1000	0.50	0.90	4047	100	-	30%*

**Landscape integrity maps were cut off at the best 30% of the study area to make comparisons across resistance sensitivity models and to compare statewide results with Columbia Plateau analysis results.*

For Greater Sage-Grouse and Sharp-tailed Grouse, sufficient information on current distributions allowed us to delineate HCAs more directly. For each of these species, we started with known lek locations and resistance rasters. We then "grew" HCAs out from lek locations using increasing values of cost-weighted distance, until they encompassed 95% of known nest locations of current populations (See Appendices A.1 and A.2).

2.7.2. Landscape Integrity Core Areas

To identify landscape integrity core areas, we followed the same computational steps used to identify focal species HCAs described above, using landscape integrity condition values in place of habitat values, and the linear sensitivity resistance model in place of species-specific resistance models. See Table 2.2 for parameters used in the computational steps.

So that large natural habitat blocks divided only by rivers and lakes would not be lost, we set landscape condition values for water to 0.9. This resulted in significant portions of core areas overlapping open water. To refine these areas, we masked out 90 m grid cells that were majority water in the land cover/land use layer from core areas. We then connected all remaining fragments of single core areas that were within 500 m of one another. This allowed fragments separated only by water to be joined; fragments from neighboring core areas separated by other land cover types were not joined. Lastly, we removed resulting habitat blocks that were less than 10,000 acres (4047 ha). As in the statewide analysis, this process resulted in core areas consisting mostly of natural land cover and excluding freeways, major highways, secondary highways, or areas of high low-use road densities.

2.8. Linkage Modeling

Our linkage modeling approach followed that of the statewide analysis, and is briefly summarized here. Although we refer to habitat concentration areas (HCAs) and focal species throughout for simplicity, these methods also apply to core areas and connecting linkages generated from landscape integrity models.

We used Linkage Mapper version 0.7.5 (McRae & Kavanagh 2011) to create cost-weighted distance maps and least-cost corridor maps. The cost-weighted distance maps represented, for each cell in the landscape, the minimum sum of cell costs accumulated as an animal moves from the nearest HCA to the target cell. The resulting map provides an estimate of the relative accessibility of each grid cell to the nearest HCA, considering the cumulative effect of features that facilitate or impede movement (Singleton et al. 2002). This map is particularly useful for identifying barrier effects and broad areas that contribute to connectivity.

For each adjacent HCA pair, we then used Linkage Mapper to map least-cost corridors (See McRae & Kavanagh 2011 for a description of how adjacent HCA pairs are identified). These depict the relative value of each grid cell in providing connectivity between the HCA pair, allowing users to identify which routes encounter more or fewer features that facilitate or impede movement while moving between the two HCAs. Linkage Mapper normalized each corridor, so that grid cells in a given corridor range in value from 0 (the best or least-cost path) on up. Cell values were still in cost distance units, and reflected how much more costly the (locally optimal) path between the HCAs passing through each cell was relative to the (globally optimal) least-cost path connecting the HCA pair. The software then built mosaic corridor maps to create a composite linkage map in which each cell represented the minimum value of all individual normalized corridor layers and generated linkage statistics that are informative for comparing and ranking linkage quality and degree of connectivity between HCA pairs. These statistics included:

- *Euclidean distance*—Shortest straight-line distance between two HCAs.

- *Cost-weighted distance*—Minimum cost-weighted distance an animal can accumulate moving from one HCA to another. This is equal to the total resistance accumulated moving along the least-cost path between the two HCAs.
- *Non-weighted least-cost path length*—Length of the least-cost movement route, without accounting for cost.
- *Cost-weighted/Euclidean distance ratio*—Ratio of cost-weighted to Euclidean distance between two HCAs. Higher ratios mean least-cost corridors are longer or have higher resistance.
- *Cost-weighted/non-weighted path length ratio*—Ratio of cost-weighted distance to the non-weighted least-cost path length. This is equivalent to the average per-cell resistance encountered moving along the least-cost route between two HCAs. High values indicate pathways that pass through low quality movement habitat or across barriers.

For example, the ratio of cost-weighted distance to non-weighted path length provides a measure of linkage quality by quantifying how much more difficult it is to move along the least-cost path connecting two HCAs than it would be if the path was composed of ideal movement habitat (i.e., a land cover type with a resistance of one). Please refer to WHCWG (2010) for more details on mapping and interpreting least-cost corridors, and McRae & Kavanagh (2011) for details on Linkage Mapper and the products it creates, including least-cost corridors and linkage statistics.

2.8.1. Focal Species Linkage Modeling

For each focal species, we chose maximum Euclidean and cost-weighted distances for corridors based on species dispersal abilities (Table 2.2; see also Appendix A). Linkages for some species were allowed to considerably exceed documented dispersal distances because suitable habitat was expected to occur between core areas, providing stopover habitat or multigenerational connectivity.

As with the statewide analysis, the normalized least-cost corridor algorithms produced "wall-to-wall" linkage maps, with every grid cell in the study area having a value that represented its deviation from the nearest least-cost movement route. This necessitated creating maps that displayed only values from zero (the optimum modeled route) to a species-specific linkage width cutoff to identify areas that contribute most to connectivity between each HCA pair. Because of the smaller extent of this analysis and the finer-scale data that were available, we chose cutoff values (Table 2.2) that produced linkage zone widths that were somewhat narrower than those mapped at the statewide scale, while being mindful of the intent that linkage zones serve not only focal species, but other species and processes as well. Keeping linkage zones reasonably wide also acknowledges that there is still considerable uncertainty in GIS base data, resistance models, and other parameters used in our modeling process. We did not wish users of our products to assume that very narrow corridors necessarily indicate the areas most important for wildlife movement.

Of particular importance is the fact that modeled corridors will "punch through" significant barriers, particularly when no maximum cost-weighted distance length is specified for a species. This means that the presence of a modeled corridor does not imply that HCAs are functionally connected. Any future finer-scale linkage design focused on connecting a pair of HCAs will still necessitate close examination of the corridor and the area surrounding it before actions to conserve or restore connectivity are taken. Additional detail on focal species linkage modeling decisions can be found in Appendix A.

2.8.2. Landscape Integrity Linkage Modeling

We created four landscape integrity-based linkage maps using, respectively, the four resistance layers described in Section 2.5.2. We allowed adjacent core areas within 100 km Euclidean distance (based on the maximum distance value used in focal species models) of one another to be connected, with no maximum cost-weighted distance.

Because we used an identical set of core areas in each of the four linkage models, we were able to additively combine them into a single composite map to identify lands that were most robust to assumptions about sensitivity to human-caused barriers. To do this, we divided each of the combined least-cost corridor rasters into 100 equal-area bins, then summed raster values across all connectivity models to create one composite map to represent the landscape integrity connectivity results. To identify connectivity areas in common among the four resistance models, we extracted each resistance model connectivity raster to include only the top 30% area (raster bin values <30) of the landscape, ranked in order of normalized least-cost distances. Both binning and ranking were limited to the study area excluding the 25 km buffer. These four 30% connectivity zone rasters were then overlaid to show areas identified by one, two, three, or all four resistance models. Those connectivity areas associated with the greatest number of models were considered most robust to assumptions of sensitivity to human influence.

2.9. Network Correspondence Analysis

The purpose of this analysis was to identify patterns of correspondence across the 11 focal species and landscape integrity linkage networks for the Columbia Plateau Ecoregion. The methods we used are generally consistent with those used for the correspondence analysis for the statewide assessment (WHCWG 2010). In summary, we used hierarchical cluster analysis (a multivariate statistical analysis technique commonly used in plant community ecology) to quantify the degree to which linkage patterns overlapped among focal species. We also included landscape integrity products to quantify the degree to which linkage patterns identified in the landscape integrity analysis were similar to results for individual focal species.

To conduct the cluster analysis, we sampled the cost-weighted distance, least-cost corridor, and binary habitat concentration area (HCA) values for each of the focal species at 37,334 points arranged in a 1.5 km square grid across the Columbia Plateau ecoregional analysis area (not including the 25 km buffer). We then determined whether each sample point was inside or outside of the four linkage networks identified in the landscape integrity analysis (See Section 2.8.2). We used two different analysis approaches to evaluate the robustness of the clustering results. The first approach classified each sample point as inside or outside the linkage network (binary classification) for each of the 11 focal species and the four landscape integrity networks. We classified the sample points as being inside or outside each network based on the linkage width cutoff value for each focal species (Table 2.2). All areas with cost-weighted distance or least-cost corridor values less than the linkage width cutoff, or within an HCA for that focal species, were considered to be within the linkage network for that focal species. To determine the sensitivity of this binary classification approach to network width differences, we repeated the analysis using five different network widths ranging from 0.5 to 3 times the linkage width cutoff for each focal species.

The second analysis approach compared continuous cost-weighted distance and least-cost corridor values across the focal species. To cope with differences in different landscape resistance and maximum movement distances across the focal species, we standardized the least-cost corridor and cost-weighted distance values using a percentile transformation. This transformation calculated the value at each sample point divided by 4 times the linkage width cutoff. For each focal species, this transformation resulted in values ranging from 0 to 1 for all areas within 4 times the reference network width, and a value of 1 for all areas beyond 4 times the reference network width. We used 4 times the reference network width as the maximum value for the percentile transformation because this produced a reasonable maximum dispersal distance value for the focal species (range 20–80 km cost-weighted distance). To be consistent with the binary network analysis, we also conducted a cluster analysis using the minimum of the transformed cost-weighted distance or least-cost corridor value at each sample point for each focal species. The purpose of the latter analyses was to provide an additional examination of the robustness of clustering patterns identified using the binary network reference. All cluster analyses were conducted using the *hclust* function in R (version 2.13.1, R Development Core Team 2011).

Chapter 3. Results from the Connectivity Analysis of the Columbia Plateau Ecoregion

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This chapter presents results from focal species analyses (See Section 3.1), landscape integrity analyses (See Section 3.2), focal species and landscape integrity linkage networks (See Sections 3.3 and 3.4), and a correspondence analysis across focal species and landscape integrity networks (See Section 3.5). In the final section (See Section 3.6) we consider how effective this project has been in adding detail to the Washington statewide analysis (WHCWG 2010), and thus providing a crucial step toward local-level analysis and linkage design. Because of the breadth and depth of our analysis, the results presented in this chapter are not all-inclusive and we encourage users to refer to the Appendices for additional detail and insight.

3.1. Focal Species

Summarized here are our results of focal species selection, resistance surfaces, habitat maps and habitat concentration areas (HCAs), cost-weighted distance surfaces, and linkages. For detailed results by focal species, see individual accounts in Appendix A.

3.1.1. Focal Species Selection

We selected 11 focal species representing six major vegetation classes in the Columbia Plateau Ecoregion (Table 3.1): two birds, seven mammals, one amphibian, and one reptile. Of these 11 focal species, seven are at-risk (state threatened species, state or federal candidate species, or state monitor species conservation status); in addition, five are climate-sensitive based on our selection criteria (Sharp-tailed Grouse, Greater Sage-Grouse, Townsend's ground squirrel, Washington ground squirrel, tiger salamander; see Appendix E). Both grouse species were rated as sensitive to wind power. However, lack of data precluded rating other focal species for this criterion.

The majority of species (8 of 11), are strongly representative of the shrubsteppe vegetation class, and six species additionally provide strong representation for the grassland class. Cliff, canyon, and talus are strongly represented by one species, the Western rattlesnake, with supplemental representation by four other species. Likewise, the riparian and wetlands classes are each strongly represented by two species (beaver and Sharp-tailed Grouse, and beaver and tiger salamander, respectively), but supported by at least four other selected species. Dunes are represented in an ancillary manner by five focal species chosen to represent other vegetation classes (Table 3.1).

Table 3.1. Focal species selected to represent connectivity priorities in six broad vegetation classes. The vegetation class for which a species ranked well enough for selection is indicated with an "X." Additional vegetation classes where a species occurs are indicated with an asterisk. Although no species were chosen specifically to represent Dunes, at least five of the selected species use the Dunes habitat.

Focal Species	*Federal/State Status*[a]	*Shrub-steppe*	*Grass-land*	*Cliff, Canyon, Talus*	*Riparian*	*Wetland*	*Dunes*
Sharp-tailed Grouse *Tympanuchus phasianellus*	ST	X	X	*	X	*	
Greater Sage-Grouse *Centrocercus urophasianus*	FC/ST	X	X	*	*	*	
Black-tailed jackrabbit *Lepus californicus*	SC	X	*				*
White-tailed jackrabbit *Lepus townsendii*	SC	X	X		*		
Townsend's ground squirrel *Urocitellus townsendii*	SC[b]	X	X				*
Washington ground squirrel *Urocitellus washingtoni*	FC/SC	X	X				*
Least chipmunk *Neotamias minimus*		X	*				
Mule deer *Odocoileus hemionus*		X	X	*	*	*	*
Western rattlesnake *Crotalus oreganus*		*	*	X	*	*	*
Beaver *Castor canadensis*					X	X	
Tiger salamander *Ambystoma tigrinum*	SM	*	*	*	*	X	

[a]*FC = Federal Candidate, ST = State Threatened, SC = State Candidate, and SM = State Monitor.*
[b]*Subspecies townsendii.*

3.1.2. Resistance Surfaces

Across all focal species, resistance values (i.e., numeric values related to the expected difficulty for movement across the landscape) for individual landscape elements ranged from 0 to 1000, with most scores falling at the low end of that range (See Appendix C). Landscape elements assigned the highest average resistance scores included: housing density of 1 dwelling unit per 10 ac or greater, freeway and major highway centerlines, 45 m radius around wind turbines, irrigation canals, and elevation between 2500 and 3300 m. Landscape elements consistently assigned low resistance values included: shrubsteppe vegetation, housing density less than 1 unit per 80 ac, elevation between 0 and 1000 m, slope 20 degrees or less, and road, railroad, and transmission line buffers.

Focal species accounts (See Appendix A) include a resistance map for each species. We present examples here to acquaint the reader with these maps, and to illustrate specific points. For instance, the mule deer resistance map (Fig. 3.1) indicates a spectrum of landscape conditions that range from favorable to unfavorable for movement. Close-up views of this map show the modeled increase in resistance to movement from wind turbines and major irrigation canals (Fig. 3.2; see also Appendix A.8).

As a second example, the Western rattlesnake has high sensitivity to development and traffic (See Appendix A.9). For rattlesnakes, modeled landscape elements of housing density 20 ac or less per dwelling unit and freeway centerlines result in high resistance to movement, while elements of housing density >80 ac or more per dwelling unit, elevation ≤1250 m, and landcover/landuse categories of basin grassland, basin shrubsteppe, shrubsteppe, cliffs, rocks, barren, riparian, and aspen woodland result in low resistance to movement (Fig. 3.3; Fig. 3.4).

3.1.3. Habitat Maps and Habitat Concentration Areas

We developed habitat maps for eight focal species, and habitat concentration areas (HCAs) for all 11 focal species. In-depth habitat and HCA details for each species may be found in Appendix A.

The habitat models and maps supported identification of the HCAs that were connected during linkage modeling. They also provide a useful product for understanding the spectrum of favorable to unfavorable habitat patterns across the Columbia Plateau Ecoregion. For the eight species with habitat maps (beaver, black-tailed jackrabbit, least chipmunk, mule deer, tiger salamander, Townsend’s ground squirrel, Washington ground squirrel, and white-tailed jackrabbit), landscape elements that tended to rate very high for habitat importance include basin grassland, shrubsteppe, and basin shrubland vegetation types; housing densities of 40 ac or more per dwelling unit; elevation 1200 m or less; and gentle slopes of 20 degrees of less. Conversely, landscape elements that tended to rate very poorly for habitat across many species include: freeways, highways, local roads, and active railroads; irrigation canals; housing density of one or more dwelling units per 10 ac; slopes greater than 40 degrees; elevation 2500 m or greater; and areas classed as cliffs, rocks, and barren. A full listing of the habitat modeling values across the eight species is located in Appendix C.

The tiger salamander habitat map (Fig. 3.5) illustrates a number of the above-noted characteristics. In particular for the salamander, areas of basin grassland, shrubsteppe, meadow, herbaceous wetland, and riparian vegetation, and housing density of greater than 40 ac per dwelling unit strongly influence areas rated as good habitat, while mountain ridgetops, highly structured agriculture (such as orchards and vineyards), and housing density of one unit or more per 10 ac are examples of landscape elements that contributed to areas being ranked as less favorable habitat.

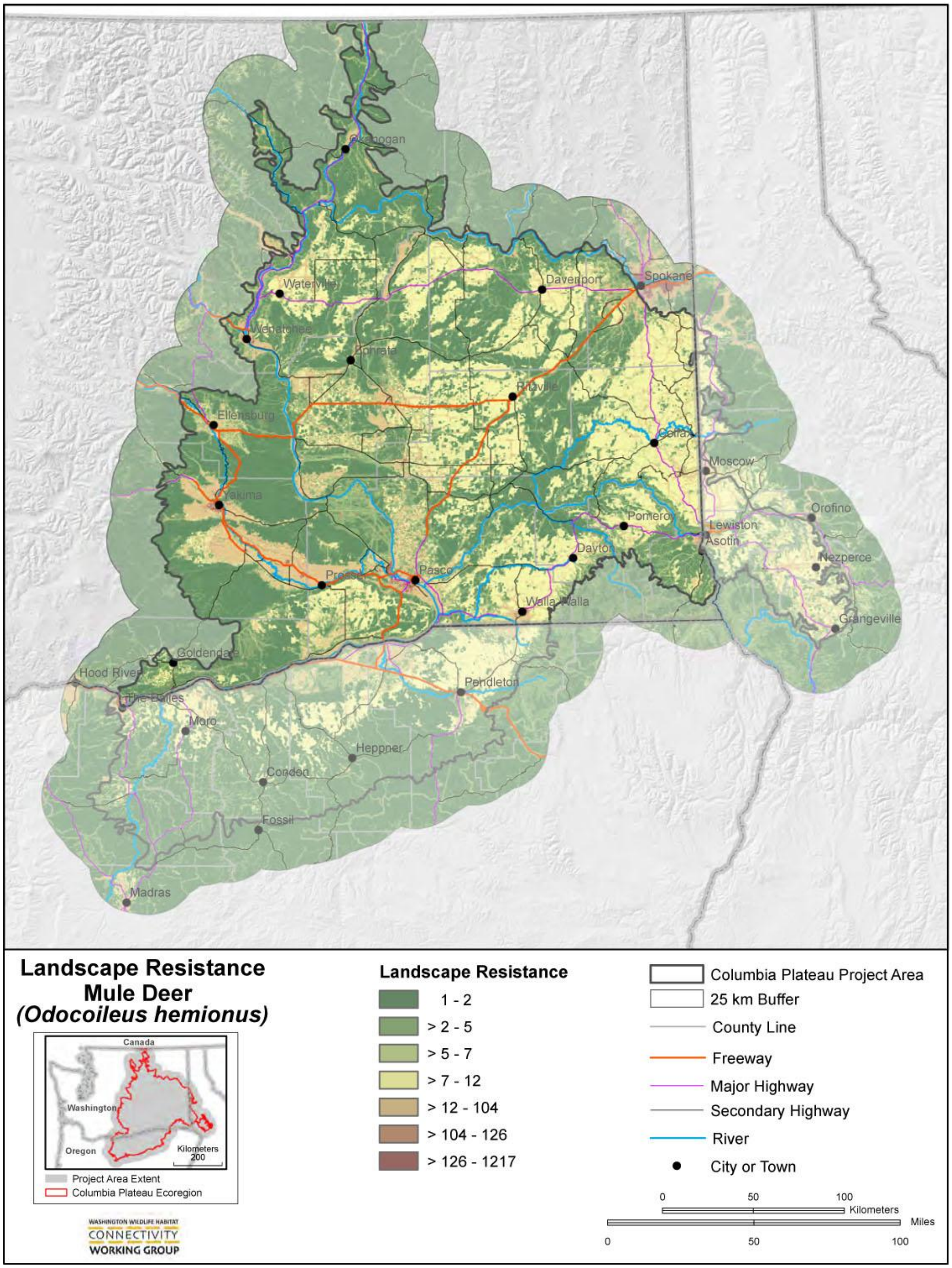

Figure 3.1. Landscape resistance for mule deer. Green areas represent landscape locations within the Columbia Plateau Ecoregion where movement conditions are generally expected to be favorable for mule deer, whereas tans to red-browns are expected to be less favorable or potentially unfavorable to movement.

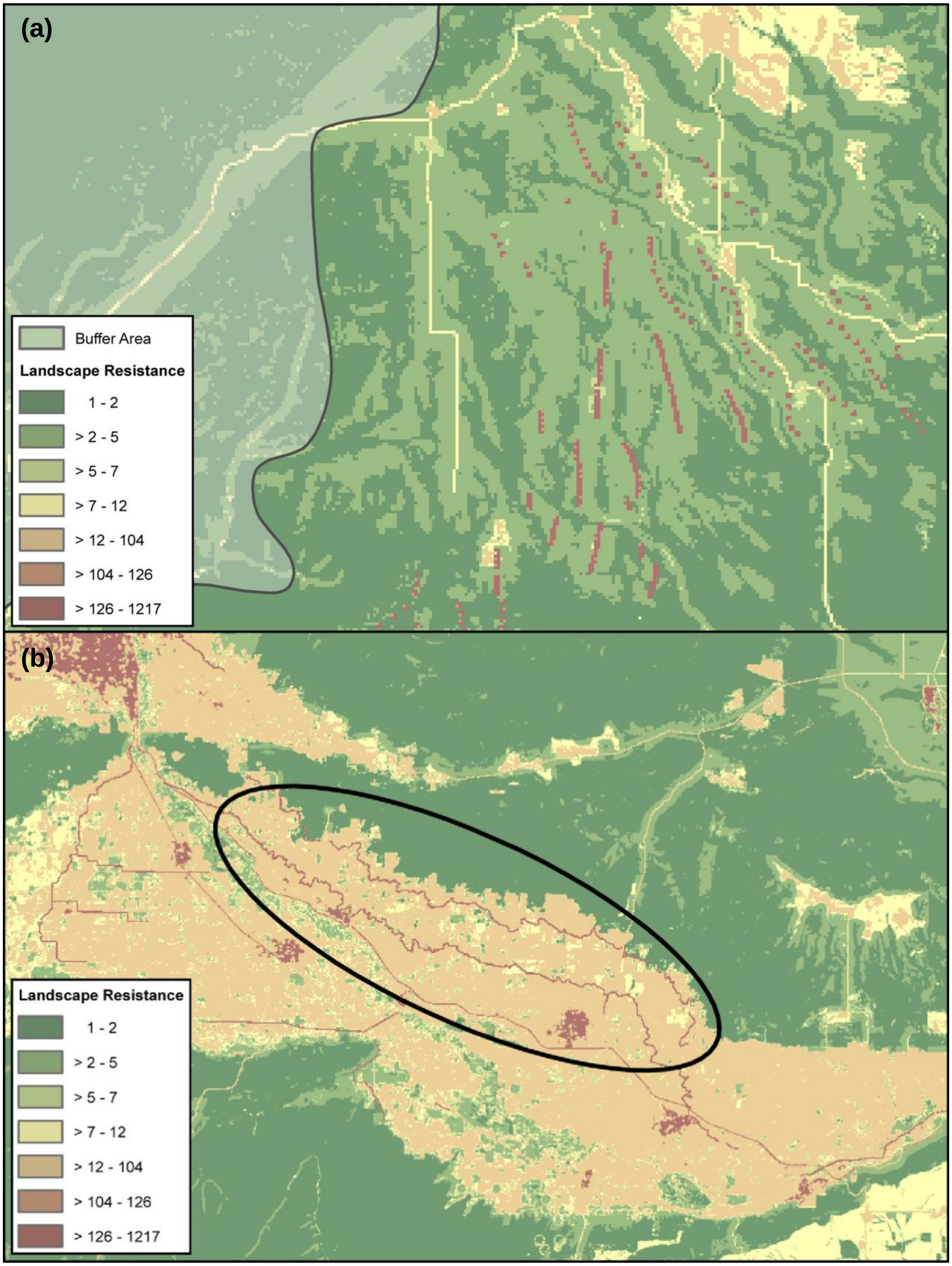

Figure 3.2. Mule deer zoomed in landscape resistance examples. (a) The resistant linear features of wind turbine locations on the landscape in the Horse Heaven Hills of south-central Washington can be seen as strings of dark red-brown rounded areas. (b) Illustration of the landscape resistance pattern resulting from major irrigation canals southeast of Yakima (squiggle lines within the black ellipse).

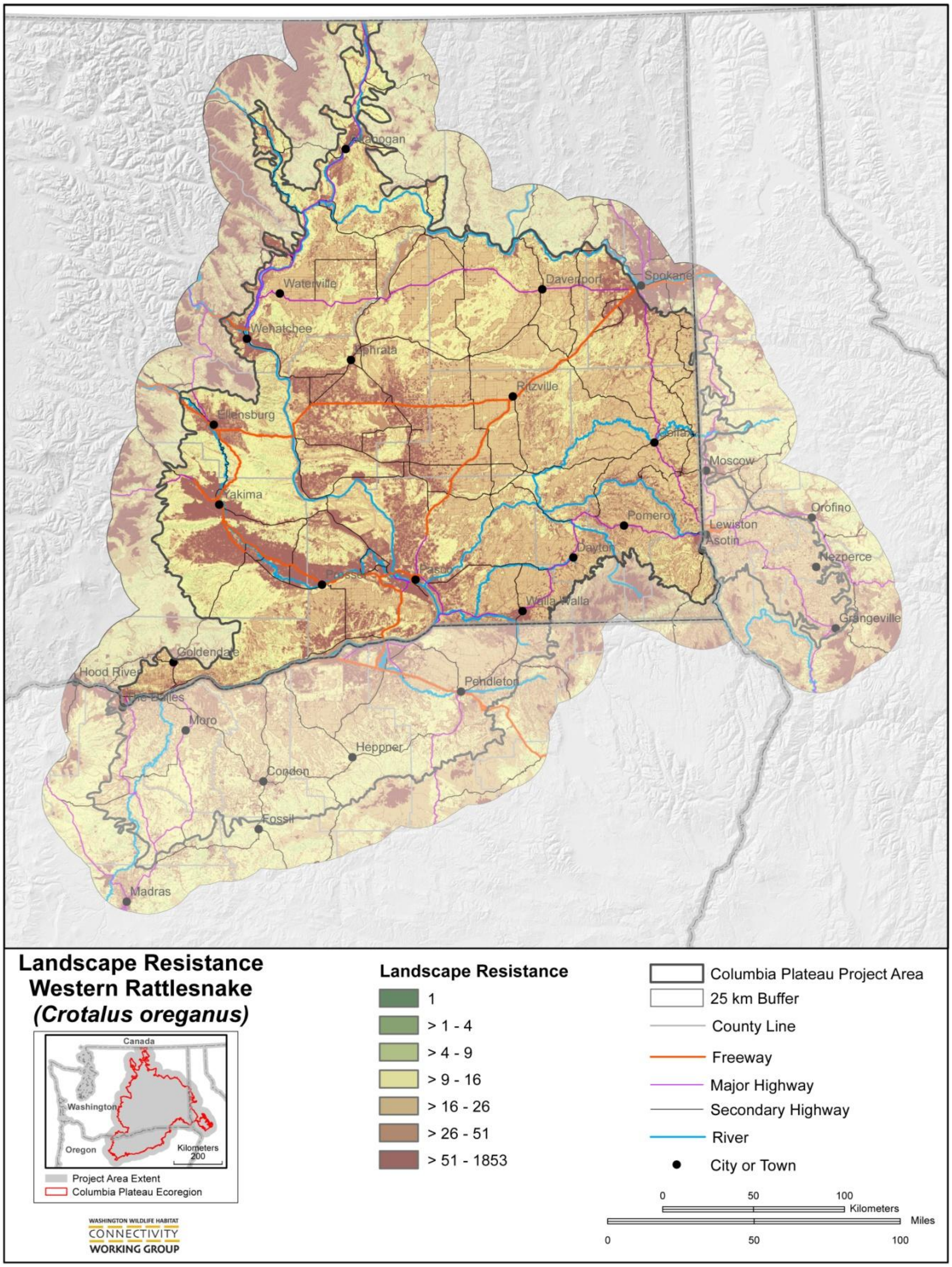

Figure 3.3. Landscape resistance for Western rattlesnake. Green areas represent landscape locations within the Columbia Plateau Ecoregion where movement conditions are generally expected to be favorable, whereas tans to red-browns are expected to be less favorable or potentially unfavorable to movement.

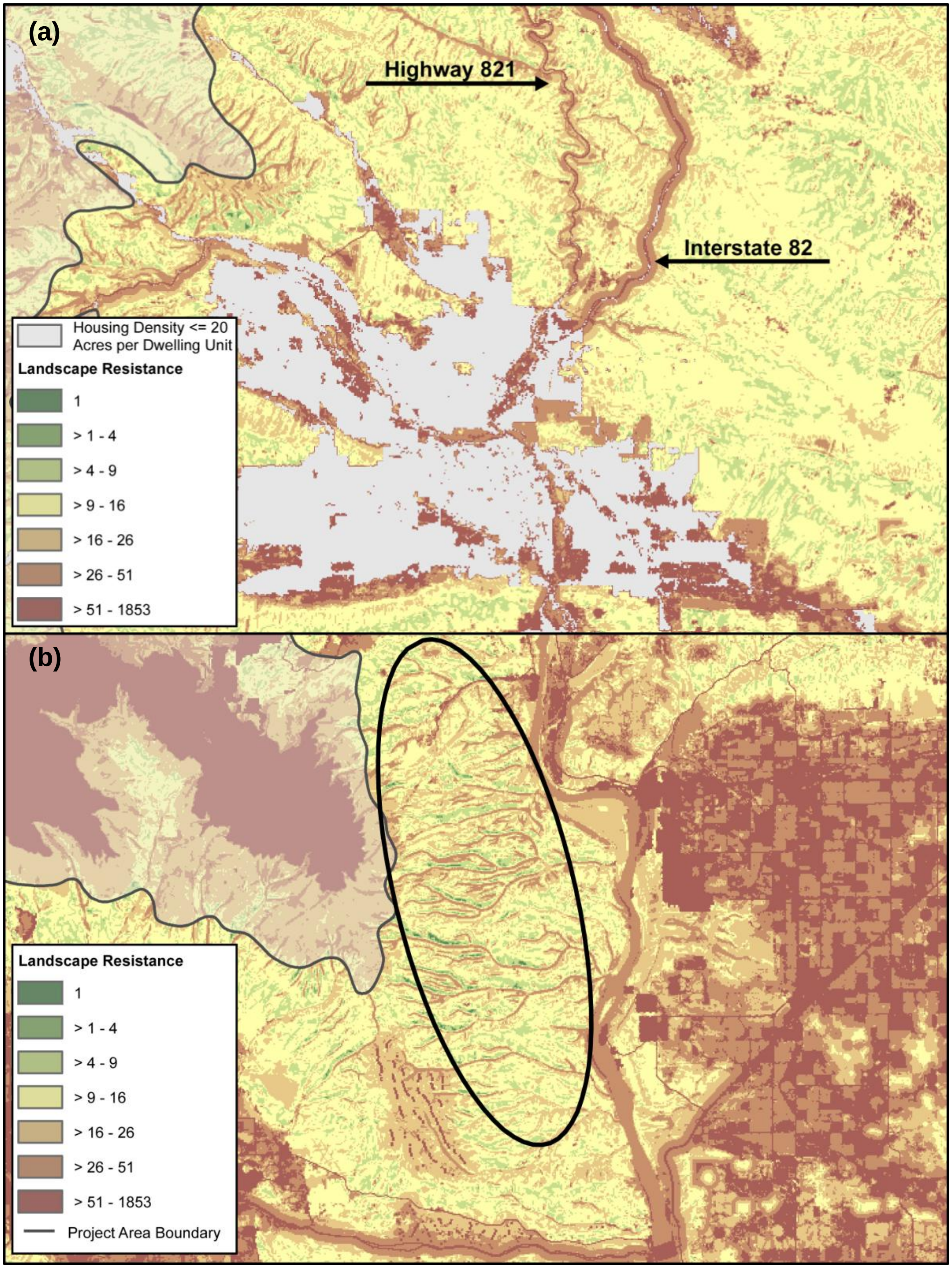

Figure 3.4. Western rattlesnake zoomed in landscape resistance examples. (a) Illustration of Yakima and adjacent lands to the north, showing the pattern of high resistance: housing densities of 20 acres or less per dwelling unit highlighted in gray, and road, highway, and freeway centerlines in dark red-brown. (b) Illustration of the areas of low resistance (green) northeast of Ellensburg near the Columbia River.

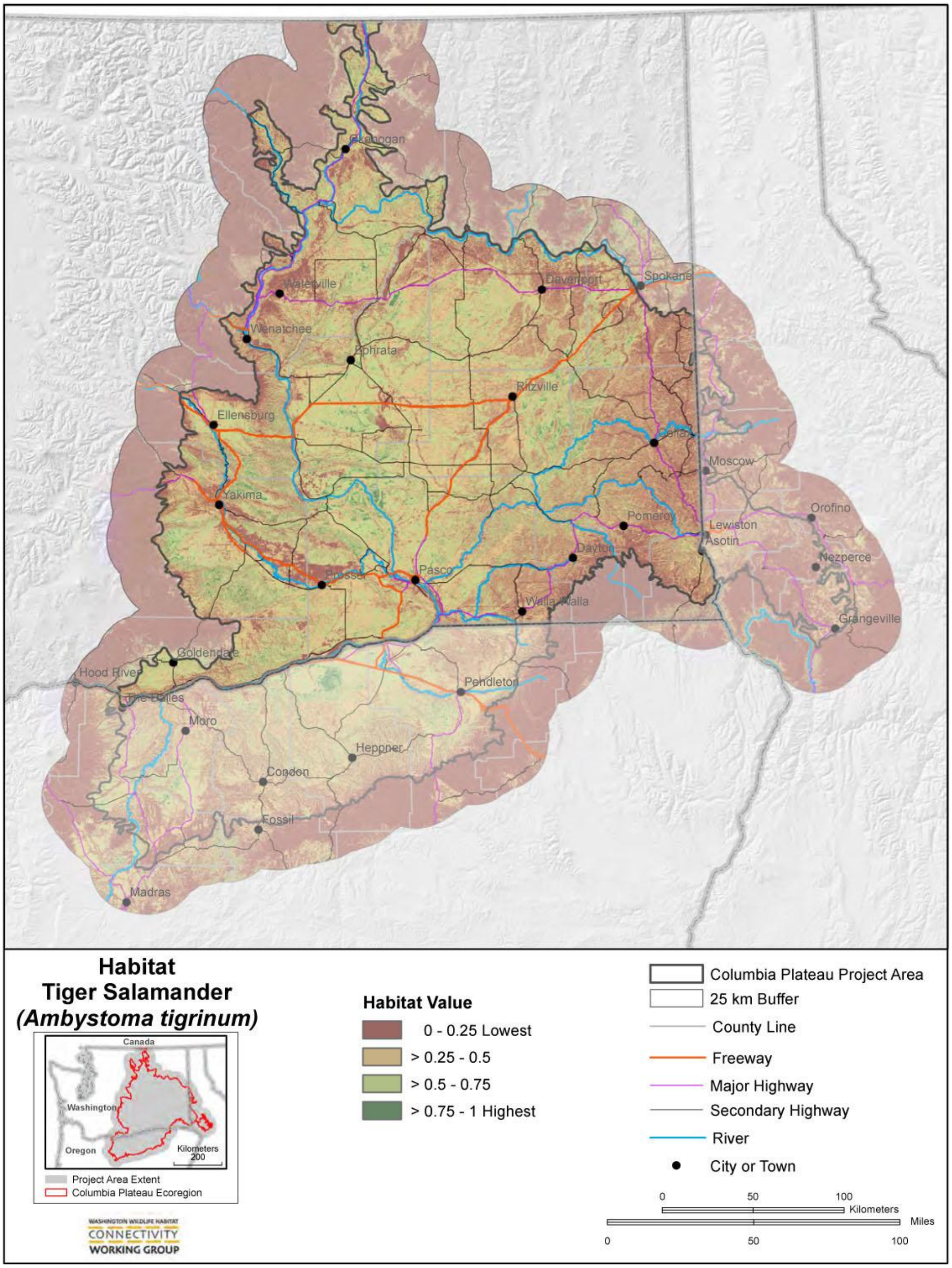

Figure 3.5. Modeled tiger salamander habitat conditions in the Columbia Plateau Ecoregion. Dark green indicates areas expected to have habitat conditions favorable for tiger salamanders while the tans to red-browns indicate less favorable habitat conditions. To meet both aquatic and terrestrial habitat conditions necessary for the tiger salamander biphasic life history, wetlands are tied to favorable habitats identified in this map during habitat concentration area modeling.

In the Columbia Plateau Ecoregion and the 25 km buffer, the number of HCAs identified for each species ranged from four for the Greater Sage-Grouse to 115 for the tiger salamander (Table 3.2). Focal species HCAs ranged in size from 5 km^2 (Washington ground squirrel) to 3371 km^2 (mule deer).

Table 3.2. Number and size characteristics of focal species habitat concentration areas (HCAs) and landscape integrity core areas within the Columbia Plateau Ecoregion and its buffer.

Focal species/landscape integrity	*Number of HCAs*	*HCA size (km^2) range*	*HCA size (km^2) mean (SD)*	*Total area of HCAs (km^2)*
Sharp-tailed Grouse	15	32–268	94 (72)	1412
Greater Sage-Grouse	4	305–1868	932 (725)	3728
Black-tailed jackrabbit	54	25–766	126 (162)	6825
White-tailed jackrabbit	90	25–1141	111 (165)	9963
Townsend's ground squirrel	48	13–595	61 (97)	2907
Washington ground squirrel	97	5–699	59 (110)	5679
Least chipmunk	47	6–342	58 (68)	2706
Mule deer	71	71–3371	515 (580)	36,574
Beaver	73	25–1394	134 (223)	9787
Tiger salamander	115	13–678	52 (85)	5977
Western rattlesnake	106	13–1147	92 (147)	9759
Landscape integrity*	113	41–1112	140 (167)	15,829

Includes only core areas that were ≥40 km^2 (4047 ha) within the Columbia Plateau Ecoregion but not the buffer.

The HCAs for each focal species occur in a distinct landscape pattern. The patterns vary in:

- *Breadth of coverage*. The mule deer HCAs broadly encompass 36,574 km^2 across the ecoregion and its buffer, while Sharp-tailed Grouse HCAs encompass 1412 km^2.
- *Geographic location*. Sharp-tailed Grouse HCAs are only found in the northern part of the ecoregion, whereas those for Townsend's ground squirrels are found in the southwest portion.
- *Shape and extent of coverage*. Habitat concentration areas for beaver are long, narrow areas following rivers and larger landscape areas where aquatic habitats are expected to be abundant (Fig. 3.6), whereas tiger salamander HCAs tend to be composite clusters of small, round areas, focused around ponds and wetlands (Fig. 3.7).

Habitat concentration areas are largely intended to represent high-quality habitat and do not represent all areas of a species' range. For example, the range for least chipmunk predicted by the Washington State Gap Analysis (Cassidy et al. 1997) is of greater extent than that of the HCAs for the least chipmunk (Fig. 3.8). Similar maps for each focal species are presented in Appendix A.

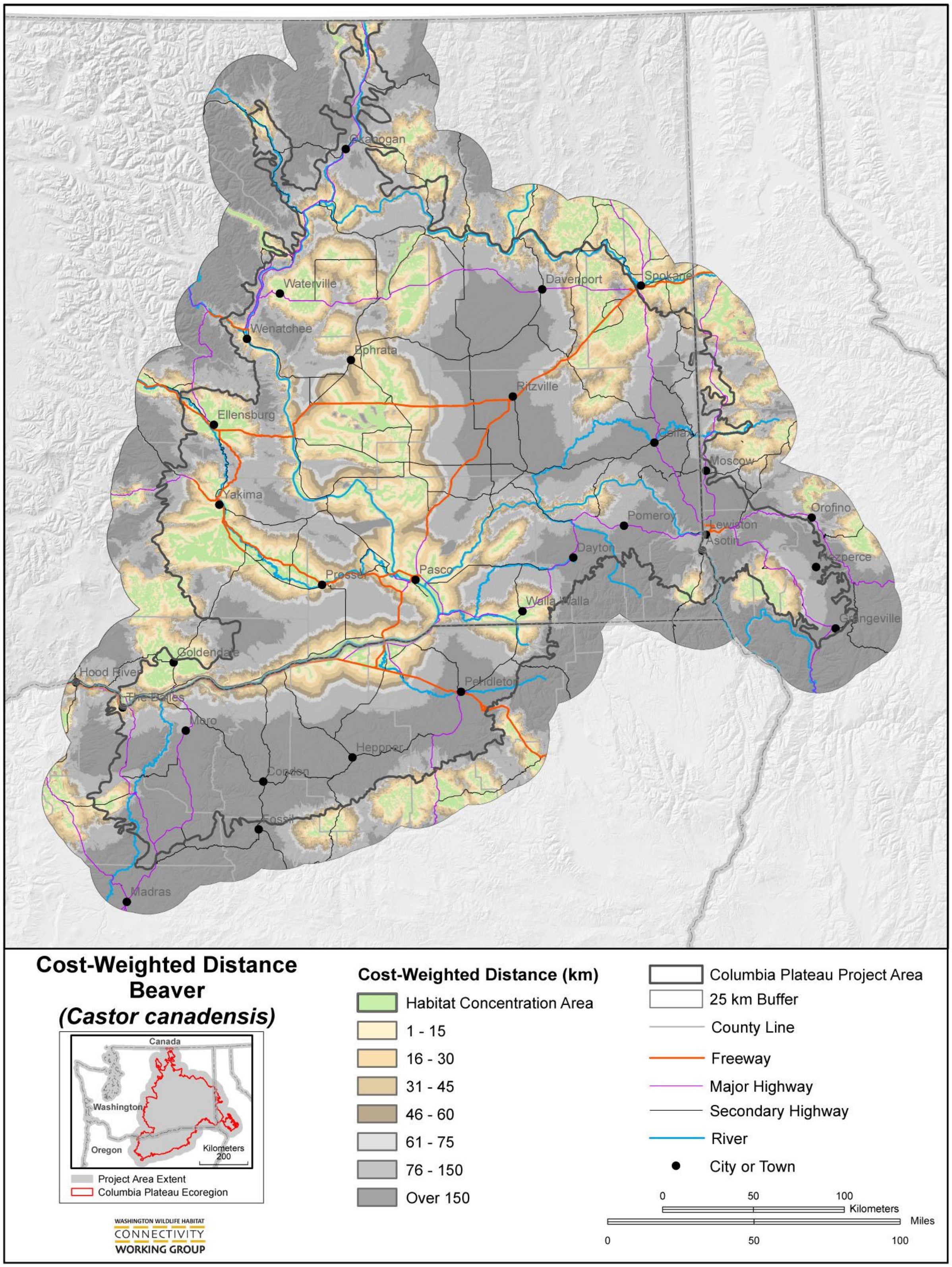

Figure 3.6. Cost-weighted distance map with beaver habitat concentration areas (HCAs). The patterns on the landscape of the beaver HCAs are a combination of long, narrow areas along rivers, and larger landscape areas where aquatic habitats may be abundant.

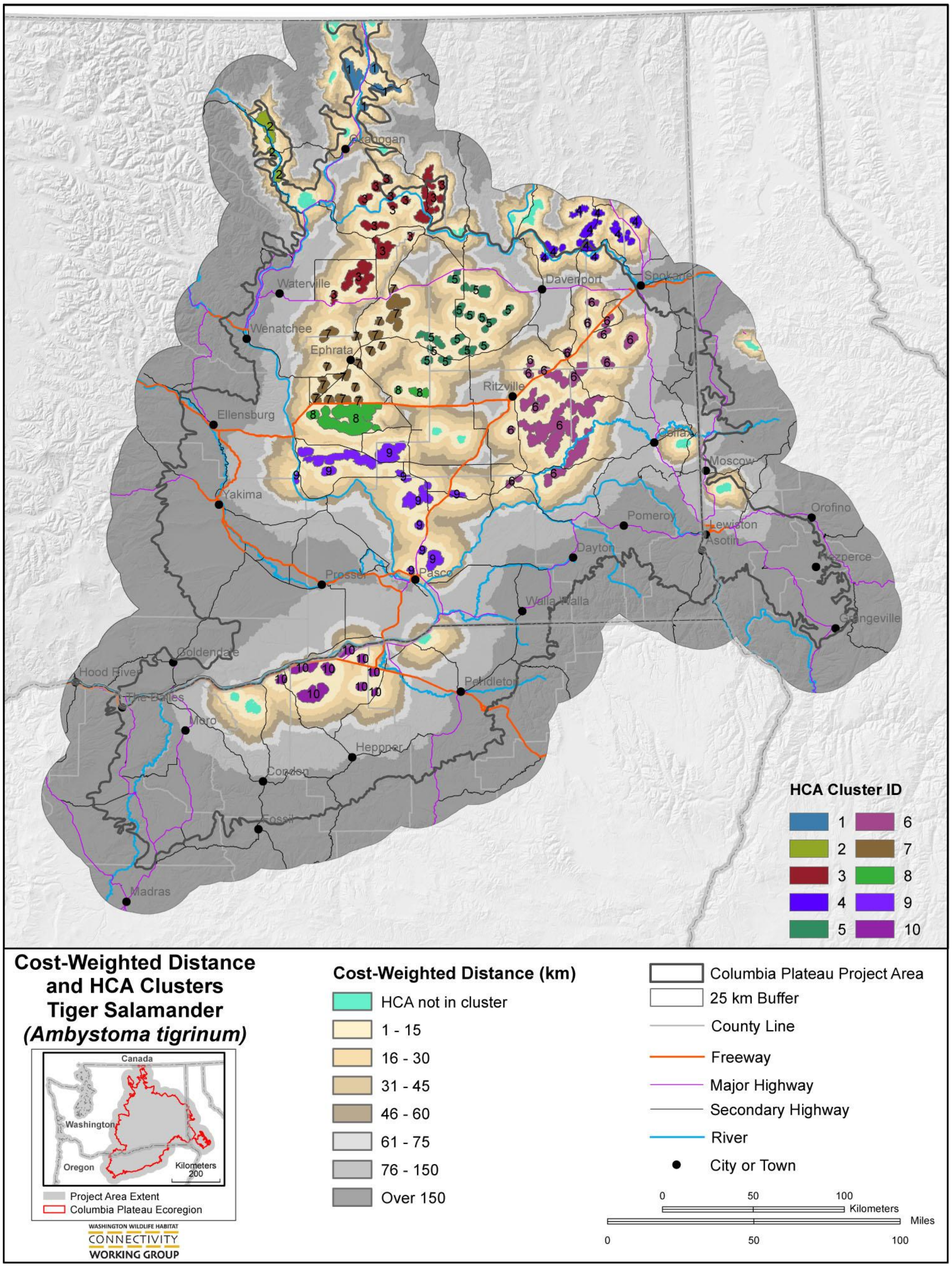

Figure 3.7. Cost-weighted distance map with tiger salamander habitat concentration areas (HCAs). These HCAs tend to be composite clusters of small, round areas, focused around ponds and wetlands. There are 10 clusters of HCAs, and an additional 16 HCAs appear to be isolated as singles or pairs.

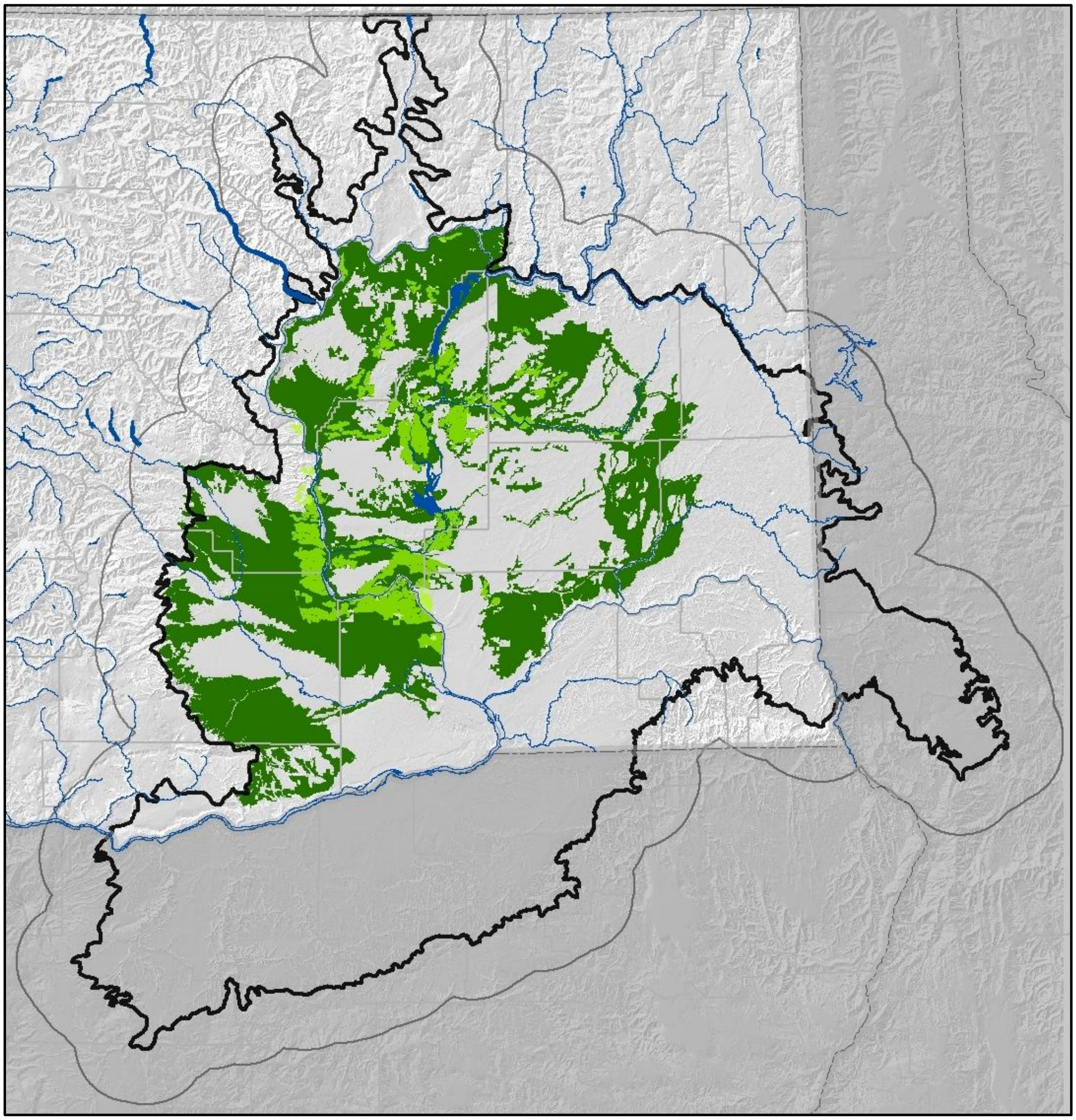

Figure 3.8. Least chipmunk habitat concentration areas and the predicted Washington State range. Habitat concentration areas (HCAs) are indicated in light green, and the predicted range based on the Washington State GAP Analysis (Cassidy et al. 1997) is shown in dark green. HCAs are largely intended to represent high quality habitat and they are not expected to represent all areas of a species' range.

3.1.4. Cost-Weighted Distance Maps

Cost-weighted distance maps show the cumulative resistance encountered when moving to any point in the study area from the nearest habitat concentration area (HCA). These maps can be read like a topographic map: the HCA isopleths indicate increasing categories of accumulated resistance—a continuous variable—starting at the edge of an HCA. They are particularly important because they simultaneously highlight areas that: (1) suggest the best movement pathways between HCAs, (2) indicate the difficulty of moving between different HCA pairs, and (3) act as "pinch points" or fracture zones.

Locations where movement cost accumulates rapidly for multiple species include housing densities of 1 dwelling unit per 10 ac or less; freeway and highway centerlines; wind turbine locations; irrigation canals; and natural features such as large areas of water, forest, high elevations, and very rugged terrain. Valley bottoms with rivers and various elements of human infrastructure, as well as highway corridors that also have transmission lines, railroads, and irrigation canals tend to create abrupt increases in cost-weighted distance that appear as linear barriers that limit access to habitats. Movement cost accumulates more gradually in agricultural landscapes and these lands may be traversed if they are not too extensive. In particular, the Land Cover/Land Use categories of Pasture Hay Ag at buffer 0–250 m and buffer 250–500 m from native habitat were rated as very permeable to all species, and this is reflected in the cost-weighted distance maps. Conversely, extensive agricultural conversion can lead to sufficient accumulation of cost, such that connectivity between HCAs becomes unlikely and results in impermeable “holes” in the landscape (e.g., eastern Adams County). Three examples of cost-weighted distance maps, and how they illustrate movement potential, follow.

The cost-weighted distance map for Greater Sage-Grouse (Fig. 3.9 and Appendix A.2) illustrates patterns of movement potential for this species. For example, connectivity between the southernmost HCA (on the Yakama Reservation) and the closest northerly HCA (on theYakima Training Center) includes a severe pinch point on Ahtanum Ridge and over to Rattlesnake Hills, just south of Yakima.

A visual inspection of the relative proximity of tiger salamander HCAs on the cost-weighted distance map, together with linkage results, highlighted 10 clusters and 16 HCAs isolated as singletons or pairs (Fig. 3.7). This coarse clustering of HCAs suggests subdivision of populations within the Columbia Plateau into subunits, with roughly 14% of HCAs being isolated or nearly so.

In another example, the white-tailed jackrabbit cost-weighted distance map portrays good north–south movement potential in the Okanogan Valley (Fig. 3.10), indicating this may be an important area to protect to conserve the northern extent of the population in Washington and to potentially facilitate future movement into British Columbia (See Appendix A.4).

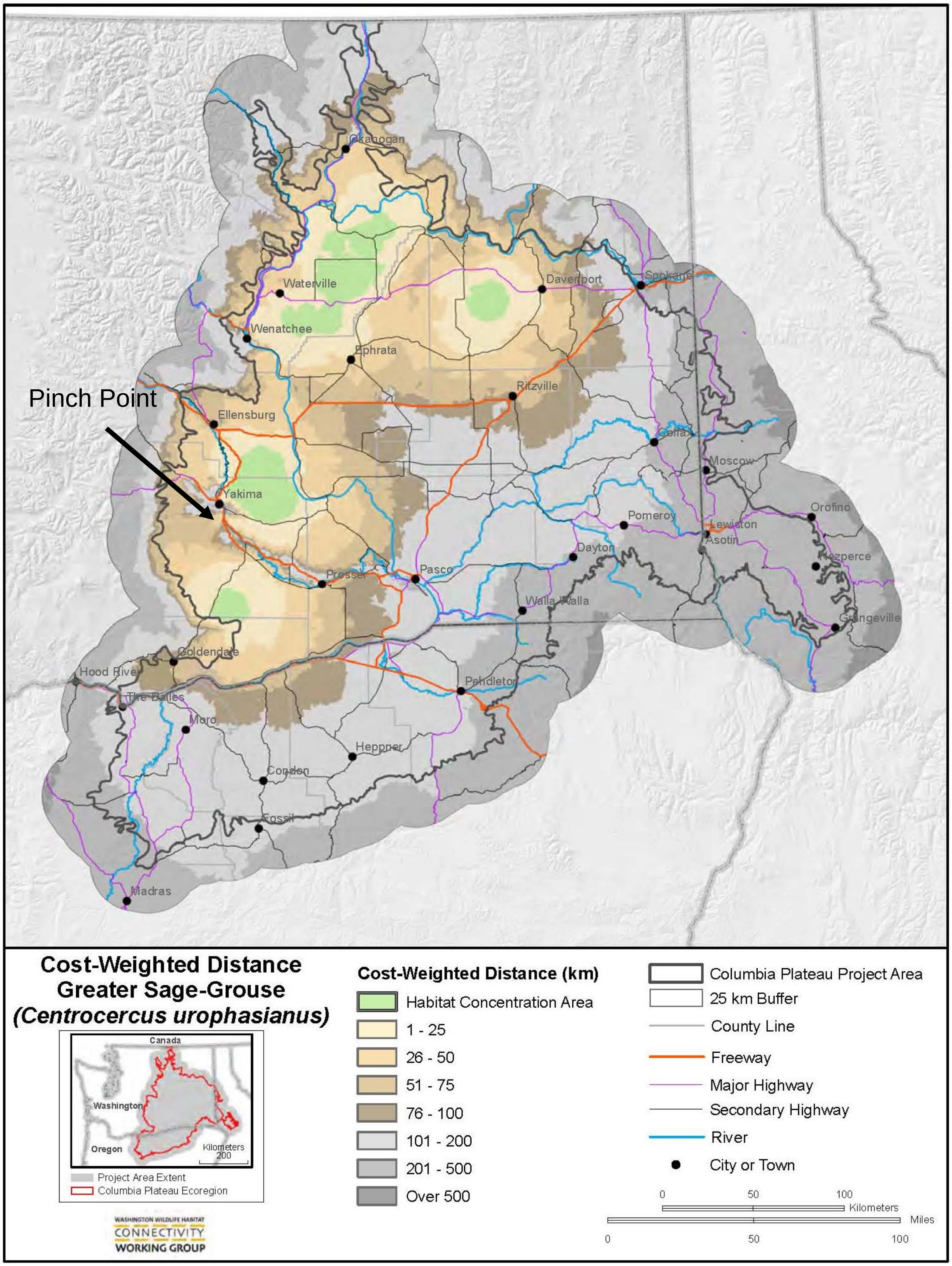

Figure 3.9. Cost-weighted distance map for Greater Sage-Grouse in the Columbia Plateau Ecoregion. This map illustrates patterns of movement potential: for example, connectivity between the southernmost habitat concentration area (HCA) and the closest northerly HCA includes a severe pinch point.

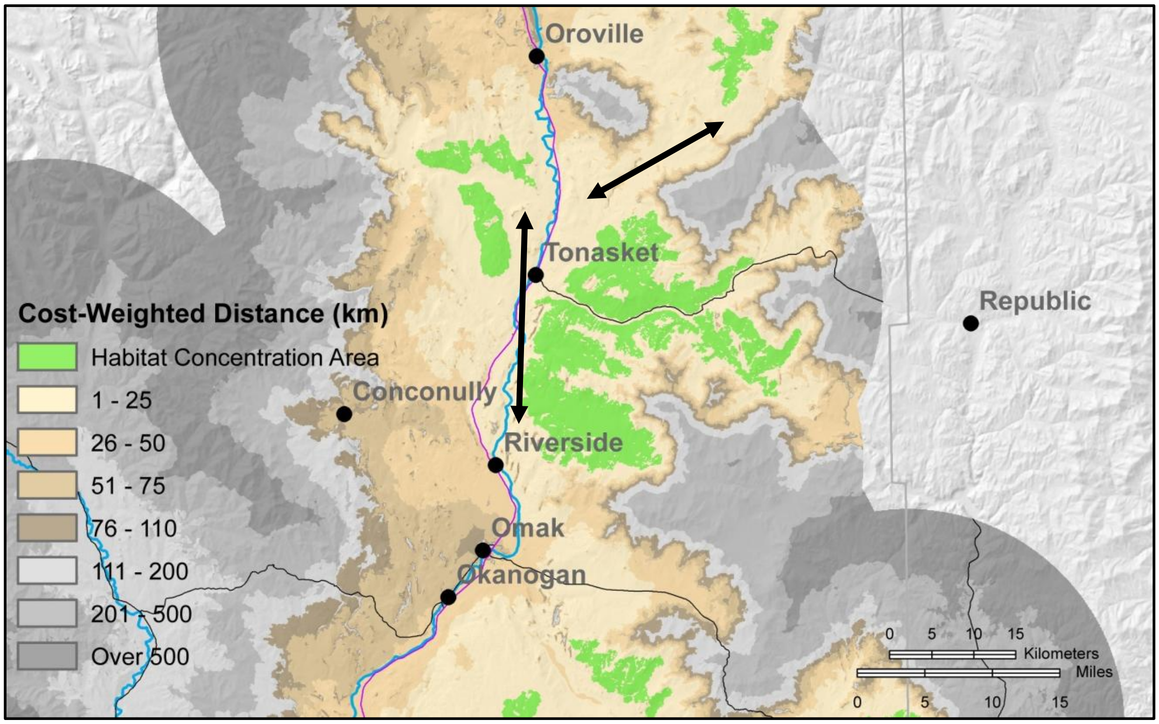

Figure 3.10. White-tailed jackrabbit zoomed in cost-weighted distance map. This is a view of the Okanogan Valley, and conditions that may facilitate north–south movement for this species. Green areas are habitat concentration areas, and the light tan colors indicate potential for north–south dispersal (indicated by arrows) from the Canadian border south to the Riverside area.

3.1.5. Linkages

The number of linkages identified for individual focal species ranged from three for Greater Sage-Grouse, to 226 for Western rattlesnake, and mean lengths of linkages along the least-cost path ranged from 4 km for Townsend's ground squirrel and least chipmunk, up to 78 km for Greater Sage-Grouse (Table 3.3). The Appendix A species accounts provide extensive results regarding the modeled linkages; for instance the black-tailed jackrabbit account describes the importance of HCAs and linkages in the Yakima Valley, along the Yakima River, and within the I-82 corridor, which, if lost, could divide the black-tailed jackrabbits into two separate Washington populations (Fig. 3.11; see also Appendix A.3).

Table 3.3. Number, length, and quality characteristics of focal species and landscape integrity linkages within the Columbia Plateau Ecoregion and its buffer.

Focal species/ landscape integrity	*Number of linkages project-wide*	*Euclidean distance (km) mean (SD) range*	*Cost-weighted length (km) mean (SD) range*	*Non–weighted LCP length (km) mean (SD) range*	*Cost-weighted/ Euclidean mean (SD) range*	*Cost-weighted/ non-weighted mean (SD) range*
Sharp-tailed Grouse	27	17(16) <1–54	26(24) 1–81	21(19) 1–65	2(2) 1–12	1(1) 1–5
Greater Sage-Grouse	3	50(11) 40–62	103 (17) 91–123	78(17) 68–98	2(1) 2–3	1(<1) 1–1
Black-tailed jackrabbit	108	10(10) <1–49	41(39) <1–198	14(13) <1–73	7(10) 1–45	4(5) 1–32
White-tailed jackrabbit	164	9(11) <1–49	28(36) <1–219	13(15) <1–82	4(5) 1–55	3(2) 1–11
Townsend's ground squirrel	75	3(5) <1–26	6(10) <1–50	4(7) <1–31	4(8) 1-60	2(2) 1–16
Washington ground squirrel	201	9(10) <1–48	23(33) <1–191	13(16) <1–75	4(7) 1–63	2(4) 1-31
Least chipmunk	52	3(3) <1–11	6(6) <1–24	4(4) <1–14	3(3) 1–24	2(2) 1–12
Mule deer	145	20(24) <1–97	52(64) <1–273	27(33) <1–119	3(2) 1–17	2(2) 1–14
Beaver	135	16(16) <1–59	127(131) 1–560	24(24) <1–98	13(25) 1–281	7(5) 1–58
Tiger salamander	144	4(3) <1–10	25(17) 1–88	6(3) <1–17	8(13) 2–134	5(4) 2–33
Western rattlesnake	226	15(15) <1–50	281(272) 3–1333	19(18) <1–71	29(37) 9–375	21(18) 7–204
Landscape integrity Linear model*	398	7(12) <1–68	54(102) 1–830	11(20) <1–132	8(6) 2–40	6(4) 1–24
Landscape integrity Maximum model*	344	7(10) <1–68	310(690) <1–6429	12(18) <1–107	58(76) 1–851	34(49) <1–549

**Landscape integrity values do not include linkages within the ecoregional buffer.*

Cost-weighted linkage lengths ranged from <1 km for most species, to as much as 1333 km for a Western rattlesnake linkage (Table 3.3). The ratio of the cost-weighted length divided by the straight line (Euclidean) distance separating HCA pairs can indicate corridor quality. Mean values of this ratio for seven focal species were 2–4, indicating the potential for relatively strong linkage connections. However, four species had much higher ratios indicating the likelihood of poor linkage connections: the highest was that of the Western rattlesnake, which has a mean ratio of 29 (Table 3.3). The linkage ratios can also be used to consider the potential strength of individual linkages or groups of linkages for a species. As an example, the linkage quality metrics for Washington ground squirrel indicate linkages in Washington may be of lesser quality than those in Oregon. The cost-weighted/non-weighted mean (SD) for Oregon linkages is 1 (SD 1), while this ratio for Washington linkages is 3 (SD 5), suggesting a three-fold difference in corridor quality between the two states (See Appendix B). Linkage width also can indicate linkage quality, as corridors spread out where resistances are lower. The Washington ground squirrel linkage map illustrates a combination of wide and narrow linkages (Fig. 3.12). For example, a number of the linkages in the vicinity of Ephrata are wide, likely indicating more favorable movement conditions in this area than many other portions of the network. The following species account excerpts further illustrate the usefulness of the linkage metrics for interpreting linkage maps:

> *Western rattlesnake (See Appendix A.9, page A.9-18)*— "There were 226 linkages that fit within the criteria of a Euclidean distance of 50 km or less, and all HCAs were connected to at least one other […]. On average each HCA had 4 connections. The number of intact linkages is reduced to 201 if we restrict linkages to those with a [non-weighted] least-cost path distance of 50 km or less, and only 49 had a cost-weighted distance less than 50 km. Thus, while the landscape is well-connected for rattlesnakes based on Euclidean distance, the estimated landscape resistance suggests connectivity has been dramatically altered by anthropogenic development. In fact, relying on a CWD cutoff of 50 km would mean only 62 HCAs had at least one connection, so 44 HCAs are isolated at this threshold. It is difficult to assess whether a cutoff of 50 km CWD is truly meaningful since the resistance values are not empirically determined, but it is likely that at least some formerly connected populations are now isolated."

> *Tiger salamander (See Appendix A.11, from pages A.11-34 to A.11-39)*— "[…] We divided the total of 144 linkages into those between clusters (7 linkages) and those within clusters (137 linkages; Table A.11.3). Surprisingly, the mean Euclidean distance of linkages between clusters (4.2 km) was less than the mean for linkages within clusters (4.5 km; Table A.11.3). This pattern reflects that 4 of the 7 between-cluster linkages cross I-90 between HCAs in clusters 7 and 8. These short linkages across the Interstate reduce the mean Euclidean distance, but the high resistance of the Interstate led these linkages to have a high mean cost-weighted distance (32.7 km) compared to the within-cluster mean (24.8 km; Table A.11.3). […] Our overall interpretation of the linkage patterns we modeled for the tiger salamander was that the spatial architecture of populations in the Columbia Plateau may not be conducive to long-term persistence. […] At least half of all clusters we identified were isolated, with a very low likelihood of successful immigration or recolonization if extirpation occurred. These disconnected clusters, especially those without large HCAs, likely have a reduced probability of long-term persistence, assuming they are likely to support relatively small populations. Linkages between clusters were limited, with most clusters linked to only one other cluster. Fortunately, remaining between-cluster linkages appear to be in relatively good condition or to provide reasonable opportunities for enhancement or restoration."

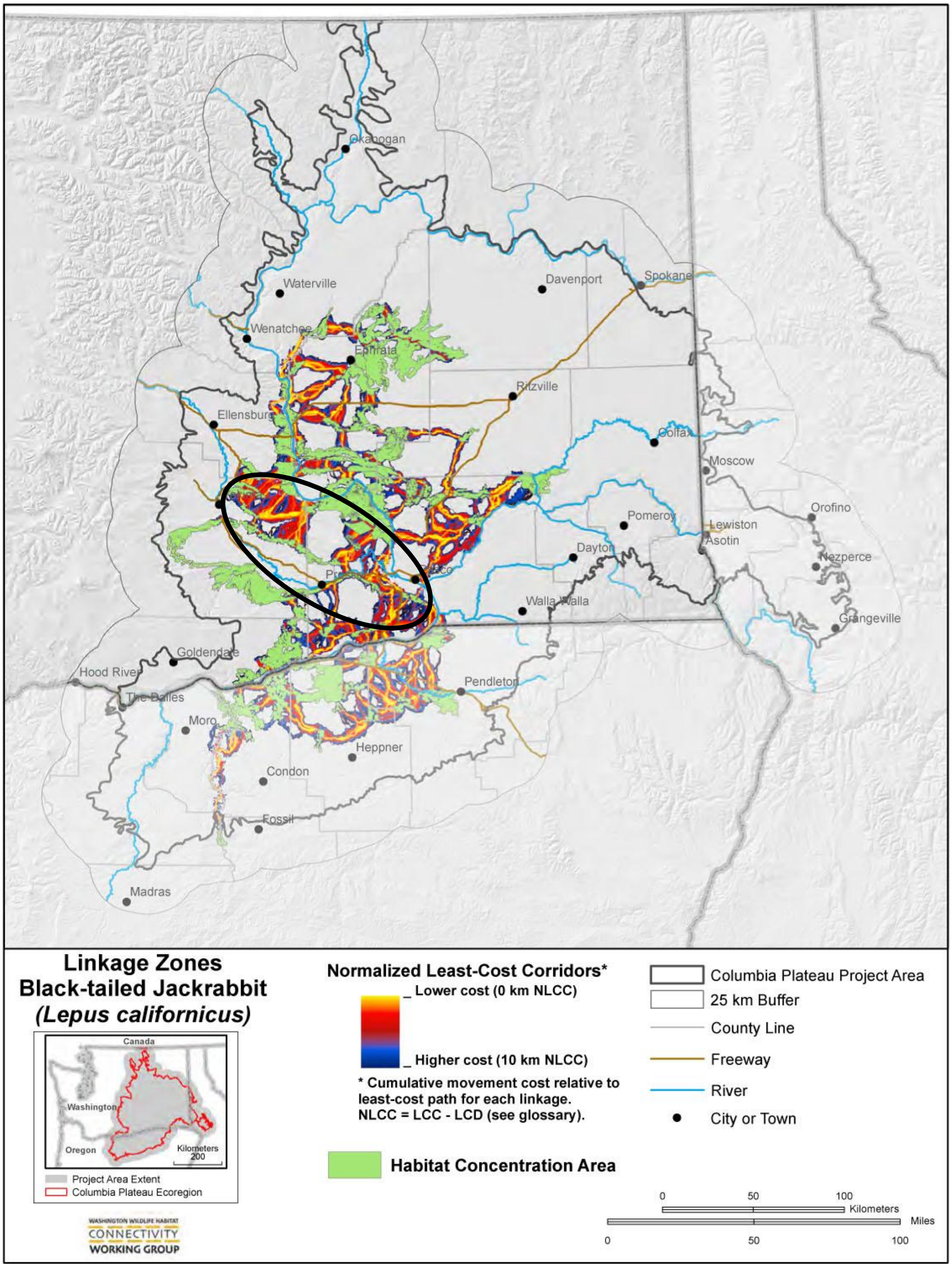

Figure 3.11. Linkage map for the black-tailed jackrabbit. The ellipse indicates a region where connections are tenuous and populations may be vulnerable to separation into two distinct populations.

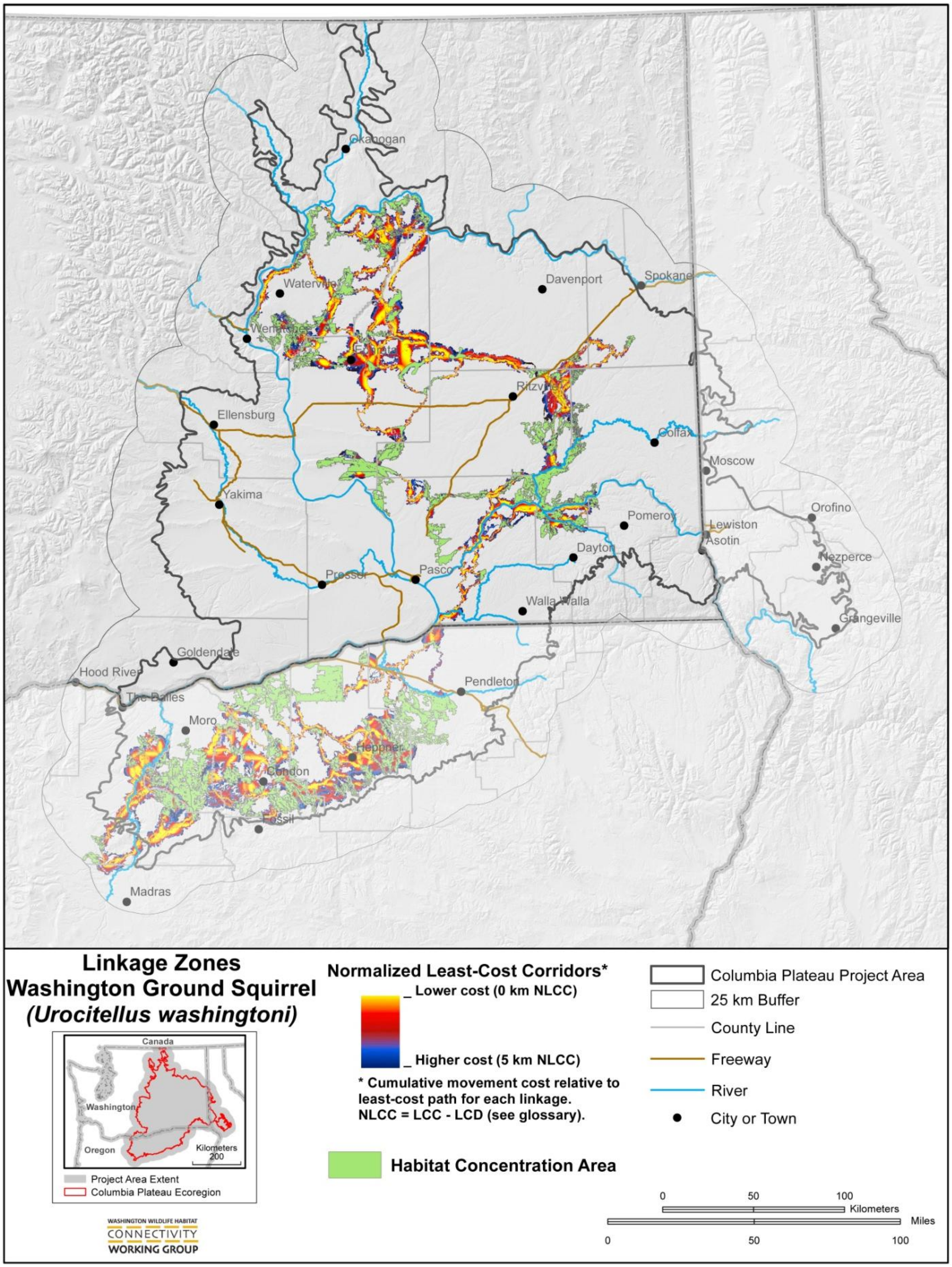

Figure 3.12. Linkage map for the Washington ground squirrel.

3.2. Landscape Integrity

In this section we present landscape integrity core area and linkages results. Additional landscape integrity results are provided in Sections 3.4 and 3.6.

3.2.1. Landscape Integrity Core Areas

We identified 113 core areas in the Columbia Plateau Ecoregion; their sizes ranged from 41 to 1112 km^2 (Table 3.2). The largest core areas in Washington within the Columbia Plateau Ecoregion, were associated with Department of Defense lands (Yakima Training Center), the Hanford Arid Lands Ecological Reserve (part of the Hanford Site), the Yakama Reservation, and WDFW wildlife areas. Smaller core areas were distributed in the central and western portions of the Columbia Plateau Ecoregion. Few core areas were identified in the eastern portion (e.g., Lincoln and Whitman counties) of the project area. This pattern is consistent with the extensive agricultural conversion of the deep tillable soils associated with the Palouse Prairie. Soil conditions in the western half of the ecoregion are less uniform and include significant areas with shallow, rocky soils (which are less amenable to agriculture), resulting in large areas remaining in native shrubsteppe habitat. All of the GAP protected uplands with status codes “1” and “2”—i.e., those with highest levels of protection—that met minimum size requirements of 4047 ha (10,000 ac) overlapped with our core area network (Fig. 3.13).

3.2.2. Landscape Integrity Linkages

We identified 398 linkages based on the linear model, and 344 linkages based on the maximum sensitivity model. The mean values for the least-cost distances of these two models are 11 and 12 km respectively (Table 3.3). We modeled landscape integrity linkages using four different resistance surfaces, representing varying levels of resistance associated with different levels of ecological sensitivity to human-induced changes on the landscape. The resulting four connectivity maps identified similar linkage networks, despite their differing resistance surfaces (Fig. 3.14). Linkage locations are largely determined by the locations of core areas, and areas where core areas that are separated by long, narrow barriers (e.g., secondary highways) have broad areas with similar linkage values, as seen near the Hanford Site and along the east slope of the Cascade Range. Linkages in the central portion of the Columbia Plateau that connect core areas that are farther apart are longer and more sinuous. In this part of the ecoregion, native habitats are significantly fragmented and confined to coulees, shallow rocky soils that have not been converted to agriculture, and riparian areas (Fig. 3.15).

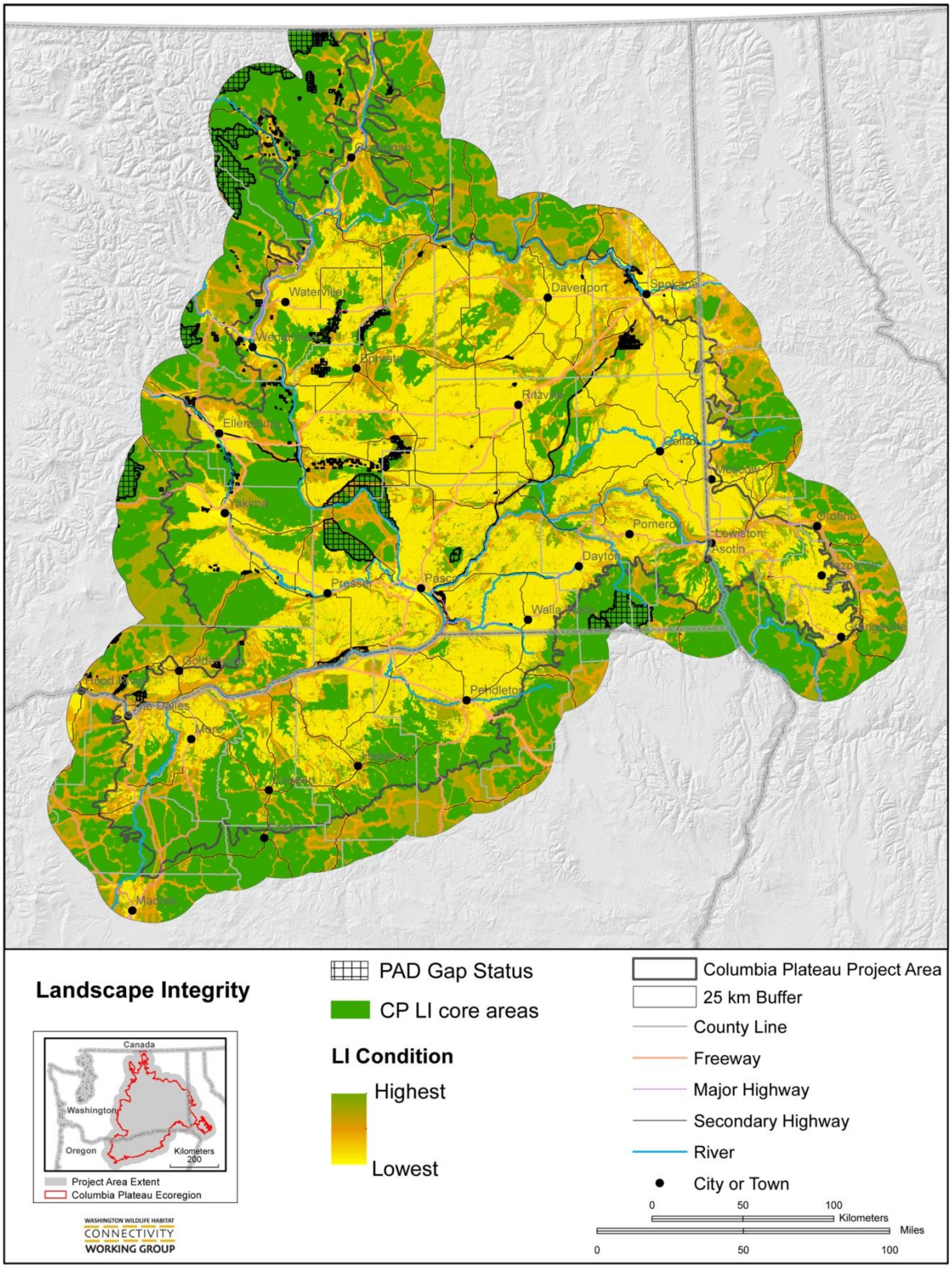

Figure 3.13. Landscape integrity of the Columbia Plateau Ecoregion. Areas in shades of green represent high integrity, while orange to yellow represents lesser levels of integrity. Core areas are indicated in dark green. Those lands with highest levels of protection status (GAP levels 1 and 2) are indicated by black hatching.

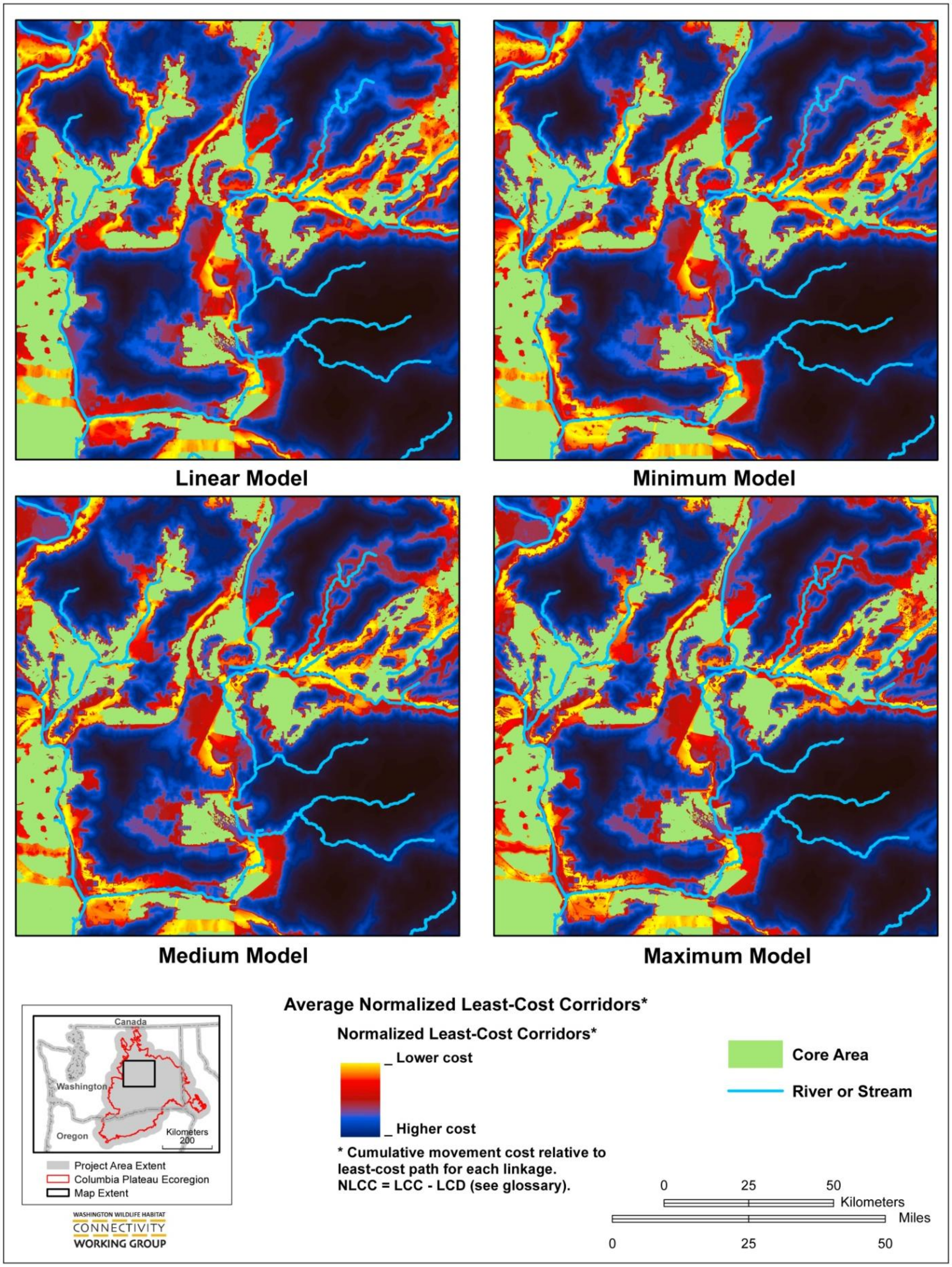

Figure 3.14. Landscape integrity results from four different linkage models.

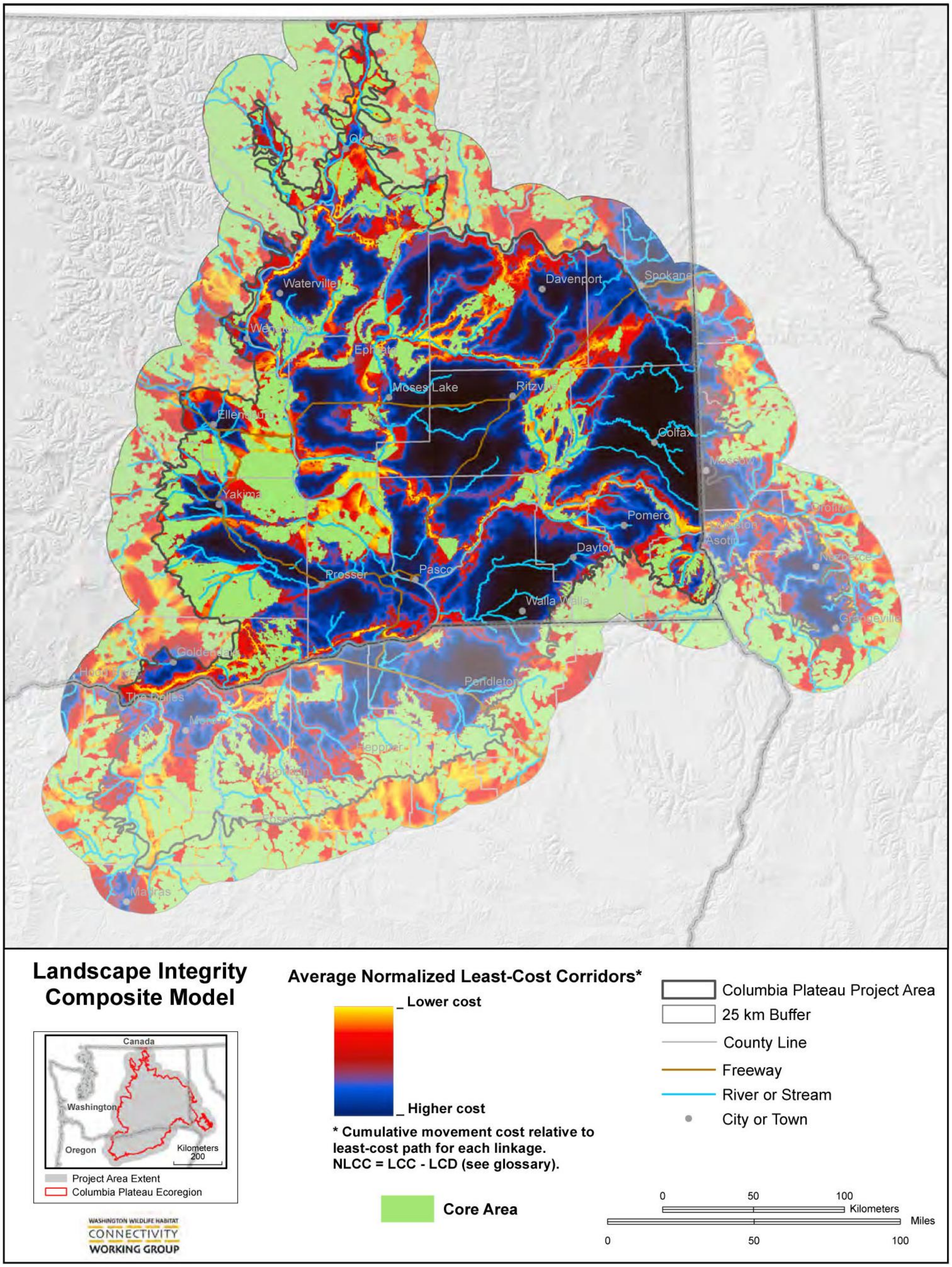

Figure 3.15. Landscape integrity composite model map. This map indicates the results from the combined linear, minimum, medium, and maximum linkage models.

3.3. Columbia Plateau Ecoregion Composite Network

The composite network map for the Columbia Plateau Ecoregion (Fig. 3.16)—built from habitat concentration areas for the 11 focal species, the landscape integrity core areas, and their respective linkages—portrays distinct patterns. These include:

- The western portion of the ecoregion has more habitat areas, core areas, and linkages than the eastern portion where networks are narrower and tend to vary more among species.
- Many of the prominent connectivity patterns in the western portion are identified by four to nine of the focal species as well as landscape integrity.
- The western portion of the ecoregion is dominated by a marked north–south network which we have named the Backbone that extends from near the border with British Columbia to the border with Oregon, mostly following the Okanogan Valley, Moses Coulee, and Columbia River.
- The Backbone in the western portion of the ecoregion includes several narrow or otherwise tenuous connections:
    - The Horse Heaven Hills connection to the Hanford Site, east of Prosser.
    - Connections across the Yakima Valley, both north and south of the city of Yakima (e.g., Ahtanum Ridge to Rattlesnake Hills).
    - The crossing of the Columbia River between Rock Island and Trinidad.
- The dominant feature of the eastern portion of the ecoregion is a north–south trending habitat network we have named the Scablands Swath. Separate forks feed into this network from the north and east: one from Lake Roosevelt and the other from northern Idaho (at the foot of Mica Peak). These forks join near Turnbull National Wildlife Refuge and continue southwest to the Oregon border on the east side of the bend in the Columbia River at Wallula Gap. The Scablands Swath has several important connections to the Backbone:
    - The most northerly east–west connection follows a route along the north and south sides of Lake Roosevelt, tying in with the western portion's Backbone in the vicinity of Banks Lake.
    - A second northerly connection largely follows Upper Crab Creek from near Sprague west to the Grand Coulee.
    - A third major east–west connection runs from the Palouse River vicinity near the vicinity of Washtucna and follows Washtucna Coulee and Lower Crab Creek west to the Columbia River.
    - A less prominent east–west network component extends from the vicinity of Cow Creek in the Scablands Swath across Lind Coulee to near the Potholes Reservoir.
- Prominent network connections to surrounding jurisdictions are as follows:
    - The Backbone connection to British Columbia through the Okanogan Valley and Antoine and Myers creeks (in the vicinity of Chesaw).

- Connections between the Scablands Swath to Oregon and Idaho via the Tucannon River in one location and via the Snake River in another (crossing into Idaho just north of Lewiston). The Scablands Swath also originates at the Idaho border in the Mica Peak vicinity.
  - Connections to Oregon via the east side of the Columbia River at Wallula Gap and at points that cross the Columbia River near Roosevelt and The Dalles.
- The network pattern of the 25 km buffer is also distinct. The buffer is indicated as a nearly solid band around the Columbia Plateau Ecoregion; this band is largely comprised of combined networks from landscape integrity and mule deer, but also includes portions of beaver, tiger salamander, Western rattlesnake, Sharp-tailed Grouse, Washington ground squirrel, and white-tailed jackrabbit networks as well.
- Naturalness of the ecoregion and its buffer (Fig. 3.17):
  - The landscape integrity network overlaps with extensive areas of the composite focal species network, including areas where multiple focal species networks overlap.
  - Landscape integrity results diverge from focal species results in other areas of the ecoregion where naturalness may not rate high but habitat areas and linkages have been identified for focal species. For example, eight of the focal species models identified the Mansfield Plateau as important, but naturalness did not rate high.
  - The landscape integrity results include some areas not identified by the focal species. These largely occur within the forested ecoregion buffer.

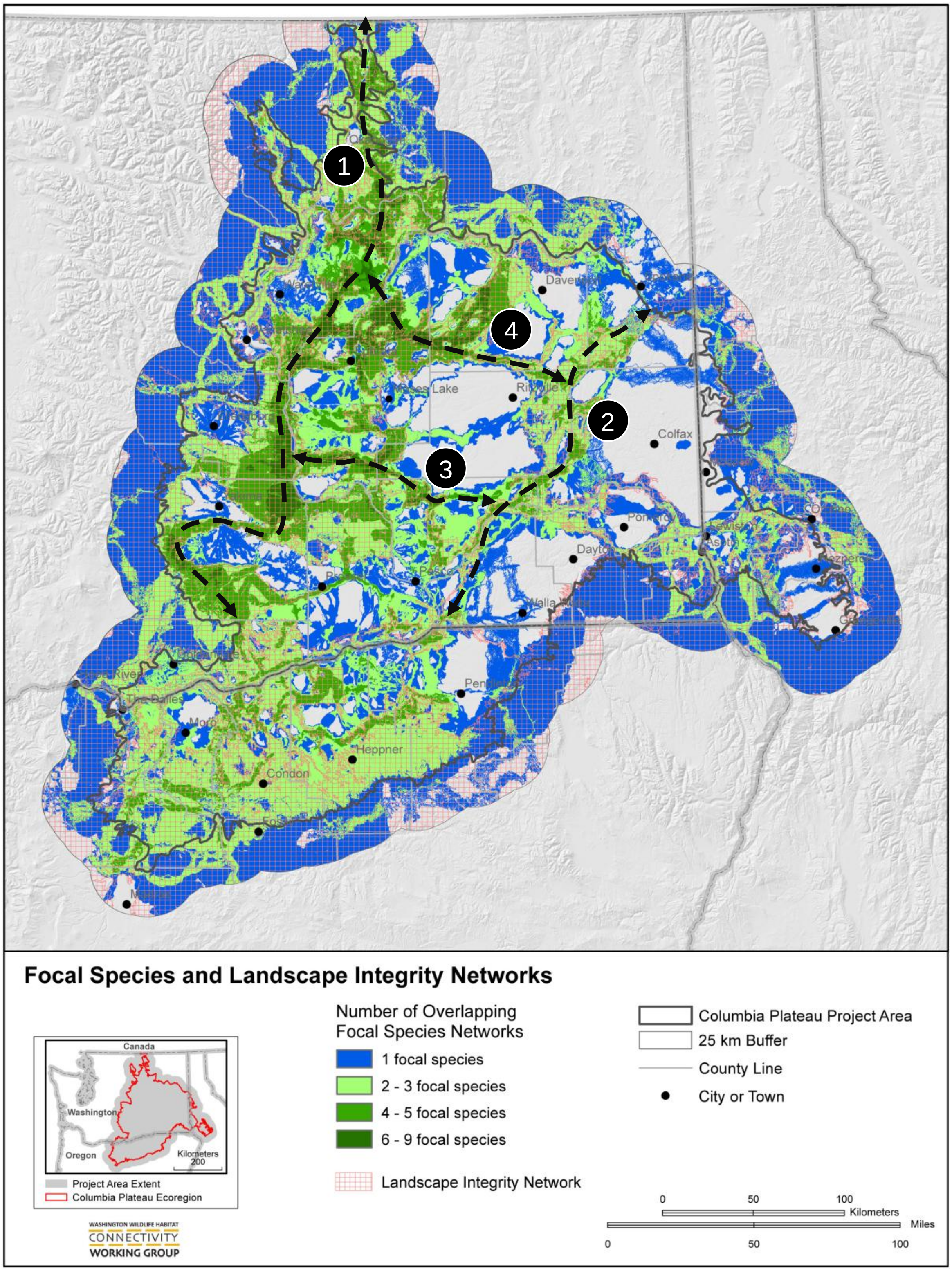

Figure 3.16. Composite focal species and landscape integrity network for the Columbia Plateau Ecoregion. This map is based on 11 focal species and landscape integrity results. Prominent connectivity patterns are: (1) the Backbone, (2) the Scablands Swath, (3) Lower Crab Creek, and (4) Upper Crab Creek.

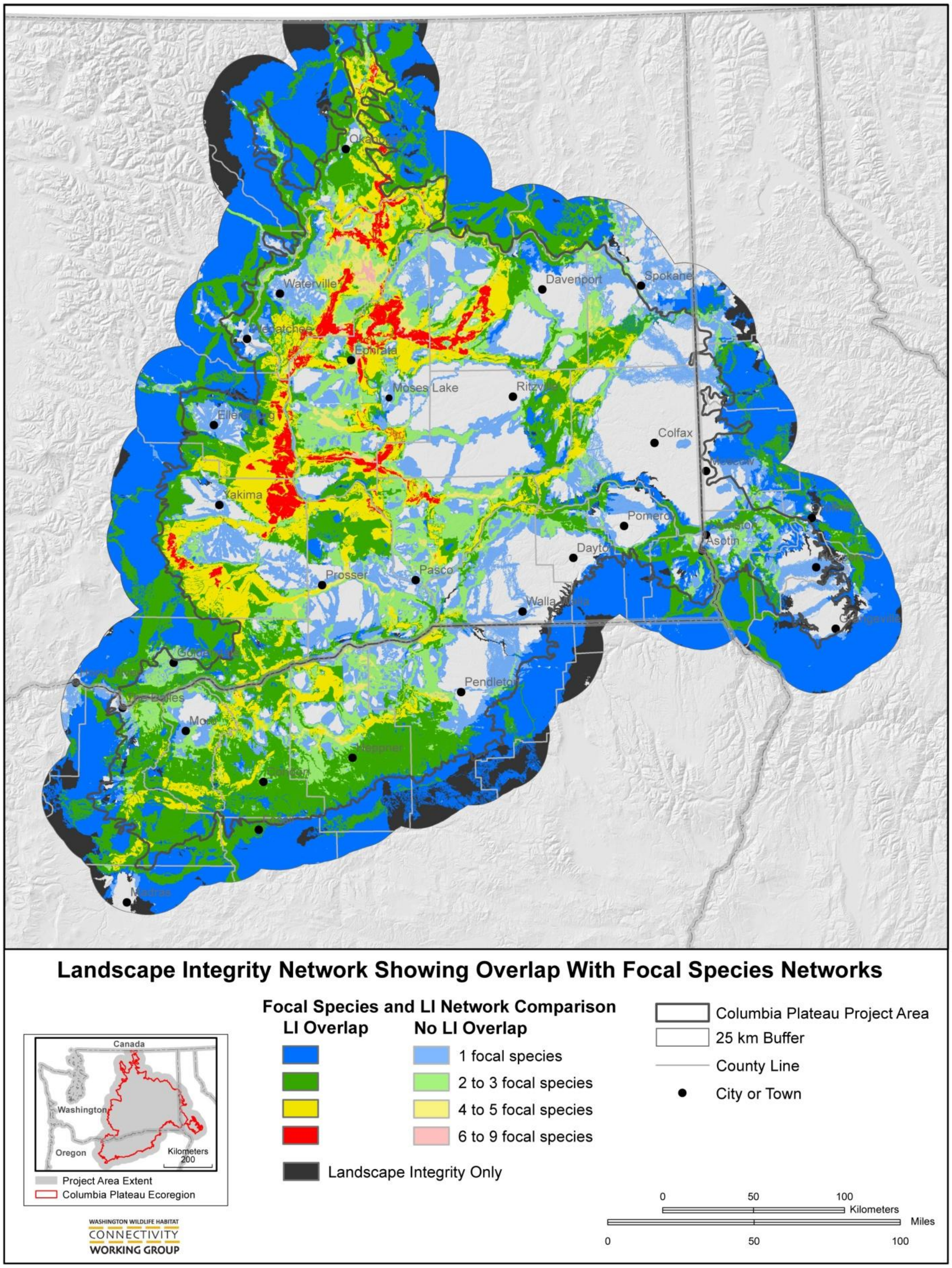

Figure 3.17. Landscape integrity network map depicting concordance across varying numbers of focal species networks.

3.4. Columbia Plateau Network Groups and Key Patterns and Insights

We organized the 11 focal species and the landscape integrity networks into three groups based on landscape pattern similarities and the rationale that we used to select the suite of focal species and landscape integrity models (e.g., broad representation for Columbia Plateau natural landscapes and identification of areas of the landscape with the least human footprint).

1) *Upland Network*—Species most closely associated with upland shrubsteppe habitat (Sharp-tailed Grouse, Greater Sage-Grouse, Townsend's ground squirrel, Washington ground squirrel, black-tailed jackrabbit, white-tailed jackrabbit, and least chipmunk).
2) *Drainage/Aquatic and Canyon Network*—Species most closely associated with aquatic, riparian, cliff, canyon, and talus habitats (beaver, tiger salamander, and Western rattlesnake).
3) *Generalist/Landscape Integrity Network*—Species that have broad coverage across the Columbia Plateau and the buffer (mule deer) and the landscape integrity network.

We provide detailed discussion for each of these network groups below.

3.4.1. Upland Network

OVERVIEW

This composite includes the combined networks of the seven species closely associated with upland shrubsteppe habitat: Sharp-tailed Grouse, Greater Sage-Grouse, Townsend's ground squirrel, Washington ground squirrel, white-tailed jackrabbit, black-tailed jackrabbit, and least chipmunk (Fig. 3.18). Notable features of this composite follow:

- This composite network is strongly focused within the western half of the ecoregion and includes connections to the Scablands Swath in the eastern portion.
- The networks for the seven species tend to be contained within the ecoregional boundary indicating a high likelihood that these species are isolated from external populations. One exception to this is at the northern end of the ecoregion where species networks extend into the 25 km buffer; even so, Sharp-tailed Grouse remain isolated from other populations outside of Washington.
- The network does not connect into Idaho; it does include potential linkages to Oregon, including east of the Columbia River at the Wallula Gap.
- The seven-species composite network is mapped as fully connected, i.e., no components of the network are isolated. Detailed results in Appendices A and B provide information that can be used to determine the strength of these connections, thus providing a better understanding of which areas might be strongly connected and which may not currently function as connections.

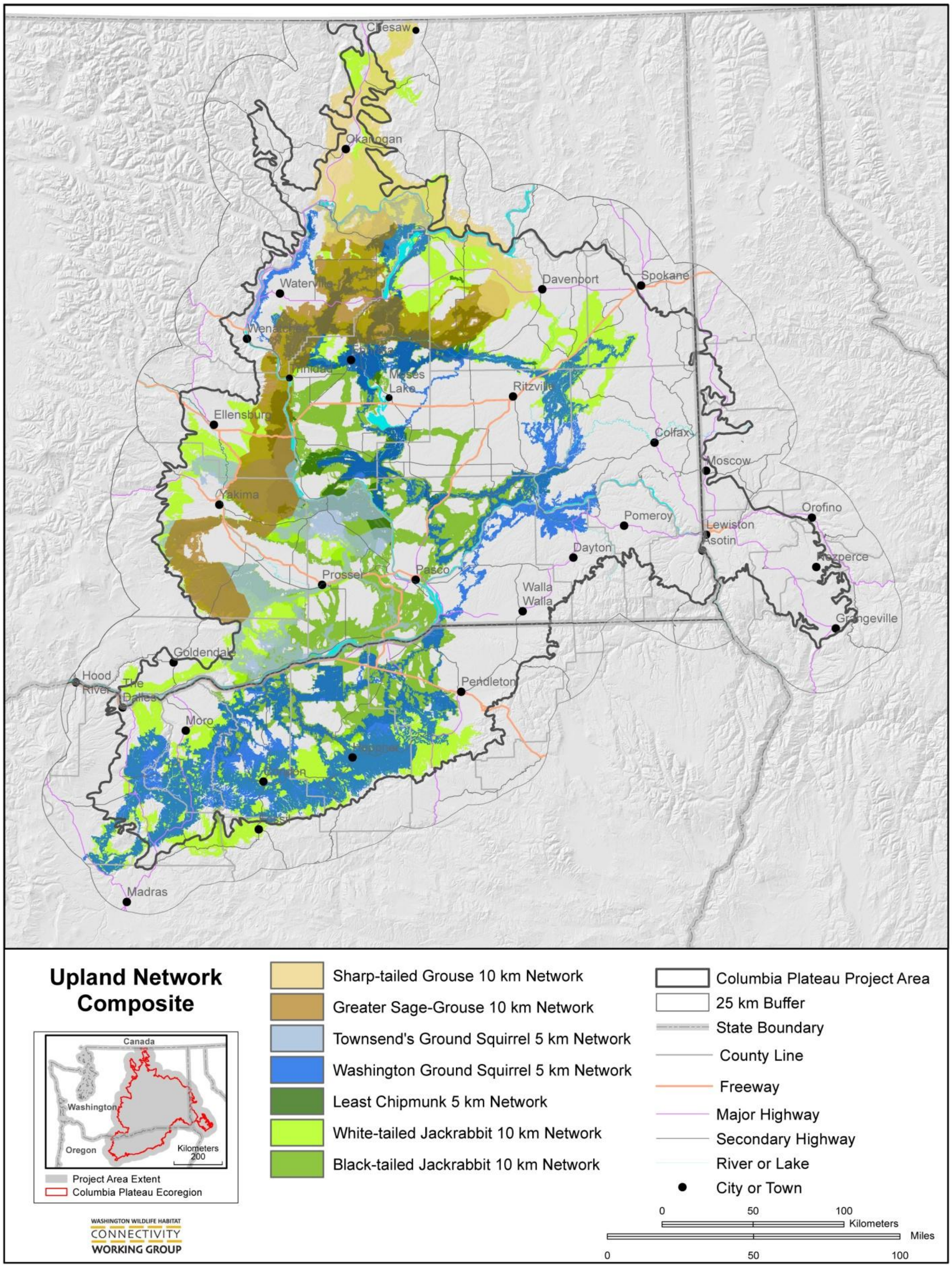

Figure 3.18. Upland Network composite map. This map is based on seven species closely associated with upland shrubsteppe habitat.

KEY INSIGHTS FOR FOCAL SPECIES

In this section we summarize the key insights for linkage networks for each species in the Upland Network. We encourage readers to refer to Appendix A for more detailed discussion.

Sharp-tailed Grouse

Historically, the distribution of Sharp-tailed Grouse would have covered much of the Columbia Plateau. Yet this species is sensitive to the human footprint, and features such as agriculture, development, roads, powerlines, and wind turbines constrain and fragment areas of low resistance for movement. As well, the HCAs for Sharp-tailed Grouse are few in number and tend to be arranged in a linear, stepping-stone pattern along the northern boundary of the ecoregion (See Appendix A.1 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.19a) include:

- HCAs are located on the northern edge of the Columbia Plateau Ecoregion and several are on the boundary.
- HCAs in Lincoln County, the western side of the Okanogan Valley, and the northernmost HCA near Chesaw are peripheral and potentially at higher risk of becoming isolated.
- Development associated with U.S. Highway 97 in the Okanogan Valley creates a north–south band of resistance for movement across the valley.
- Only two linkages were modeled across the Okanogan Valley, one of which has a severe pinch point.
- The HCA in southern Okanogan County exhibits high centrality as it connects with seven other HCAs.

Greater Sage-Grouse

This species has the fewest HCAs, all of which are isolated and peripherally located in the western portion of the ecoregion. Areas with low resistance to movement are constrained and fragmented by agriculture, development, roads, powerlines, and wind turbines. Options for movement of Greater Sage-Grouse between HCAs are limited (See Appendix A.2 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.19a) include:

- A crescent with low resistance to movement is formed by the areas of Upper Crab Creek, Moses Coulee, the Colockum Wildlife Area, and the Yakima Training Center.
- The Mansfield Plateau/Moses Coulee HCA narrows in the vicinity of U.S. Highway 2 due to agriculture (wheat fields) to the east and west.
- A linkage pinch point between Mansfield Plateau/Moses Coulee and Yakima Training Center HCAs occurs near Rock Island Dam.
- Additional resistance in the linkage between Mansfield Plateau/Moses Coulee and Yakima Training Center may impede movement potential of Greater Sage-Grouse between these HCAs.
- The I-82 corridor between Yakima and the Tri-Cities is a barrier to movement.

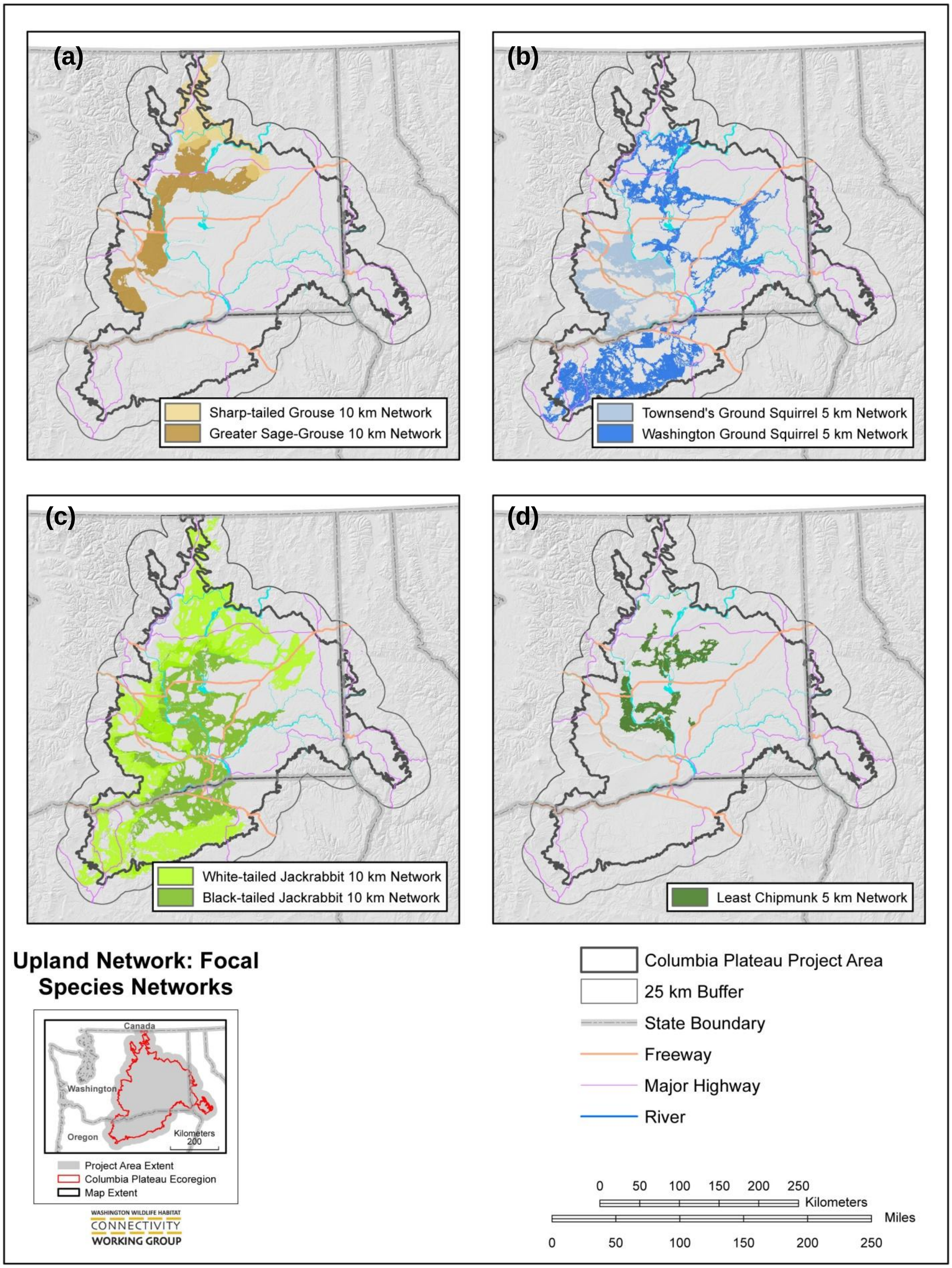

Figure 3.19. Upland Network individual species networks. Shown are: (a) Sharp-tailed Grouse, Greater Sage-Grouse, (b) Townsend's ground squirrel, Washington ground squirrel, (c) white-tailed jackrabbit, black-tailed jackrabbit, and (d) least chipmunk.

Townsend's Ground Squirrel

The Townsend's ground squirrel is restricted to the area west of the Columbia River and south of Ellensburg. The Yakima River further delineates two subpopulations, *Urocitellus townsendii nancyae* lives east and north of the river, whereas *U. townsendii townsendii* occurs west and south of the river. Townsend's ground squirrels appear to tolerate human proximity and some human-modified habitats, including some areas of highly structured agriculture, reasonably well. Information on the population status, habitat preferences, movements, and other aspects of the biology of Townsend's ground squirrel is inadequate and requires study. Main factors influencing landscape resistance are associated with encroaching intensive agriculture and urban growth (See Appendix A.5 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.19b) include:

- Public lands, including the Yakima Training Center, the Hanford Reach National Monument (Hanford Site), and several WDFW wildlife areas, support sizeable HCAs and associated linkages.
- Our model shows linkages that cross the Yakima River in two locations. Lack of differences in genetic patterns within this species suggest these linkages should be disregarded; however, they may be important for other species.
- Some corridors may be vulnerable, including linkages connecting HCAs in eastern Horse Heaven Hills to those in southeastern Benton County.

Washington Ground Squirrel

The Washington ground squirrel occurs east of the Columbia River in Washington and south of the Columbia River in Oregon. Washington ground squirrels appear to tolerate human proximity and some human-modified habitats reasonably well. Agricultural conversion has displaced Washington ground squirrels from extensive areas with deep, silty soils, which are preferred by squirrels, thereby leaving populations in habitats where soil texture or depth may be marginal. More intensive surveys in habitat concentration areas and other locations with potentially suitable habitat may find populations previously overlooked (See Appendix A.6 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.19b) include:

- Many of the sites occupied by Washington ground squirrels within Washington appear to be isolated, one from the other, reflecting the highly fragmented condition their habitat.
- Washington ground squirrels are found along the Washington/Oregon border in the Wallula Gap vicinity, where a connection between populations in the two states may exist.
- Examples of potentially essential linkages are those connecting HCAs in Douglas, Grant, and southwestern Lincoln counties.
- Some long and narrow linkages, thus more vulnerable, are those connecting: (1) HCAs in the Saddle Mountains, Wahluke Slope, and the area west of Esquatzel Coulee to HCAs in northern Frankin County; and (2) connections to HCAs in southern Lincoln County to HCAs in eastern Adams County.

Black-tailed Jackrabbit

The primary area for black-tailed jackrabbits appears to extend from Pasco in the southeast to the Yakima Training Center and up to southern Grant County. What once may have been an area with many jackrabbit observations—to the west and across the Columbia River from Pasco—now has little, if any, prime jackrabbit habitat. Areas of low resistance on the landscape are constrained by development, freeways and major highways, rivers, and agriculture (See Appendix A.3 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.19c) include:

- When looking at all effects of landscape conversion, roads and agriculture appear to impart the greatest impact on jackrabbit habitat.
- The I-82/Yakima River corridor between Yakima and the Tri-Cities is a barrier to north–south movement. Further development and expansion in this area either to the north or south will further widen this gap.
- When reviewing the HCA maps along with data representing recent (post-2000) and historical (pre-2000) jackrabbit occurrence records, there are a number of HCAs that have no recent observations. These include relatively large HCAs in both the north and one relatively large HCA in the south. If these areas are for some reason "lost" to black-tailed jackrabbits, it would eliminate a large portion of the northeastern section of their range and also a portion of their range in southern Washington which serves to connect populations between Washington and Oregon.
- This analysis shows a reduced area of core range relative to the GAP distribution predictions (Cassidy et al. 1997). This likely represents a true loss of habitat, but could also be due to having better data and the tools to analyze it.

White-tailed Jackrabbit

The white-tailed jackrabbit range occurs throughout much of the Columbia Plateau. However, a widely-observed decline in the Washington population has occurred (See Appendix A.4). Some of the habitat concentration areas for white-tailed jackrabbits are small and isolated: if they and associated linkages are lost, the range of this species would be further decreased. Areas of low resistance on the landscape are constrained by development, freeways and major highways, rivers, and agriculture. Roads and agriculture seem to affect jackrabbit habitat and dispersal most (See Appendix A.4 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.19c) include:

- There appear to be four major zones or concentration areas for the white-tailed jackrabbit in Washington—Okanogan, Lincoln-Douglas down to Malaga, Kittitas-Yakima centered on the Yakima Training Center, and south Yakima centered on the Yakama Reservation. Connectivity within these zones appear to be good; however connectivity between the zones is of concern. The areas of greatest concern are Omak, Malaga to Crescent Bar, and the Yakima Valley, from Yakima to Benton City.
- A major pinch point occurs in the area between Malaga, Rock Island, and Crescent Bar and any increased resistance could potentially split the population into two isolated north and south zones.

- The I-82/Yakima River corridor between Yakima and the Tri-Cities is a barrier to north–south movement. Further development and expansion in this area either to the north or south will further widen this gap.
- There are four small HCAs in Spokane County and Benton County that are important because they are likely the last remnants of habitat in the area, and in the case of the Benton County HCAs, may provide the only link between other HCAs. Protection of these areas are likely of high priority for maintaining connectivity.
- When reviewing the HCA maps and occurrence data there are relatively few observations of white-tailed jackrabbits in the Yakima County HCAs. If indeed white-tailed jackrabbits do not occupy these HCAs and if their absence is due to a lack of habitat (i.e., our model incorrectly predicted this area to have jackrabbit habitat), the connectivity between Benton and Kittitas County HCAs is severely limited, and the available habitat for the southern Washington population of white-tailed jackrabbits is vastly diminished.

Least Chipmunk

The least chipmunk network occurs largely in the western and central parts of the Columbia Plateau Ecoregion, and on both sides of the Columbia River. Least chipmunks are not well-studied in the ecoregion. Large areas of potential habitat have not been surveyed and there are few recent records (See Appendix A.7 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.19d) include:

- Habitat concentration areas are restricted largely by agricultural development. Irrigated agriculture has an especially large impact. Residential and industrial development and transportation corridors are also restrictive.
- Development, agriculture, and fire impacts increase the resistance of linkages. Fire may pose the greatest large-scale, short-term threat to landscape connectivity for this species, while development may pose the greatest small-scale, long-term threat.

3.4.2. Drainage/Aquatic and Canyon Network

OVERVIEW

The beaver, tiger salamander, and Western rattlesnake networks provide a focus for aquatic, riparian, and the cliff, canyon, and talus landscapes (Fig. 3.20). Notable features of this composite are:

- Rivers, lakes, wetlands, and coulees are strongly represented by this composite network which is extensively comprised of long, somewhat narrow, components.
- The network connects into the ecoregion buffer and, as a whole, appears well-connected to jurisdictions neighboring Washington, particularly along drainages and river corridors.
- Key components of the network follow the main river systems in an open ring around the Columbia Plateau in Washington. This ring starts in the northeast, follows the Spokane River westward to its mouth, and from there follows the Columbia River west, south, and back east to the mouth of the Snake River, and further east following the Snake River upriver.
- In the western portion of the Columbia Plateau Ecoregion stronghold areas for this network appear to be: (1) Mansfield Plateau, Grand and Moses Coulee vicinities; and (2) Moses Lake, Potholes Reservoir, Lower Crab Creek, Hanford Site, Yakima Training Center drainages/aquatic areas, and Columbia River vicinity. These areas connect with many other network components.
- Network components in the vicinity of Crab, Cow and Rock creeks, and Turnbull National Wildlife Refuge appear to be an aquatic stronghold and important areas for maintaining aquatic connections for the eastern Columbia Plateau area.
- The tiger salamander network includes disconnected clusters, and many of the Western rattlesnake network linkages have high resistance. Both factors underscore the importance of connectivity conservation.

KEY INSIGHTS FOR FOCAL SPECIES

In this section we summarize the key insights for linkage networks for each species in the Drainage/Aquatic and Canyon Network. We encourage readers to refer to Appendix A for more detailed discussion.

Beaver

Historically, beavers inhabited complex aquatic systems of the Columbia Plateau Ecoregion. This ecoregion has many areas where the hydrology is now modified, and the beaver now inhabits or uses a combination of natural aquatic areas, such as streams, as well as modified aquatic areas, such as irrigation systems. Water in the form of streams, rivers, wetlands, and lakes is a vitally important element within the shrubsteppe landscape. These waters and the associated riparian vegetation form oases in a dry landscape and support a host of fish and wildlife species. The beaver is inextricably linked to water and riparian vegetation, and their actions influence the riparian environment and broadly benefit riparian-dependant species. Conversely, prolonged absence of beavers can reduce the quality or suitability of a riparian area for the other species that depend on these areas for some aspect of their life history. Human tolerance levels for beaver are significant factors in their abundance and distribution, and reduction in beaver numbers or their absence can lead to decreased or degraded riparian habitat (See Appendix A.10 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.21a) include:

- This network appears well-connected within the Columbia Plateau Ecoregion as well as the buffer.
- Broad patterns within the Washington portion of the ecoregion include large dispersed areas, and extensive linear paths along major rivers such as the Columbia, Snake, and Yakima rivers.
- The most dense network areas include: (1) the Grand and Moses Coulee vicinities, (2) the Kittitas Valley (near Ellensburg), and (3) Potholes and nearby areas to the west and southeast.

Tiger Salamander

This species has a biphasic life history with an aquatic larval phase and a terrestrial adult phase. Tiger salamanders are found in wetland habitats within the Columbia Plateau Ecoregion, as well as nearby shrubsteppe and grassland vegetation types and cliffs, canyons, and talus. Our results suggested remaining habitats are concentrated in areas less suitable to agriculture, i.e., scoured by the Missoula floods. This analysis indicates the connectivity of populations in the Columbia Plateau may be poor; thus follow-up to clarify needs for long-term persistence for this species is suggested (See Appendix A.11 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.21b) include:

- Anthropogenic features contributed most to landscape resistance in relatively flat areas of the Columbia Plateau. In areas with more topographic relief, areas of low resistance tended to follow valley bottoms and drainages with natural vegetation. Cliffs and scoured plateaus of the channeled scablands had higher resistance to dispersal.
- Highways limit tiger salamander access to habitat. Agricultural development does not form sharp-edged boundaries as do highways, but agricultural fields and farms limit habitat access because they are so extensive, especially in western and central Adams County and in the Palouse. The combined influence of highways, railroads, reservoirs, and residential, commercial, and agricultural development in valley bottoms constrains habitat access. These features contribute to the barrier effect of the Columbia, Snake, and lower Okanogan rivers.
- The distribution of modeled HCAs (115 total) suggested they could be subdivided into 10 clusters, 5 of which are isolated from other clusters; 16 HCAs were either completely isolated or found in pairs (Fig. 3.7).
- Linkages show a pattern of generally moderate quality within HCA clusters, but tenuous connections among clusters. Linkages among clusters in the west-central portion of the Columbia Plateau were marginally better than in other portions of the study area.

Western Rattlesnake

The extent of HCAs for this species is much reduced compared to the GAP distribution predictions (Cassidy et al. 1997). It is possible that much of the GAP distribution was historically good rattlesnake habitat, but now is no longer suitable due to agriculture or urban modifications. Roads, housing, high elevations, and agriculture are projected to be most resistant to movement, and low resistance landscapes for Western rattlesnakes are concentrated primarily in areas of low human use or restricted human access. Results suggest connectivity has been dramatically altered by human development, and it is likely that at least some formerly connected populations are now isolated. Habitat concentration areas for rattlesnakes are concentrated along riverine corridors and are quite linear (See Appendix A.9 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.21c) include:

- Spanning the western side of the Columbia River from Wenatchee south through the Yakima Training Center, a single habitat concentration area has 11 linkages connected to it: this HCA represents a core area for rattlesnake conservation.
- An additional five HCAs each have eight linkage connections indicating strong conservation importance as well. Of these, three are in relatively close proximity in the Okanogan region; one is on the north side of the Snake River; and one is in the Saddle Mountains area.
- Taken together, the above highly connected HCAs suggest a primary pattern of connectivity linking the Okanogan Valley through the Columbia River to the Snake River in Idaho. There is a smaller connectivity corridor running from the Yakama Reservation lands to the Columbia River Gorge into Oregon.
- Upper Crab Creek in Lincoln County, Hells Canyon on the Snake River, and the Methow Wildlife Area contain linkages where low resistance should be maintained to avoid isolating populations.

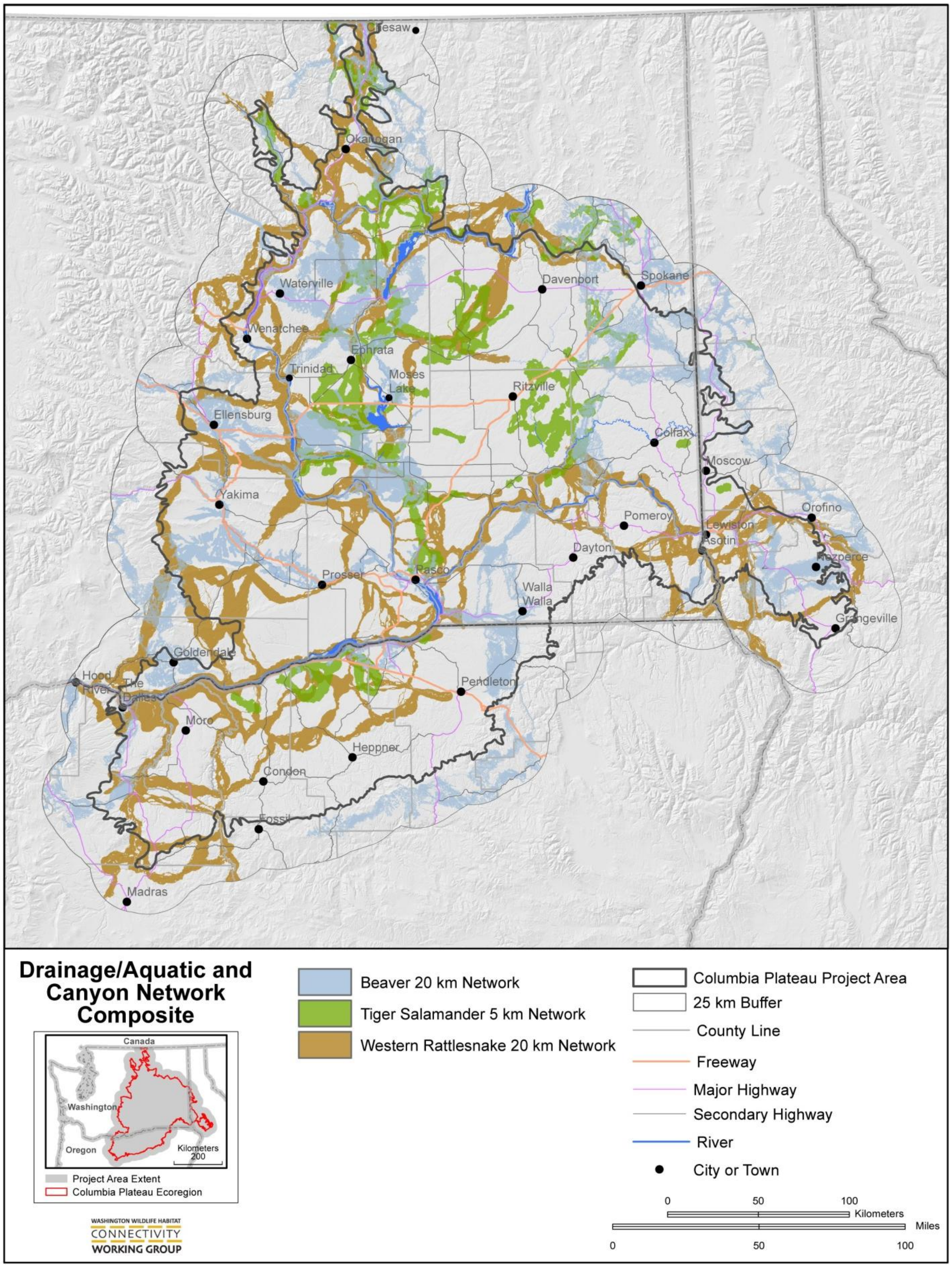

Figure 3.20. Drainage/Aquatic and Canyon Network composite map. This map includes beaver and tiger salamander, species selected to ensure inclusion of aquatic and riparian environments in the Columbia Plateau connectivity analysis; as well as Western rattlesnake, chosen to represent cliffs, canyons, and talus.

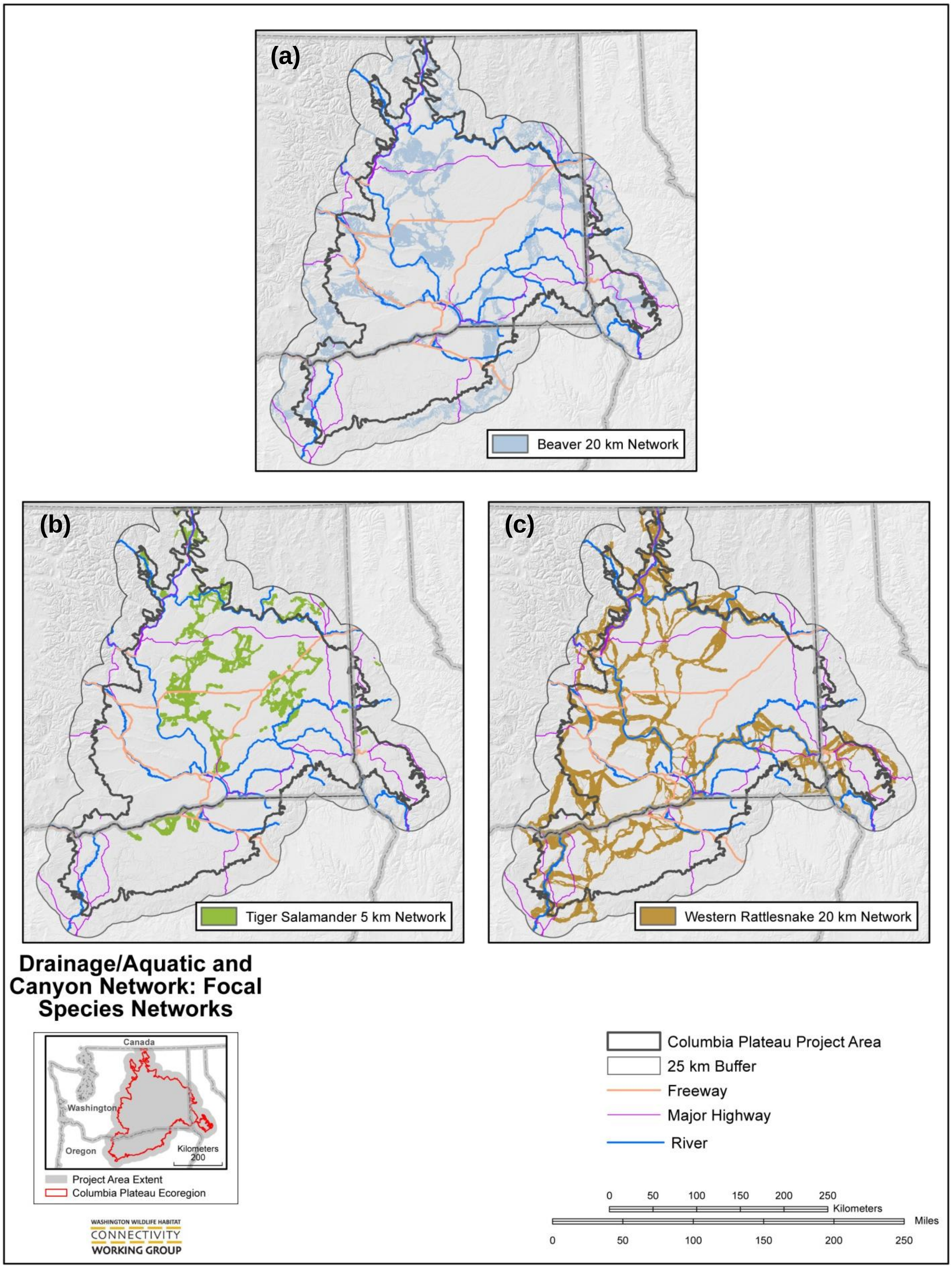

Figure 3.21. Drainage/Aquatic and Canyon Network individual species networks. Shown are: (a) beaver, (b) tiger salamander, and (c) Western rattlesnake.

3.4.3. Generalist/Landscape Integrity Network

OVERVIEW

The final composite is comprised of the mule deer network and the landscape integrity network (Fig. 3.22). Correspondence analysis of the statewide connectivity networks (i.e., an analysis of network spatial similarities), grouped landscape integrity together with generalist species including mule deer (WHCWG 2010). This composite group differs from the Upland Network and the Drainage/Aquatic and Canyon Network in that the two network patterns are nearly the same. The same finding resulted from the ecoregional correspondence analysis (See Section 3.5). Notable features of this composite are:

- The network includes: (1) extensive connections within the western portion of the Columbia Plateau Ecoregion; (2) lesser connections in the eastern portion, which includes large areas not included in the network; and (3) a nearly continuous network area within the buffer, indicating the likelihood of strong connectivity to neighboring areas.
- The landscape integrity and mule deer networks are similar in coverage across the Columbia Plateau, but each includes areas not found in the other. For instance, the landscape integrity network identified areas within Washington expected to have high naturalness not identified in the mule deer network as follows: north of Banks Lake, near Ellensburg, at the Hanford Site, south of Horse Heaven Hills near the Columbia River, as well as in the ecoregional buffer. The mule deer model identified important network habitats not identified as having high naturalness: on the Mansfield Plateau, near Davenport, between Ellensburg and Ritzville, north of Pasco, Horse Heaven Hills, and the Wallula Gap to Snake River vicinity.

KEY INSIGHTS FOR FOCAL SPECIES AND LANDSCAPE INTEGRITY

In this section we summarize the key insights for linkage networks for mule deer and landscape integrity in the Generalist/Landscape Integrity Network. We encourage readers to refer to Appendix A for more detailed discussion about the mule deer, and Sections 3.2, and 3.6 for landscape integrity.

Mule Deer

Suitable habitat identified for mule deer habitat concentration areas (HCAs) represent the distribution of remnant shrubsteppe and other native habitats within the Columbia Plateau. Areas predicted to have low resistance for movement are composed primarily of remaining tracts of shrubsteppe and other native vegetation types through which mule deer can move freely. Conversely, areas predicted to have low-quality habitat include areas of intensive irrigated agriculture, large tracts of dryland monoculture, and urban/suburban development (See Appendix A.8 for full modeling results). Some key patterns and insights regarding the linkage network (Fig. 3.22) include:

- Two large polygons with high cost-weighted distance (CWD) values, one located in the central portion of the Columbia Plateau and one in the eastern part, with four HCAs between them, have the potential to limit or block mule deer movements. Future connectivity should be closely monitored to ensure protection of links between populations and genetic viability.

- Modeling at the finer ecoregional level produces results that predict the highest quality mule deer habitat and identify the important linkages between these habitats, including those that could be at risk to disruption.
- The ability to predict high quality mule deer habitat and movement corridors at this ecoregional scale provides the level of knowledge that would allow government planners and deer managers to protect those areas.

Landscape Integrity

The Columbia Plateau landscape is highly modified and fragmented compared to most of the rest of the state. As a result there were few differences in the connectivity areas identified among the four sensitivity models (i.e., the linear transformation of landscape integrity values, plus three transformations representing different sensitivities to human development). The strong contrast between human-modified and natural lands, and the presence of linear features such as coulees, scablands, and riparian areas, meant that corridors followed similar routes among the four models. The overall composite landscape connectivity map identified areas important for connectivity when all sensitivity models were considered. Some key patterns and insights regarding the linkage network (Fig. 3.22) include:

- Overlaying the best 30% of each connectivity map (i.e., the 30% with the lowest normalized least-cost distances for each sensitivity model) taken from each sensitivity model indicated there was strong agreement among the four models. Approximately 80% of the area represented by the top 30% of all four models combined was included in three or more models (Fig. 3.23). The area associated with only a single model accounted for 11% of the best 30% of the connectivity landscape; 10% of the combined area was important for two of the four models.
- There were four significant connectivity areas that were identified as important (top 30%) by one model but not the other three models (Fig. 3.24). These include:
    - Two corridors identified by the linear sensitivity model crossed large expanses of agricultural areas in Douglas and Lincoln counties. One corridor along the Horse Heaven Hills and the lower reaches of the Yakima River (from Benton City to the Columbia River) was identified in the top 30% of the minimum sensitivity model. These three corridors may be important for those species/organisms that are able to adapt and cross human-modified landscapes.
    - One area between the towns of Connell and Kahlotus in Franklin County was identified as important by the maximum sensitivity model and connected core areas along the Hanford Site and Palouse River to the east along the border of Franklin and Whitman counties. This corridor may be especially important for species/organisms that are most likely to avoid human-modified areas.

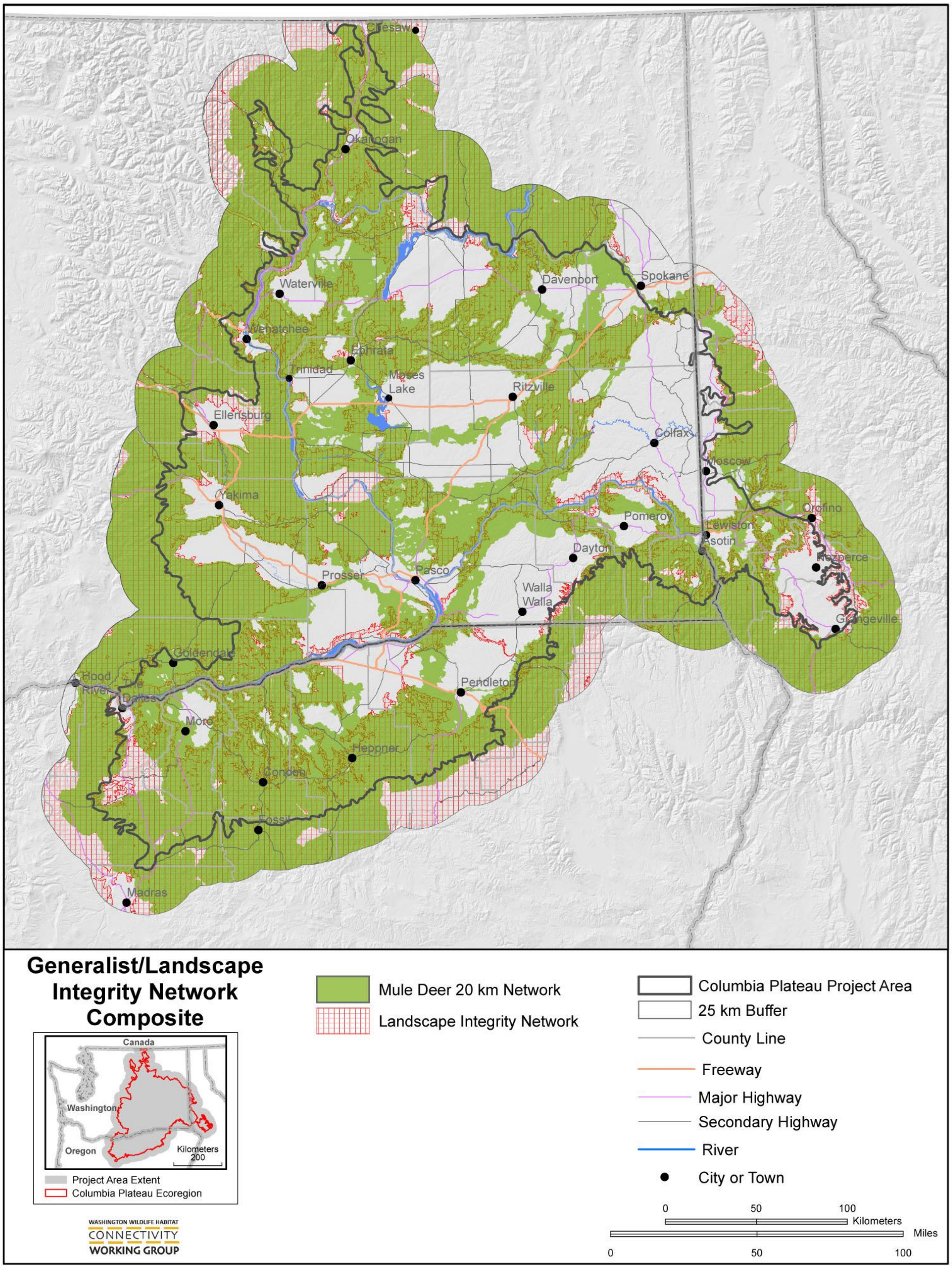

Figure 3.22. Generalist/Landscape Integrity Network composite map. Shown are mule deer and landscape integrity networks.

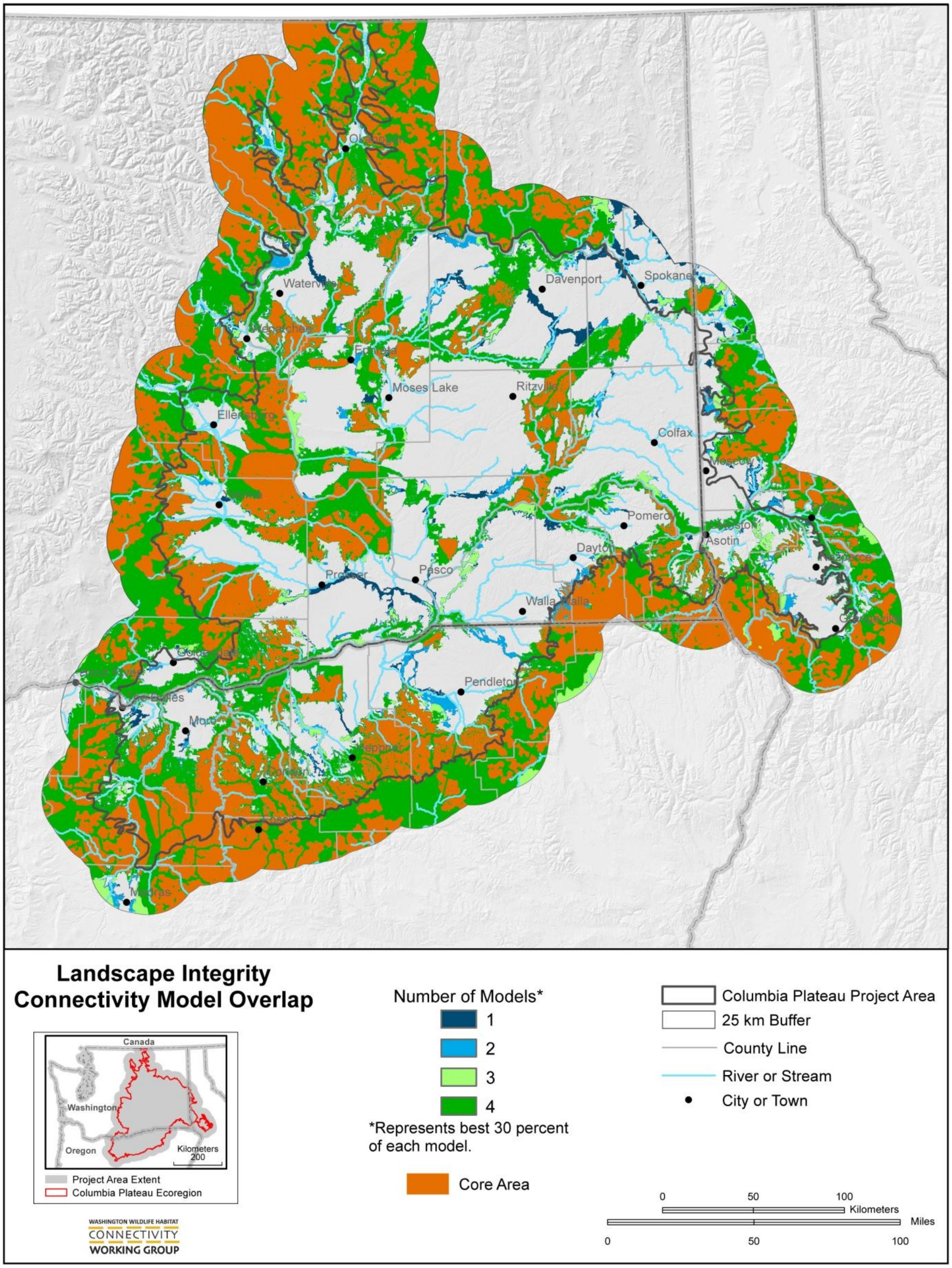

Figure 3.23. Landscape integrity of the Columbia Plateau Ecoregion showing the top 30% linkage locations. This map is based on the linear, minimum, medium, and maximum models.

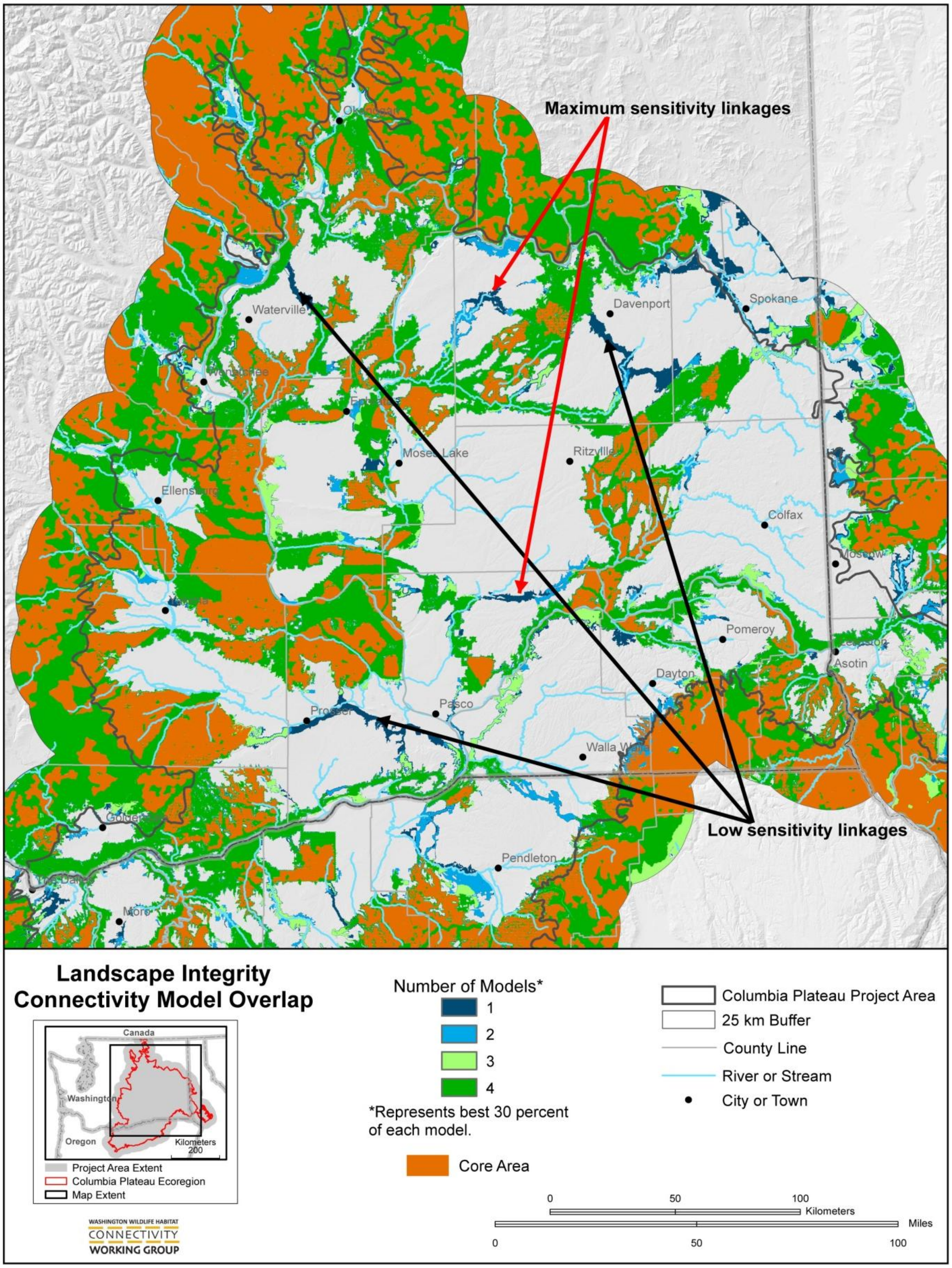

Figure 3.24. Landscape integrity of the Columbia Plateau Ecoregion showing significant connectivity areas. These are based on the top 30% linkage locations and the linear, minimum, medium, and maximum models.

3.5. Network Cluster Analysis

To explore patterns among the 11 focal species and landscape integrity model results, we used a cluster analysis similar to that performed for the statewide analysis (WHCWG 2010). However, this analysis did not show a pattern of unique species groups (or guilds) as emerged from the statewide analysis. This is not surprising, since the Columbia Plateau focal species as a group are more ecologically similar to one another than are the focal species chosen for the statewide assessment. While we are not using the results of the cluster analysis as the basis of a guild structure for the Columbia Plateau, the analysis results are of interest towards interpretation of the modeling results.

For the cluster analysis, we used two different approaches including eight individual cluster analysis runs (See Section 2.9). Clustering patterns were highly consistent across the analyses, indicating that the clustering patterns were robust to different network width assumptions and analysis approaches using binary and continuous network measures (Singleton 2012). Here we present results that are based on the linkage mapping cutoff widths for each focal species, and four landscape integrity binary networks.

Patterns in the scree plots for the network cluster analysis (Fig. 3.25) indicate that clustering the focal species into groups based on the binary networks did not explain the variation across the 11 focal species. Clustering patterns were substantially influenced by the distribution and extent of HCAs and resulting linkage networks. Species with more limited networks tended to cluster together. Patterns that emerged from the cluster analysis included the following (Fig. 3.25):

- Tiger salamander, least chipmunk, and Washington ground squirrel clustered together. Habitat concentration areas, and consequently networks for these species, are concentrated in the north and central portions of the Columbia Plateau study area. These are very narrow networks; all of these species had cost-weighted linkage widths of 5 km.
- Sharp-tailed Grouse, Greater Sage-Grouse, and Townsend's ground squirrel clustered together. These are limited distribution species located in the northern and western portion of the Columbia Plateau study area, and associated with the relatively large blocks of natural habitat in these areas. While the linkages for Sharp-tailed Grouse and Townsend's ground squirrel do not overlap, the Greater Sage-Grouse network broadly overlaps the other two. Sharp-tailed Grouse and Townsend's ground squirrel are represented by very narrow networks—they may cluster because they are limited in spatial extent—and most of the analysis area is well outside of the networks for these two species.
- White-tailed jackrabbit and mule deer are outliers of a different sort, with network patterns that differ somewhat from those of the other focal species. Both are relatively widespread, especially in the southern, western, and northern portions of the Columbia Plateau study area. White-tailed jackrabbit HCAs in particular are absent in the eastern portion. Habitat concentration areas for these species overlap substantially. The four landscape integrity networks corresponded most closely to these two focal species networks because, like the landscape integrity networks, the networks for these focal species are relatively widespread across the analysis area.

- Western rattlesnake, black-tailed jackrabbit, and beaver are relatively broadly distributed species with substantial connectivity values in the central portion of the analysis area. The beaver network and Western rattlesnake network both largely coincide with riverine systems in the plateau.

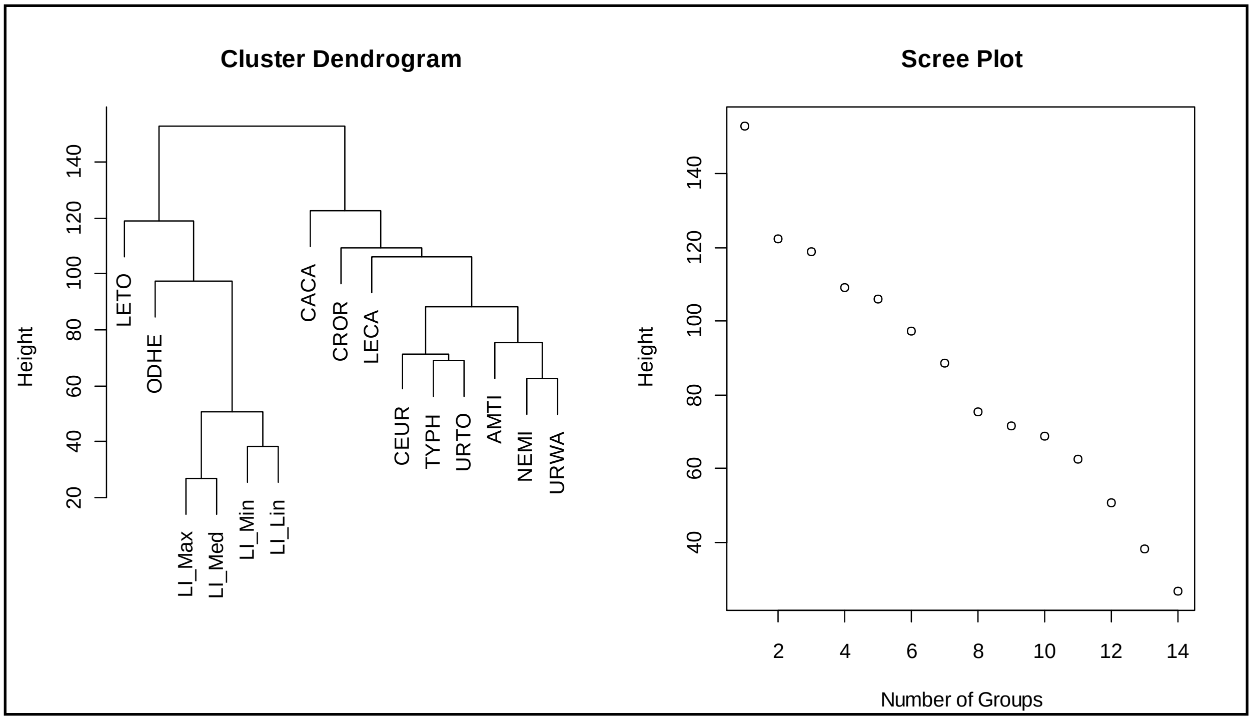

Figure 3.25. Network cluster analysis results. Hierarchical cluster analysis dendrogram and scree plot results for 11 focal species and four landscape integrity networks. Cluster dendogram codes: AMTI = tiger salamander; CACA = beaver; CEUR = Greater Sage-Grouse; CROR = Western rattlesnake; LECA = black-tailed jackrabbit; LETO = white-tailed jackrabbit; NEMI = least chipmunk; ODHE = mule deer; TYPH = Sharp-tailed Grouse; URTO = Townsend's ground squirrel; URWA = Washington ground squirrel; LI = landscape integrity, and Max, Med, Min, Lin refer to the maximum, medium, minimum, and linear models.

3.6. Comparisons between the Ecoregion and Statewide Scales of Analysis

To consider issues of wildlife habitat connectivity in Washington, the WHCWG conceptualized a three-tiered approach, with analyses at statewide, ecoregional, and local scales (See Fig. 1.1). The first tier, a broad-scale assessment (447,000 km^2) was addressed by the *Washington Connected Landscapes Project: Statewide Analysis* (WHCWG 2010). The analysis of habitat connectivity across the Columbia Plateau Ecoregion (132,200 km^2), presented in this report is a second-tier, sub-statewide-scale analysis.

Our intent is for this ecoregional analysis to add greater detail to the statewide analysis (WHCWG 2010) and to be a key step toward supporting local and project-level conservation efforts and linkage designs. Five of the focal species (Sharp-tailed Grouse, Greater Sage-Grouse, black and white-tailed jackrabbits, and mule deer) plus landscape integrity were modeled at both the statewide and ecoregional scales. This allowed us to consider how our results differ at the two different scales of analysis. Cumulatively, we find the ecoregional results provide extensive detail important for understanding habitat connectivity in the Columbia Plateau Ecoregion, and the insights we report below lend strong support to the usefulness of the ecoregional analysis to bridge the statewide results for use at the local scale.

3.6.1. Overview

We refined the statewide methods and approach to model connectivity at the ecoregional scale and benefited from:

1) The engagement and participation of regional field biologists and other experts. This was particularly relevant for experts within Washington State.
2) The ability to consider issues or features particular to the ecoregion that may influence connectivity. For instance we mapped different types of agricultural crops, transmission lines, wind turbines, irrigation canals, soils, and measures of topographical complexity.
3) A broader array of arid landscape-specific species (11 focal species versus 6 species selected to represent semi-desert habitats in the statewide analysis).

Overall, the patterns in species and landscape integrity networks between the statewide shrubsteppe and generalist guilds and the ecoregional analysis are similar, constrained as they are in this landscape by an extensive human footprint. The ecoregional analysis, however, adds resolution to the results, both within and outside these converging coarse-scale networks. Highlights of this greater resolution include:

- “Tightening” of linkages and associated habitats they connect, focusing attention on what are likely to be the more important areas for conserving connectivity.
- Greater ability to interpret the importance of specific habitat areas and linkages for conservation significance.
- Broader variation in the number of focal species for which particular areas are important within the complete network, likely reflecting needs of many non-focal species in the region.

3.6.2. Landscape Integrity: Comparisons between Two Scales of Analysis

The Columbia Plateau landscape integrity analysis identified most of the same areas (87%) of the combined best 30% core and connectivity zones identified in the statewide analysis (WHCWG 2010) within the Columbia Plateau Ecoregion. In both the statewide and the Columbia Plateau Ecoregion analyses, core areas overlapped with all GAP protected uplands (status codes “1” and “2”) that met minimum size requirements of 4047 ha (10,000 ac).

Differences between results from the two analyses can be explained by: the addition of new human modification data associated with transmission lines, wind turbines, and railroads, and changes in how low-use roads were used in determining core areas and resistance. The effect of including these changes resulted in sub-dividing the remaining native habitat into more (and smaller) core areas in the Columbia Plateau analysis (n = 113 core areas, average area = 140 km^2) compared to the statewide analysis (n = 76 core areas, average area = 224 km^2; Fig. 3.26).

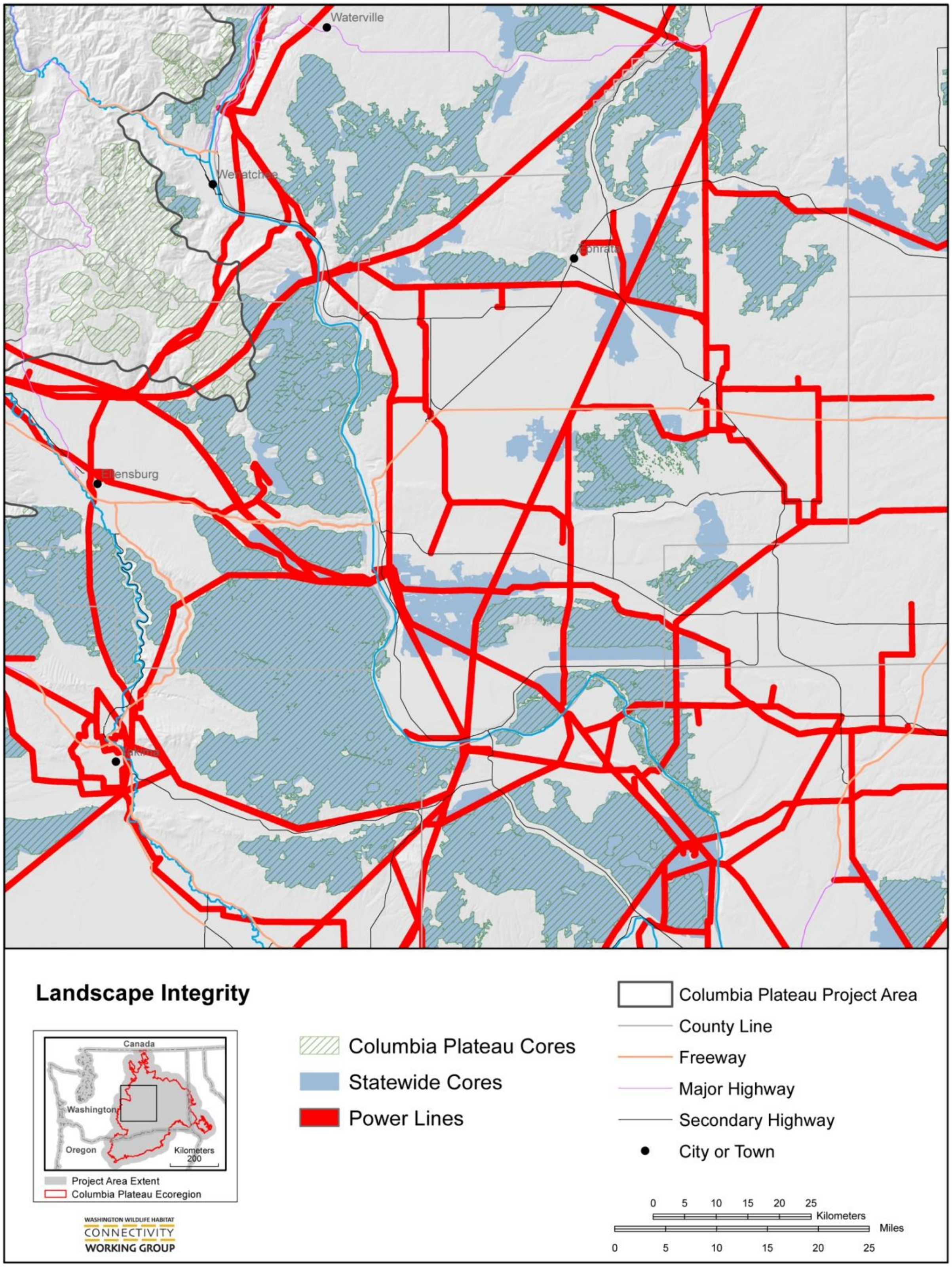

Figure 3.26. Landscape integrity core areas: comparison between ecoregional and statewide connectivity analyses. This is a close-up view of the Ellensburg, Yakima, and Moses Lake area showing powerlines as an example of the more detailed results influencing core areas in the ecoregional analysis.

3.6.3. Focal Species: Comparisons between Two Scales of Analysis

For wildlife specific to the ecoregion (e.g., the grouse and jackrabbits), refining the analysis with finer-scale data appears to highlight network weaknesses rather than network strengths. These results suggest that modeling these species at the ecoregional scale is critical for reflecting current habitat and linkage conditions, and to more realistically assess the needs for connectivity conservation.

In the case of black- and white-tailed jackrabbits, at the ecoregional scale we emphasized modeling decisions that refined HCA identification, allowing the models to better distinguish between these two closely related species. The need for conserving and enhancing connectivity becomes more obvious with these refinements.

For generalist species not limited to shrubsteppe or grassland vegetation types (e.g., mule deer), the refinements at the ecoregional scale appear to highlight areas that the statewide analysis overlooked, particularly in the center of the ecoregion. Mule deer conservation in the Columbia Plateau is likely better informed by this ecoregional-scale analysis. In the statewide analysis, where the range of habitat types reflected by the model was more widely disparate, the assignment of parameters may have underestimated the habitat and permeability of arid lands systems and land uses.

The statewide analysis (WHCWG 2010) included 16 focal species selected to represent five broad vegetation categories across the state, while this ecoregional analysis selected 11 species solely to represent the Columbia Plateau Ecoregion. A comparison of their full composite network overlaps indicates the statewide analysis identified most but not all of the same landscape areas (Fig. 3.27). Ecoregional refinements to the mule deer model, and the addition of the aquatic species, i.e., beaver and tiger salamander, provided much of the updated ecoregional spatial coverage over that provided by the statewide model. This information indicates that the two models performed similarly with respect to spatial extent, with some refinement evidenced in the ecoregional model.

In order to use the results of our analyses at more local scales, it is important to recognize and understand how focal species results differed between the statewide and ecoregional scales of analysis. An initial exploration of the results for the five species modeled at both scales allows us to provide a comparative assessment of the results and insights from the two scales of analysis (See Appendices A.1, A.2, A.3., A.4, and A.8 respectively, for details). We summarize these comparisons below in the three categories that emerged based on our assessment: (1) ecoregional inclusion of additional GIS layers, (2) refinement of HCAs and linkages, and (3) application of the results for conservation purposes.

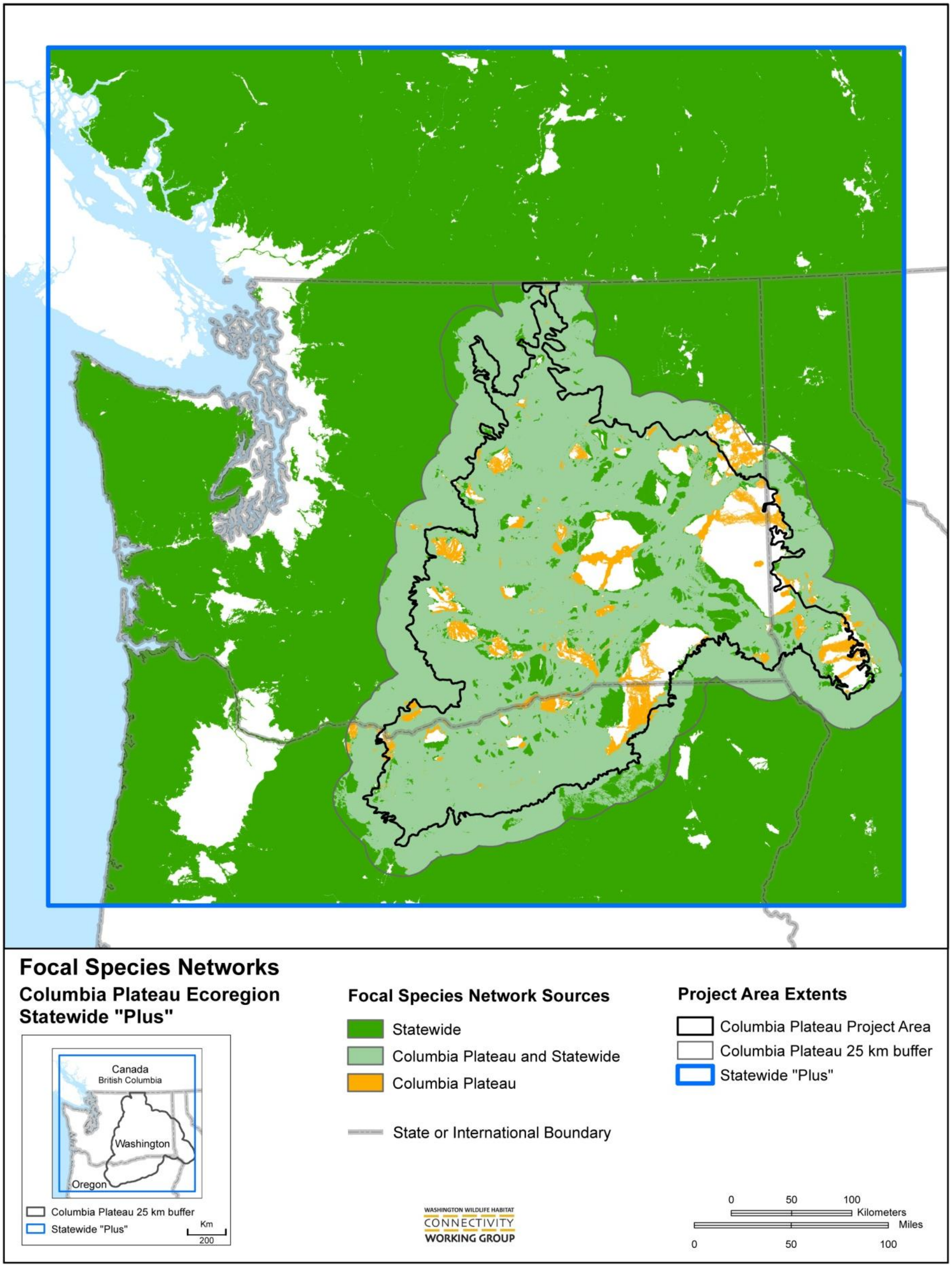

Figure 3.27. Comparison of statewide and Columbia Plateau focal species network areas.

ADDITION OF ECOREGION-SPECIFIC GIS LAYERS

The inclusion of "specialty" GIS layers was identified as a key factor of importance for the refinements represented by the ecoregional analysis. For example, the creation of a map layer that indicated where specific types of agricultural lands were located adjacent to natural shrubsteppe areas allowed better translation of species habitat use into the analysis products. Specific examples follow.

- *Sharp-tailed Grouse and Greater Sage-Grouse*: including agricultural lands adjacent to suitable habitat as a modeling parameter allowed greater opportunity for movement in some locations, and the inclusion of wind turbines and transmission lines as GIS layers contributed to the remapping of a primary Greater Sage-Grouse corridor.
- *Black- and white-tailed jackrabbits*: in some instances, the specialized within-agricultural-area buffer appeared to support larger HCAs for both rabbit species.
- *Mule deer*: the refined agricultural classes improved the differential depiction of resistance to movement posed by irrigated and dryland agriculture, something not modeled in the statewide analysis.

REFINEMENT OF HABITAT CONCENTRATION AREAS AND LINKAGES

A combination of specialty GIS layers, updated methods for identifying habitat concentration areas (HCAs), and finer resolution of landscape features were reflected in the refined HCAs and linkages in the ecoregional analysis as compared to the statewide analysis. For example:

- The number of HCAs stayed the same for Greater Sage-Grouse, however for the Sharp-tailed Grouse and both rabbit species the number of HCAs within the Columbia Plateau project area roughly doubled, and for mule deer the number of HCAs increased from 26 to 71 (Table 3.4). These refinements resulted from several factors, for instance, in the ecoregional analysis the Sharp-tailed Grouse model used lek locations (traditional breeding sites) to refine identification of HCAs as there was interest in understanding potential connectivity both within and between known populations.
- The average size of an HCA was smaller for the ecoregional analysis, about one-quarter to two-thirds of the mean sizes of the statewide HCAs (Table 3.4). Numerous factors account for this difference. For example, the black-tailed jackrabbit results indicate several cases where a chain of smaller HCAs modeled in the ecoregional analysis occurs directly along a linkage modeled in the statewide analysis.
- Total HCA area was 51% of that for the statewide HCA area for the Sharp-tailed Grouse, 65% of the statewide area for the Greater Sage-Grouse, 7% larger for the black-tailed jackrabbit, roughly the same for the white-tailed jackrabbit, and 79% of the statewide HCAs area for the mule deer (Table 3.4).
- Linkages tended to change between the statewide and ecoregional analyses commensurate with changes to HCA locations and sizes. Also changes in characteristics of the resistance surface from the new and refined layer categories resulted in changes in characteristics such as linkage length. For instance the longest modeled linkages became shorter for both rabbit species in the ecoregional analysis.

Table 3.4. Ecoregion and statewide analyses comparisons of habitat concentration areas (HCAs) within the ecoregion and the 25 km buffer, for five species modeled in both analyses.

Focal species	*Number of HCAs: Columbia Plateau analysis*	*Number of HCAs: statewide analysis**	*Mean size of HCAs: Columbia Plateau analysis (km^2)*	*Mean size of HCAs: statewide analysis* (km^2)*	*Total area of HCAs: Columbia Plateau analysis (km^2)*	*Total area of HCAs: statewide analysis* (km^2)*
Sharp-tailed Grouse	15	8	94	345	1412	2761
Greater Sage-Grouse	4	4	932	1428	3728	5711
Black-tailed jackrabbit	54	31	126	206	6825	6372
White-tailed jackrabbit	90	38	111	273	9963	10,372
Mule deer	71	26	515	1766	36,574	45,929

**Contained within the Columbia Plateau Ecoregion and the 25 km buffer.*

APPLICATION TO CONSERVATION EFFORTS

Both the coarse-scale statewide analysis and the sub-statewide scale ecoregional analysis provide useful information for conservation purposes. But while the statewide analysis provided broad general patterns, we identified greater conservation utility based on the detailed results of the ecoregional analysis. In particular:

- *Sharp-tailed Grouse*—The ecoregional analysis indicates that populations may be more discontinuous than previously believed, and the added detail will enhance consideration of restoration scenarios and the implementation of efforts to enhance or maintain connectivity for this species.
- *Greater Sage-Grouse*—The addition of powerline and wind turbine data in the ecoregional analysis illustrates that resistance to movement between the two resident populations is higher than previously thought. Overall, addition of energy layers, refinement of agriculture land use classes, and the increased resolution of the analysis are felt to be immensely valuable for understanding the actual level of connectivity that exists in linkages mapped by the statewide analysis.
- *Black- and white-tailed jackrabbits*—Differences in linkage locations and greater refinement of HCAs indicate a higher level of precision than in the statewide analysis results. However, field surveys are needed to confirm this.
- *Mule deer*—Modeling at the ecoregional scale using higher habitat values produces results that not only predict the highest quality mule deer habitat, but also identify the important linkages between these habitats, including those that could be at risk of disruption. From ecological and conservation planning perspectives, the ability to identify or predict potential influences to mule deer use areas and movement corridors at this finer ecoregional scale provides the level of knowledge that could be used by government planners and deer managers to protect those areas. Such knowledge is not available from the statewide level models.

Chapter 4. Important Areas for Connectivity in the Columbia Plateau Ecoregion

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The *Washington Connected Landscapes Project: Analysis of the Columbia Plateau Ecoregion* confirmed and refined the conclusions drawn for this ecoregion in the statewide connectivity analysis (WHCWG 2010), bringing them a step closer to directly informing on-the-ground efforts to conserve connectivity in Washington's arid lands and surrounding areas. Across this ecoregion, the impacts of human activities—agriculture, development, and related infrastructure—are visible in both the limited size and distribution of habitat areas, and in the length and the irregular and narrow shape of the linkages connecting them. This pattern is strongly visible in the landscape integrity network (Fig. 3.23), which specifically models the impact of the "human footprint" (Sanderson et al. 2002; Leu et al. 2008; Theobald 2010). It is also reflected in the focal species networks, which show large gaps in habitat common to all focal species (Fig. 3.15; Appendix A). This consistent result highlights an already-identified need to conserve functional connectivity for a broad array of species of interest, many of which are declining (Vander Haegen et al. 2000; Schroeder et al. 2004; Siegel Thines et al. 2004). The results of this analysis provide the foundation for strategic decisions by showing where the opportunities lie for maintaining and enhancing connectivity across the Columbia Plateau Ecoregion.

In this chapter we interpret and synthesize the results arising from the different approaches we took to model connectivity (See Section 4.1) and present a framework for guiding decisions focused on maintaining and enhancing wildlife habitat connectivity across the Columbia Plateau in Washington and beyond (See Section 4.2).

4.1. Key Patterns and Insights

Analyzing connectivity for a carefully selected set of focal species with differing habitat needs, movement capabilities, and responses to landscape features should capture the needs of a wide array of species that use these same landscapes (WHCWG 2010). The landscape integrity analyses complement these results by providing a structural connectivity approach that should capture large, undeveloped core areas and associated linkages that may provide important habitat for additional species or ecological processes. These two approaches used at the ecoregional scale reinforce the findings of the statewide analysis for the Columbia Plateau Ecoregion (WHCWG 2010). Additionally, both the landscape integrity networks and the networks for generalist species (particularly mule deer) show core areas and connections that are likely to provide connectivity to neighboring ecoregions. As proposed in the statewide climate gradient corridors analysis, these linkages may become important for species as their ranges shift in response to climate changes (WHCWG 2011). The reinforcement of these similarities and added conclusions from the different portions of the *Washington Connected Landscapes Project* highlight the value and relevance of nested scales of analysis.

The most noticeable pattern highlighted by areas important to four or more focal species is the crescent-shaped block of loosely connected lands in central Washington that we have named the Backbone (See Section 3.3; Fig. 3.16). This pattern reoccurs in the landscape integrity results. A group of landscape integrity core areas and relatively wide linkages between them in the western portion of the Columbia Plateau provide a significant contrast to the smaller core areas and longer and narrower linkages occurring further east (Fig. 3.15). This result indicates that the crescent of habitat observed for multiple focal species results from a relatively low amount of conversion and low human footprint throughout the area. Both approaches therefore highlight a generally similar pattern in central Washington, which provides a Backbone in this ecoregion, from the Horse Heaven Hills in the south, all the way to the Okanogan Valley in the north ("1" in Fig. 3.16).

This Backbone is consistent with the results obtained at the statewide scale (WHCWG 2010), which highlighted the same crescent of lands important for most of the shrubsteppe species analyzed. It is important to note that the linkages along this Backbone vary in their characteristics, and therefore also likely vary in their capacity to function as true linkages for a wide array of species and processes. Modeled corridors will "punch through" significant barriers, and as such provide the best opportunity for a corridor, rather than representing corridors that are currently fully functional. The ecoregional scale analysis presented here emphasizes locations within the Backbone where particular attention is needed to either maintain or, in many cases, enhance or restore linkages to provide functional connectivity for the species that depend on these systems. Of particular note are the Ahtanum Ridge-Rattlesnake Hills linkage, south of Yakima, and the Rock Island-Trinidad linkage crossing the Columbia River.

> *Ahtanum Ridge-Rattlesnake Hills linkage*—In Washington, the tenuous nature of the connections between habitat within the Yakama Reservation and areas to the north (around the Yakima Valley and along Ahtanum Ridge to Rattlesnake Hills) is apparent in both the focal species and landscape integrity results (Fig. 4.1a and b, east arrow). The limitations many of the focal species face in using the generally forested—if less fragmented—lands in the buffer area (East Cascades Ecoregion) are reflected in the narrowing of most focal species' networks (with the exception of mule deer), particularly on the western end of the Yakima Valley, relative to the wider landscape integrity corridors (Fig. 4.1a and b, west arrow). Narrow corridors indicate areas where linkages pass through poor habitat (WHCWG 2010). The landscape integrity corridors are wide here because the area is relatively undeveloped, whereas most focal species' corridors are narrow because the surrounding area is forested and thus provides poor movement habitat for most of our focal species.

> *Rock Island-Trinidad linkage*—The Columbia River poses an impenetrable barrier for some species (See Appendix A for the least chipmunk and ground squirrel species accounts), and adds significant resistance to movement for other wildlife. The barrier effect of the river is compounded by infrastructure occurring

in and along the river and surrounding uplands (such as wide areas of open water behind dams, highways, railway lines, transmission lines, and waterfront development), creating a fracture zone where permeability to movement is greatly reduced. The impact of this on the Backbone of loosely connected lands can be observed in both the focal species and landscape integrity results. Because their core area locations differ, the least-cost pathways for focal species crossing the Columbia River between Rock Island and Trinidad follow different routes (Fig. 4.1c and d, oval), whereas those routes tend to converge along Moses Coulee or on the arc of the Beezley Hills to the northeast of the river (Fig. 4.1c and d, arrows). For the Backbone to be functionally connected for wildlife movement along its entire length, the area around Rock Island–Trinidad may well require particular attention. This area may also be a candidate for future research to determine which species are using it to move across the Columbia River.

Along the Backbone there are also areas where the results using the two different approaches (focal species and landscape integrity) diverge: the Mansfield Plateau (to the north of Moses Coulee) and the upper Okanogan Valley (just north of Tonasket to the Canadian border).

Mansfield Plateau—In northern Douglas County, focal species networks for multiple species have linkages that join upper Moses Coulee to the lower portion of the Okanogan Valley through the uplands (Fig. 4.2a and b, oval). The landscape integrity composite network follows a narrow band further east, along the western shore of Banks Lake (Fig. 4.2a and b, arrow). Dominated in large part by cliffs, this area along the western shore of the lake was assigned higher resistance for focal species than for the landscape integrity model. North of the Columbia River the focal species and landscape integrity models converge once again along the east side of the Okanogan Valley.

Upper Okanogan Valley—Another area where differences between the approaches are apparent is north of Tonasket to the Canadian border. Here, the landscape integrity network appears robust and wide on both sides of the valley, while avoiding the agriculture and infrastructure in the bottom of the valley (Fig. 4.2c and d, parallel northward arrows). The focal species networks diverge, either following the valley itself northward or breaking off eastward toward Chesaw, through the non-forested and less converted Antoine and Myers drainages (Fig. 4.2c and d, single curved arrow). Only the mule deer network shows similar patterns to landscape integrity, capturing broad areas in the buffer. Though we were unable to model linkages into British Columbia due to insufficient capacity to develop trans-boundary data layers, the results of the statewide analysis (WHCWG 2010) suggest that these patterns may well extend north of the Canadian border.

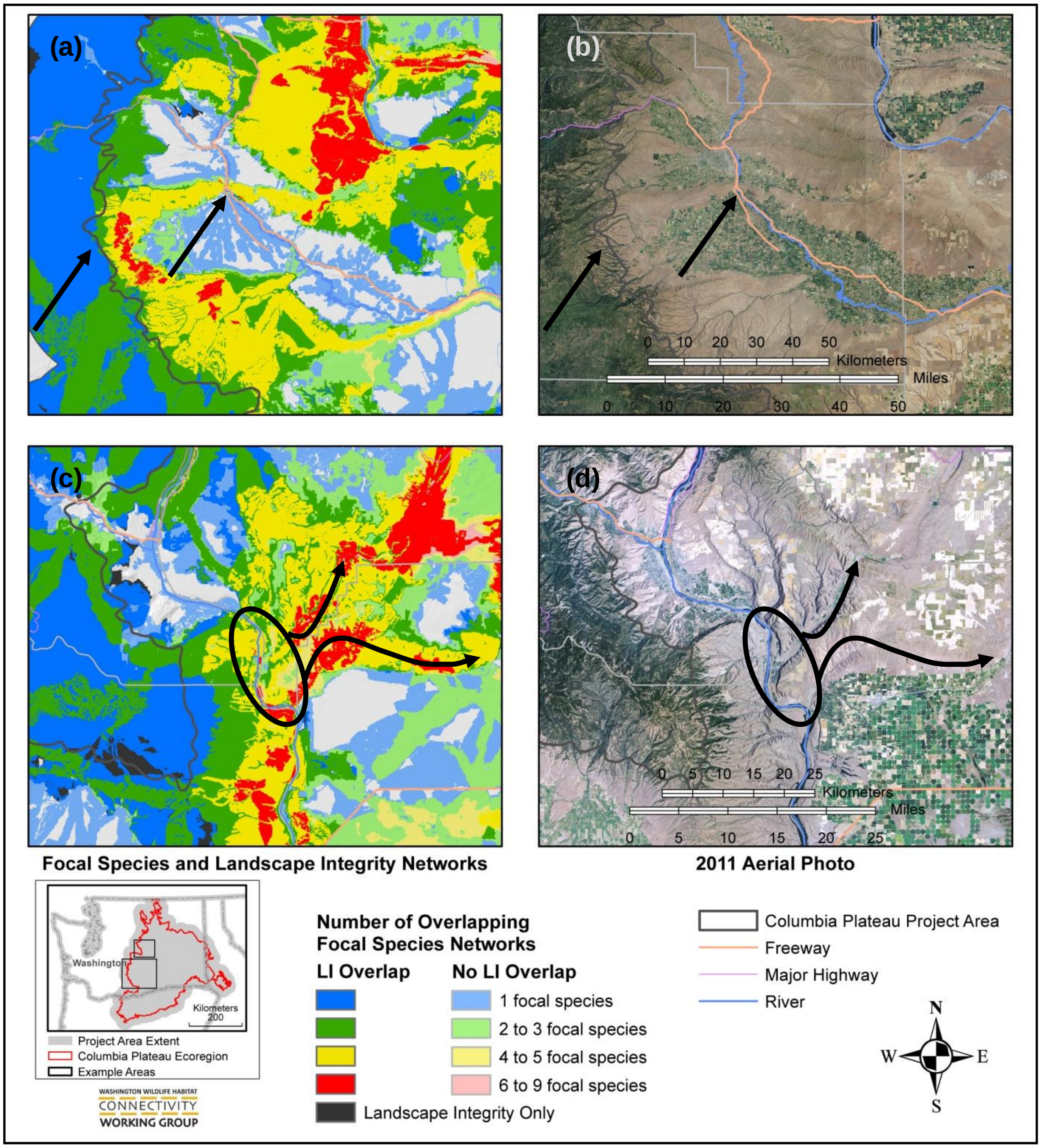

Figure 4.1. Examples of locations within the Backbone where particular attention is needed to either maintain or restore linkages to provide functional connectivity. (a) Ahtanum Ridge-Rattlesnake Hills linkage: overlap of focal species and landscape integrity networks. (b) Ahtanum Ridge-Rattlesnake Hills linkage: 2011 aerial photo. (c) Rock Island-Trinidad linkage: overlap of focal species and landscape integrity networks. (d) Rock Island-Triniad linkage: 2011 aerial photo. Bold colors reflect the number of focal species' networks particular areas belong to, where they overlap with the landscape integrity (LI) network. Variants in soft colors occur where these focal species networks do not overlap with the landscape integrity (LI) network. Arrows and shapes highlight areas that exemplify how linkages along this Backbone vary in their characteristics (See Section 4.1).

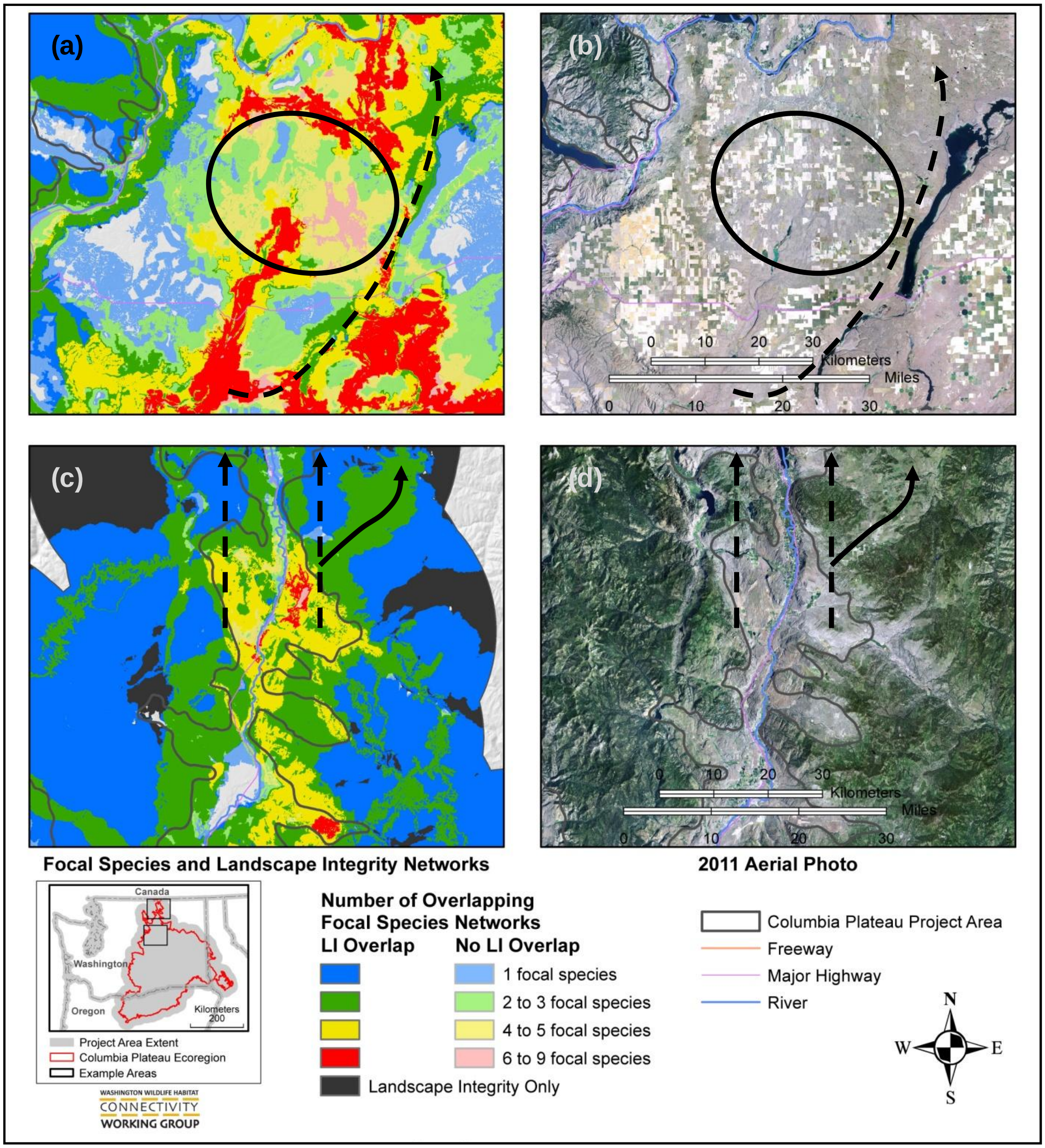

Figure 4.2. Examples of areas where the differences in results between the focal species and landscape integrity approaches are particularly noteworthy. (a) Mansfield Plateau: overlap of focal species and landscape integrity networks. (b) Mansfield Plateau: 2011 aerial photo. (c) Upper Okanogan Valley: overlap of focal species and landscape integrity networks. (d) Upper Okanogan Valley: 2011 aerial photo. Bold colors reflect the number of focal species' networks particular areas belong to, where they overlap with the landscape integrity network. Variants in soft colors occur where these focal species networks do not overlap with the landscape integrity network. Arrows and shapes highlight areas that exemplify how the networks for focal species (solid lines) and for landscape integrity (dashed lines) diverge (See Section 4.1).

Looking to the eastern half of the Columbia Plateau in Washington, several areas stand out as potentially important for achieving a connected landscape for multiple focal species. At least four focal species networks occur along the Scablands Swath that extends southwest from Spokane along Cow and Rock creeks and the Palouse River, and along the Snake River all of the way to the Columbia River ("2" in Fig. 3.16). Multiple narrower areas run approximately perpendicular to this broad swath, linking it to the Backbone in central Washington. The two broadest east–west connectors occur: (1) between the Palouse River and the Columbia River, roughly following the Washtucna Coulee, Lower Crab Creek, and the Saddle Mountains ("3" in Fig. 3.16); and (2) along Upper Crab Creek, extending north and west to the Dry Falls area ("4" in Fig. 3.16). Importantly, a block of habitat around the Swanson Lakes Wildlife Area in Lincoln County (reflected as part of the Habitat Concentration Areas of six species; Fig. 3.16; see also Appendix A) is broadly connected, via multiple Missoula Floods-scoured drainages running toward the southwest, to the Upper Crab Creek east–west connector. Model outputs suggest that this area may provide a linkage northward across the Columbia and Spokane rivers. However, the rivers—particularly the Columbia—may pose a significant enough barrier that further validation is needed to determine the effectiveness of these lands in promoting north–south movement for a wide array of species.

All of these areas in the eastern portion of the Columbia Plateau are to some extent included in the landscape integrity network, yet the connections are more tenuous in this model than in the focal species networks (Fig. 3.17). In the landscape integrity network, narrow and tortuous linkages connect clusters of relatively small core areas, which differ from the broad northeast–southwest swath of potentially connected lands visible in the focal species results (Fig. 3.17). For both sets of results, however, it is important to note that connectivity in this easternmost portion of Washington is less robust than farther west (Fig. 3.16), a result which likely relates to the greater extent of agriculture in the Palouse Prairie, and may help explain the shrinking occupied range of species like Greater Sage-Grouse and Sharp-tailed Grouse (See Appendix A).

A similar distinction between the landscape integrity network and the focal species networks can be made when analyzing patterns in north-central Oregon and in western Idaho. The results of this analysis were more extensively vetted by field biologists with greater experience in Washington than in neighboring states, so the breadth of our knowledge in Oregon and Idaho is limited. However, some general insights emerge from the focal species and landscape integrity networks crossing the state boundaries.

> *Connecting to north-central Oregon*—The models predict that the Columbia River is a significant barrier to movement. In addition, infrastructure and natural barriers follow the Columbia River Gorge, including roads, transmission lines and wind turbines (Fig. 4.3), areas of agricultural use, and steep cliffs (the latter particularly in the lower portion, in Klickitat County). The models show a few narrow linkages from Washington into Oregon for four or more focal species ("1" in Fig. 4.3a and b, curved arrows). Somewhat similar results arise for landscape integrity: linkages towards north-central Oregon begin wide as they approach the river then thin to multiple narrow connections across the river ("1" in Fig. 4.3a and b, small arrows). This is true even where substantial core areas exist on one or both sides of the river (e.g., around the Boardman Training Facility, Oregon). A linkage that does not require crossing the Columbia River is part of the network

for five focal species, ("2" in Fig. 4.3a and b, curved arrow) and the linear and minimum landscape integrity networks (Fig. 3.23). This linkage runs on the east side of Wallula Gap, where the Columbia River bends. Importantly, this linkage may be the Washington ground squirrel's sole potential connection between Washington and Oregon squirrel populations. It is noteworthy, however, that the landscape integrity network does not include the full linkages ("2") in Fig. 4.3a and b, small arrows) suggesting the Wallula Gap linkage may not be a robust connector. The Columbia River Gorge and Wallula Gap linkages are important to maintaining connectivity between Washington and Oregon. Efforts to maintain or restore these linkages should consider the tradeoffs for wildlife between needing to cross the Columbia River and the infrastructure on both sides of the river (Fig. 4.3), and the longer distances between habitat areas if the linkage goes around the bend in the river. Consideration should be given to those species where there are no trade-offs, as crossing the river may not be possible.

Connecting to the Blue Mountains in Oregon and Idaho—Results from analyses using focal species and landscape integrity both highlight two narrow linkage zones between the Scablands Swath in eastern Washington and the Blue Mountains in northeastern Oregon and across into Idaho. These linkages follow the Tucannon and Snake rivers (Fig. 4.4, curved arrows), and are constrained to the steep breaks along the river where native habitat remains. The surrounding areas, including the land between the two rivers, are dominated by agriculture, providing greater resistance to movement for most species than the remaining native habitat.

Results from the landscape integrity analysis for the Columbia Plateau Ecoregion suggest there is a significant difference in levels of human impact between the ecoregion itself and the surrounding buffer area: whereas the majority of the area in the buffer is part of the landscape integrity network, the majority of the area in the Columbia Plateau Ecoregion is outside the network (Fig. 3.15). Additionally, some of the linkages that appear more robust (broader and shorter; or with shorter cost-weighted distances, indicating fewer barriers to movement) connect the large core areas in the western portion of the Columbia Plateau Ecoregion to core areas in the buffer, rather than to other larger core areas within the Plateau (Fig. 3.15). Similar patterns can be seen in the mule deer network (Fig. 3.22), which passes through both forested and arid-lands habitats. Though these patterns may have important implications in light of climate change, allowing species and systems to shift along gradients of increasing elevation (WHCWG 2011), they pose two challenges:

- Few opportunities exist for gradual shifts northward to higher latitudes (WHCWG 2011).
- These linkages may currently not represent functional linkages for many arid lands species such as those selected to represent shrubsteppe and grasslands (Fig. 3.18), given the significant differences in vegetation and other conditions between the Columbia Plateau and the surrounding, well-connected buffer.

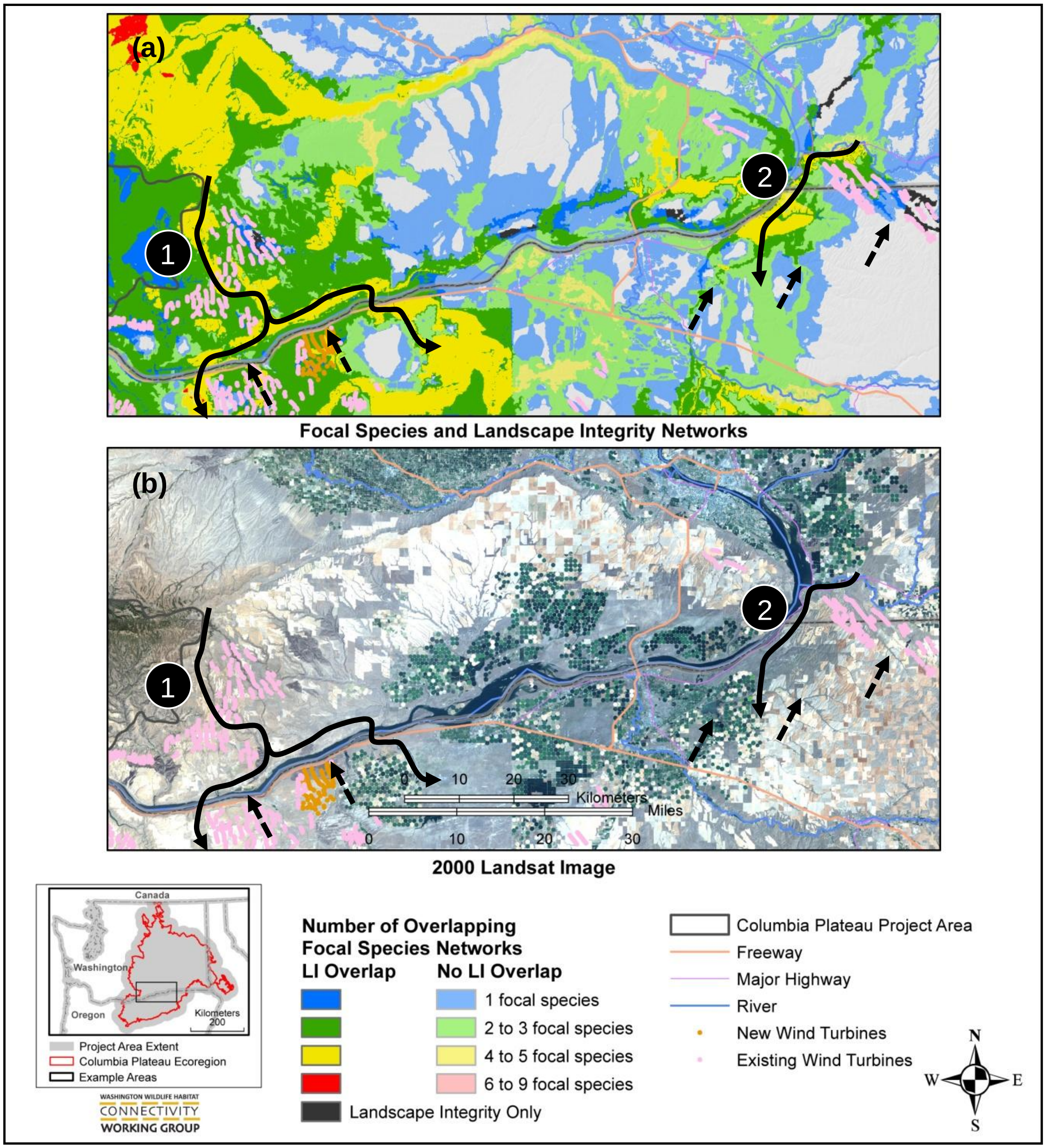

Figure 4.3. Linkages to important areas in neighboring states: connections to north-central Oregon. (a) Overlap of focal species and landscape integrity networks. (b) 2000 Landsat image. (1) Area around Woods Creek in the Columbia River Gorge, where potential linkages cross the Columbia River. (2) Area east of Wallula Gap, where potential linkages go around the bend in the Columbia River. Bold colors reflect the number of focal species' networks particular areas belong to, where they overlap with the landscape integrity network. Variants in soft colors occur where these focal species networks do not overlap with the landscape integrity network. Arrows highlight linkages that are important for maintaining connectivity between Washington and Oregon, and the different alternatives provided by the focal species (solid arrows) and landscape integrity (dashed arrows) approaches (See Section 4.1). "Existing" wind turbines were part of data used in this analysis, while "new" turbines are more recent.

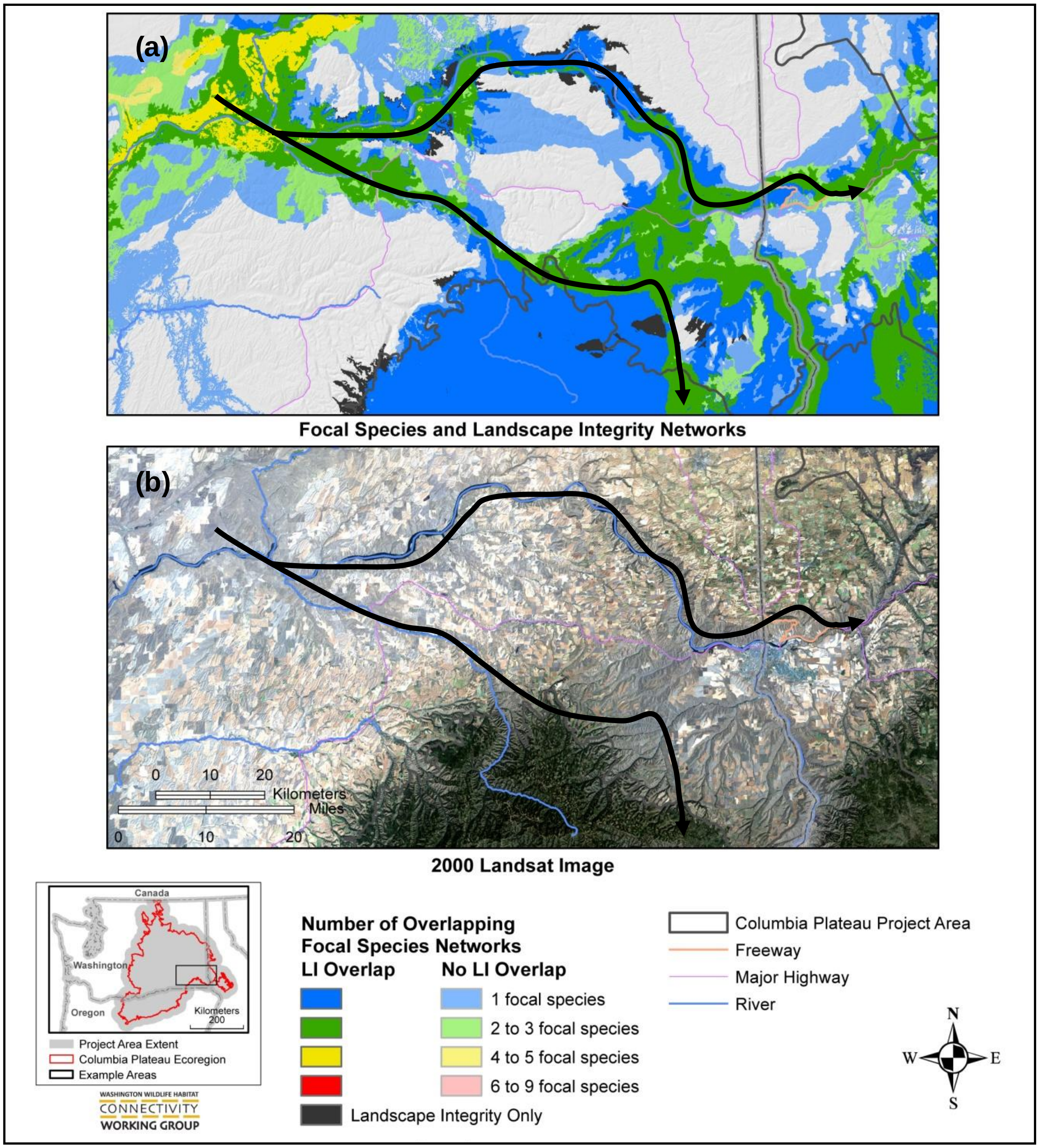

Figure 4.4. Linkages to important areas in neighboring states: connections into the Blue Mountains in Oregon and Idaho. (a) Overlap of focal species and landscape integrity networks. (b) 2000 Landsat image. Bold colors reflect the number of focal species' networks particular areas belong to, where they overlap with the landscape integrity network. Variants in soft colors occur where these focal species networks do not overlap with the landscape integrity network. Arrows highlight linkages that follow the Snake and Tucannon rivers from the Scablands Swath of loosely connected lands in eastern Washington to the Blue Mountains in neighboring states (See Section 4.1).

Many of the patterns highlighted by the overlay of landscape integrity and focal species networks are also reflected in the patterns shown when networks were grouped based on landscape pattern similarities and the rationale that we used to select the suite of focal species, including the vegetation classes they represent (Upland Network; Drainage/Aquatic and Canyon Network; and Generalist/Landscape Integrity Network; see Section 3.4). This concordance in results reinforces the need to focus on connectivity as an integral part of conservation efforts in the Columbia Plateau. One additional noteworthy pattern was captured by the Drainage/Aquatic and Canyon Network: key portions of the network follows the main river systems in a ring around the Columbia Plateau in Washington (Fig. 3.20). The Columbia Plateau connectivity analysis, as the statewide analysis before it, was explicitly focused on terrestrial connectivity. This group of species, however, emphasizes areas associated with major rivers that may well contribute to terrestrial connectivity (Beier et al. 2011). As such, these areas provide an opportunity for investing in better integration of conservation efforts focused on riverine systems (many associated to salmonid species recovery) with those focused on terrestrial systems, in this case connectivity conservation.

The habitat concentration areas and landscape integrity core areas do not capture all habitat, but are focused on the areas where suitable habitat is relatively contiguous and extensive. Most of the species do not have an upper limit to the linkage length in cost-weighted distance units, which allows linkages to be modeled through significant areas of poor habitat. This was an explicit modeling decision, partially based on the lack of available data for accurately determining maximum dispersal distances for each species. However, an important component of this decision—and a key ramification to keep in mind when interpreting these results—was our interest in identifying opportunities for connectivity conservation where linkages may not currently be functional. The results of our analysis, therefore, provide a fundamentally optimistic view of *potential* connectivity, rather than a description of *current* connectivity. Even with this optimistic approach, some linkages are still narrow and tortuous, suggesting that the connections they provide are slight. Additionally, we were unable to include ecoregion-wide data on vegetation condition and structure. Habitat quality is therefore solely determined by the size and distribution of habitat patches, leading models to overestimate habitat suitability in some cases. Restoration and enhancement efforts focused on improving the size, distribution, and quality of core areas and of the linkages between them may therefore be required to assure functional connectivity for a wide array of Columbia Plateau species.

4.2. Washington State's Connected Landscapes Framework for the Columbia Plateau

Some regions within the Columbia Plateau clearly emerge as important for connectivity. In addition, combining the focal species and landscape integrity approaches served to highlight areas that are important for particular reasons. These results provide the foundation for developing a vision for a connected landscape across the ecoregion. They also generate a framework for using these results to inform strategic decisions to achieve this vision.

The information provided by this analysis can be used to prioritize regions most important for maintaining connectivity across the whole ecoregion, as well as areas that are in most urgent need of efforts to enhance regional connectivity. Within these priority regions field surveys, model validation, or fine-scale linkage design may be necessary to guide specific actions on the ground, such as protection or restoration in specific parcels (Spencer et al. 2010; WHCWG 2010; Beier et al. 2011). Given our focus on Washington State, and the greater vetting of these results within state boundaries, we present a vision to guide connectivity conservation within this jurisdiction. We also consider the connections between lands in Washington and those in neighboring states and ecoregions, because a functionally connected landscape in Washington's Columbia Plateau depends on connections beyond Washington for its long-term persistence.

4.2.1. A Vision for a Connected Columbia Plateau Ecoregion in Washington

We have identified two broad regions and two critical sets of complex linkage zones—containing multiple individual core areas and linkages within them—that together provide a vision for a connected Columbia Plateau landscape in Washington. These are:

BROAD REGIONS

- Central Washington's **Connected Backbone** from the Horse Heaven Hills through to the Okanogan Valley (Fig. 4.5)—This series of linked core areas is a recurring pattern in all the analyses carried out so far as part of the *Washington Connected Landscapes Project*. This recurrence suggests that the findings regarding the Connected Backbone are robust to the assumptions and limitations of modeling efforts such as these. This region contains the largest remaining blocks of native vegetation, and is therefore the centerpiece of a connected Columbia Plateau.
- The **Braided Scablands Swath**, from Spokane to the confluence of the Snake and Columbia rivers (Fig. 4.5)—A well-connected system of Washington's arid lands will not be achieved with a sole focus on the north–south Connected Backbone just east of the Cascade Range. It must also include core areas and linkages across the eastern portion of the Columbia Plateau. In this portion of the ecoregion, where agriculture has more extensively modified the landscape than in central Washington, movement routes are even more constrained, and generally follow lands still dominated by native habitat, mostly the lands scoured by the Missoula Floods (Bretz 1969), where soils are too shallow and rocky or the land is too rugged to be used for agriculture.

COMPLEX LINKAGE ZONES

- Complex east–west linkage zones between the Connected Backbone and the Braided Scablands Swath (Fig. 4.5)—The **Upper Crab Creek** and the **Lower Crab Creek** Linkage Zones encompass the main pathways that would allow for east–west movement of species and processes. These complex linkage zones are critical components of a connected landscape; their existence transforms two mostly parallel bands of habitat running approximately north–south into a network of habitat that spans the majority of Washington's arid lands. Both the Upper Crab Creek and Lower Crab Creek Zones include a complex mix of linkages and generally large core areas in their western portions (including the Dry Falls and Swanson Lakes area for Upper Crab Creek, and the area around the Columbia National Wildlife Refuge and the dip south into the Juniper Dunes Wilderness Area for Lower Crab Creek), and narrower and more discrete linkages further east.
- Complex linkage zones beyond Washington, connecting the Washington network to surrounding areas (Fig. 4.5)—A connected landscape within Washington State that is isolated from the surrounding ecoregions and from areas in the Columbia Plateau in neighboring jurisdictions may not be sufficient to support species' long-term persistence under the continuing pressures of population growth and development, particularly when combined with projected climate change impacts. The complex linkage zones that can maintain connections to areas outside of Washington are therefore essential to the connected landscape vision we propose here. Our results highlight the following important linkages beyond state boundaries: (1) the **Cascade Range Linkage Zone**—the generally broad and numerous linkages between the Connected Backbone and the forested areas in the Cascade Range; (2) the **Northern Linkage Zone**—the Okanogan Valley, and the eastern arm of multiple networks extending towards Chesaw, which are likely critical areas for northward movement of species as temperatures increase in the region; (3) the **Southern Linkage Zone**—the multi-pronged linkages south of the Horse Heaven Hills, along Woods Creek and surrounding areas, that provide a pathway to the Columbia River and, at least for species capable of crossing the river, a linkage to the uplands between the John Day River and Eightmile Canyon in northern Gilliam County, Oregon. The tenuous linkage just east of Wallula Gap, which provides connectivity into north-central Oregon without needing to cross the Columbia River, is also a part of this linkage zone; and (4) the **Blue Mountains Linkage Zone**—the diverging, narrow linkages that follow the Snake and Tucannon river valleys from the Braided Scablands Swath towards the Blue Mountains in northeastern Oregon and western Idaho.

The broad regions and the complex linkage zones that compose this vision of a connected landscape reflect the current land use and the patterns of infrastructure and development across the ecoregion. This supports the conclusion that this vision, though based on a landscape modeling project with intrinsic limitations, reliably represents connectivity at the ecoregional scale. As such, this vision provides a robust platform from which entities interested in connectivity conservation can design strategies to achieve their specific goals and objectives. At the same time, results such as those obtained across the Mansfield Plateau are an example of the connectivity value that mixed native and agricultural lands can provide. This may be a model for connectivity conservation on agricultural lands that can be effectively replicated elsewhere.

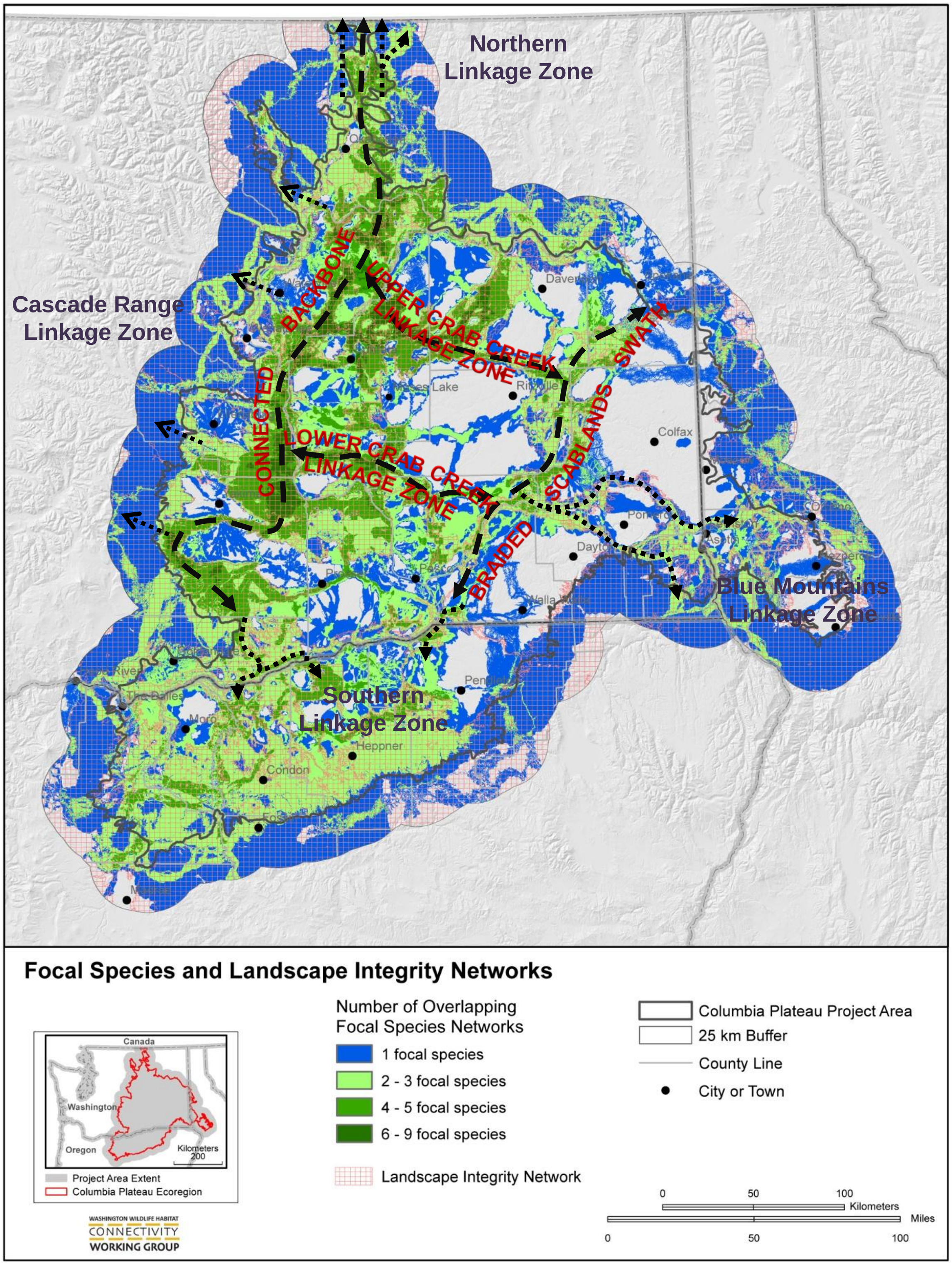

Figure 4.5. Vision for a connected Columbia Plateau Ecoregion in Washington. Solid colors reflect the number of focal species' networks particular areas belong to. The hatching represents the landscape integrity composite network. Dashed arrows highlight important areas for connectivity in Washington, and dotted arrows highlight important linkage zones to neighboring ecoregions and states (see Section 4.2.1).

4.2.2. Opportunities for Maintaining and Restoring Habitat Connectivity

The Wildlife Habitat Connectivity Working Group's mission is to promote the long-term viability of wildlife populations in Washington State through a science-based, collaborative approach that identifies opportunities to conserve and restore habitat connectivity. The connectivity analysis of the Columbia Plateau Ecoregion supports this mission by providing the information that organizations need to incorporate connectivity into conservation efforts while meeting their own organizational goals and priorities. The breadth and depth of the results lend themselves to multiple uses and ways of informing different decisions that need to incorporate connectivity, and do so based on a spatially explicit scientific analysis. Such uses will depend upon the goals and resources of the organizations themselves.

The vision for a connected Columbia Plateau we articulate here has yet to be achieved. A guiding principle as our team was making the multiple decisions that went into the development of each model—particularly at the linkage modeling stage—was to err on the side of including as many opportunities for connectivity conservation as was reasonable. For example, linkages for some species were allowed to be longer than the species' documented movement distances (Appendix A), in an effort to ensure that the best opportunities for linkages between important areas were identified, even if they might not currently function as connections. Additionally, this analysis did not include information on the current condition of the vegetation; habitat values were driven by the location and distribution of vegetation or land cover types with the potential for providing high-quality habitat when in good condition. Degraded systems influence the habitat value of such areas, and may well increase the resistance such areas pose to movement.

Even given this generous approach, many linkages shown here are tenuous and narrow, at best, suggesting that they may not persist under future environmental and land use changes. We raise these points to re-emphasize that achieving the functional connectivity portrayed by this vision will depend on restoration and enhancement efforts focused on increasing the size and improving the condition of the broad connected regions and the complex linkage zones that comprise this vision.

Grounded in this perspective, we provide some recommendations to partner entities and organizations interested in conserving and restoring habitat connectivity in the Columbia Plateau. These recommendations are concrete examples of how to use the insights gained through this analysis to inform decisions. They are not meant to be all-inclusive, nor are they meant to be prescriptive, as we recognize that each entity and organization has its own goals and priorities.

ACHIEVING THE VISION OF A CONNECTED COLUMBIA PLATEAU

Conserving and restoring habitat connectivity in the Columbia Plateau will require collaboration and action taken by a broad array of stakeholders, as it is an ambitious task across a large geography, valued by diverse sets of interests. The recommendations we detail here are focused at this broad, ecoregional scale. The entities and stakeholders in each particular area within the ecoregion are best suited to identify specific actions that can successfully be implemented in pursuit of these broad recommendations, which are:

Maintain and restore the integrity of the Connected Backbone, including the condition of the habitat occurring within it. The larger blocks of remaining native habitats and the generally broad linkages between them along this Backbone are essential to connectivity conservation in the Columbia Plateau. Future land use changes and infrastructure development projects(wind farms for example) warrant appropriate consideration of connectivity effects in this area. Additional actions might include: protecting key areas from further conversion; restoring habitat in core areas; rehabilitating sites to enhance functionality of key linkages; working with private landowners to access incentives that would help them achieve their production objectives while improving wildlife habitat or permeability to movement; and working with transportation, development, and renewable energy industry entities to avoid development that would interrupt movements, to design or enhance projects to minimize their impacts, and to collaborate on efforts to effectively mitigate unavoidable impacts.

Maintain and restore the integrity of the Braided Scablands Swath, including the condition of the habitat occurring within it. As described in the connected landscape vision, a well-connected system of Washington's arid lands will not be achieved with a sole focus on the Connected Backbone, as it would be incomplete without the core areas and linkages across the eastern portion of the Columbia Plateau. This Swath appears less consistently across focal species, and includes linkages more tenuous than those in the Connected Backbone, so the emphasis in this region may need to be on restoration, particularly of deep-soiled communities around narrow linkages, where the habitat characteristics are different to those of scabland communities which have largely avoided conversion to agriculture. Actions to be considered would be similar to those described for the Connected Backbone. As in the examples above, there may be opportunities for engaging with agricultural producers—farmers and ranchers—within and around the Braided Scablands Swath to access incentives that would allow them to enhance these linkages for wildlife while achieving resource use objectives.

Restore and expand the complex linkage zones that transform bands of connected habitat into a comprehensive network spanning the Columbia Plateau in Washington and beyond. Some of these linkage zones may currently not be functional, or may not be resilient to environmental change. Particular attention should be given to the easternmost portions of the Upper Crab Creek and Lower Crab Creek Linkage Zones, as well as the two-pronged linkages along the Snake and Tucannon rivers into the Blue Mountains, and the linkage zones into north-central Oregon, both across and around the Columbia River Gorge. There are also other linkage zones between the Connected Backbone and the Braided Scablands Swath described in individual species accounts (Appendix A) and in Chapter 3. These can provide focus areas for efforts to increase the number of functional linkages between the larger connected regions, increasing the robustness of connectivity between them. In addition to the potential actions described above, the linkages into Oregon and Idaho may benefit from specific attention to the impacts of renewable energy. Ongoing wind farm development is currently occurring in some areas, for example just south of the Columbia River Gorge, in the Southern Linkage Zone (Fig. 4.3). Collaboration with the renewable energy industry in Washington and Oregon will likely be vital to either avoid conflicts or to identify solutions to the conflicting needs of energy development and habitat quality and connectivity for some wildlife species.

Restore and expand key linkages that may be degraded or unlikely to be resilient to environmental change. It is important to recognize that this analysis is a reflection of the existing distribution of native habitat, which is not a representative subset of the types of habitat that historically dominated the ecoregion. Areas with deep soils, particularly in areas with higher rainfall or with access to water, were selectively converted to other land uses, mainly agriculture.

As a result, our vision for a connected landscape may fall short for species particularly dependent upon conditions seriously under-represented across the current landscape, such as the Columbia Basin pygmy rabbit (*Brachylagus idahoensis*), which is dependent upon big sagebrush (*Artemisia tridentata*; WDFW 1995), the dominant shrub in deep-soiled communities across much of the Columbia Plateau in Washington (Daubenmire 1988). As a consequence, habitat restoration may be a critical tool to improve conditions that might be important for some species in some locations. We suggest three steps that entities working to enhance connectivity through restoration in a particular area might consider: (1) validate these models by evaluating to what extent these linkages are currently facilitating movement for the species and processes of interest, and build from these to estimate what improvements and expansions might be needed to ensure the persistence and function of these linkages; (2) engage with landowners, lessees of public lands, private industry, developers or other interested stakeholders in a fine-scale linkage design effort, with a focus on achieving the necessary improvements to these linkages in a way that is compatible with other resource uses, interests and values; and (3) collaborate with these interested stakeholders to bring about the necessary improvements and evaluate their effectiveness.

Test innovative approaches to simultaneously achieve production and conservation objectives, based on increased understanding of the connectivity value of agricultural lands. The Mansfield Plateau is emphasized as a part of the Backbone where the landscape integrity and focal species approaches trace distinctly different paths. This is partly due to a narrow strip of land with low human modification forming a landscape integrity core area on the west side of Banks Lake and providing connectivity via a different route between Moses Coulee and more northerly core areas. There is, however, a loose matrix of scattered patches of habitat related to the rocky substrate left from the retreating glaciers (Okanogan lobe of the Cordilleran ice sheet). Since the late 1980s, this loose matrix has been supplemented with the Conservation Reserve Program (CRP), a voluntary federal program through which landowners receive annual rental payments and cost-share assistance to establish long-term, resource-conserving vegetation cover on eligible farmland. This has dramatically improved habitat conditions and connectivity for both grouse species, white-tailed jackrabbits, Washington ground squirrels, rattlesnakes, and mule deer. For example, this area supports the continued persistence of the largest Greater Sage-Grouse population in the state, despite the predictions of regional models that there is insufficient habitat to support it (See Appendix A.2). These results suggest that the Mansfield Plateau, though changed by human activities, may still be providing habitat and connectivity for an array of species, and that this functionality may be due in large part to practices such as CRP. Therefore we propose that next steps include validating the models across the Mansfield Plateau and learning from this landscape how these human-dominated lands contribute to functional connectivity. A following step to consider is to use this understanding to work with private and public partners with vested interests in the area to maintain and, if needed, improve this functionality while continuing to achieve other resource use objectives. The lessons learned through these initial steps may provide opportunity for public/private partnerships to conserve connectivity in other areas across the Columbia Plateau.

Integrate conservation of connectivity for terrestrial vertebrates with conservation of aquatic systems. Water—including the quantity, quality, and timing of its availability—is an important economic driver in the region, with agriculture being the dominant use of this resource. We encourage collaboration among resource users, conservation entities, and regulatory agencies to integrate aquatic conservation efforts with those targeting connectivity conservation.

A key strength of the connectivity analysis for the Columbia Plateau Ecoregion is that it provides information to help organizations incorporate connectivity into conservation efforts while meeting their own organizational goals and priorities. Our results lend themselves to multiple uses and ways of informing decisions that incorporate connectivity. Some users may find these recommendations directly applicable. Where these recommendations are not directly applicable, we encourage users to consider them as examples that provide guidance for how to approach the wealth of information captured in the *Washington Connected Landscape Project's* Columbia Plateau analysis to help inform decision-making.

Chapter 5. Future Work and Conclusions

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5.1. Future Work

The Connectivity Analysis for the Columbia Plateau Ecoregion follows two other products of the WHCWG's *Washington Connected Landscapes Project*, the *Statewide Analysis* (WHCWG 2010) and the *Climate-Gradient Corridors Report* (WHCWG 2011). Both publications identify future work the WHCWG is planning on carrying out, including comparing focal species and landscape integrity results to better understand how they complement each other; validating focal species models using field data; and developing a suite of climate analyses and interpretation tools to inform regional wildlife management and land-use planning decisions. Additionally, the WHCWG expects to apply the approaches and lessons learned in the Columbia Plateau Ecoregion to other areas within and around Washington. In the Columbia Plateau, planned work includes:

LINKAGE MODEL VALIDATION

- A Greater Sage-Grouse project that is currently underway under the leadership of Washington's Department of Fish and Wildlife (WDFW). This project has three elements: (1) examination of model predictions and Greater Sage-Grouse movements using radio-telemetry data, (2) examination of model predictions and patterns of lek persistence, and (3) genetic analysis of Greater Sage-Grouse populations in Washington to relate patterns of gene flow to landscape resistance.
- Washington Department of Fish and Wildlife's Eastern Washington Mule Deer project. This project has four areas of study: (1) examination of relationships between mule deer habitat quality, body condition, and reproductive potential; (2) examination of model predictions and habitat use by mule deer using radio-telemetry data; (3) examination of model predictions and movement patterns by mule deer using radio-telemetry data; and (4) genetic analysis of mule deer populations in Washington and the application of landscape genetic analyses to relate patterns of genetic relatedness between mule deer populations to patterns of landscape resistance.
- Despite nearly three decades of work on corridors, it is still largely unknown whether or not conserving connectivity will work to promote long-term gene flow and demographic exchange across highly impacted landscapes. In a first of its kind study, researchers at Northern Arizona University have identified nearly 100 landscapes that contain de facto conservation corridors (landscape configurations that resemble conservation corridors in size and context, but which exist as a quirk of the way the landscape was developed) and plan to test conservation corridor efficacy. One of these study landscapes is the Moses Coulee–Mansfield Plateau area that is part of the Columbia Plateau's Connected Backbone. This study will provide useful baseline information on the effectiveness of arid lands linkages established in Douglas County.

FUTURE ANALYSES

- Led by The Nature Conservancy, we are developing novel tools that can be applied to the habitat and resistance models of the Columbia Plateau analysis to identify: (1) critical barriers to wildlife movement that can inform restoration priorities, (2) core areas and linkages with high centrality, whose loss could disconnect large portions of the network, and (3) “pinch points” within individual linkages, whose loss could sever an existing connection between core areas. The Washington Wildlife Habitat Connectivity Working Group (WHCWG) will use these tools to run analyses most useful to entities working on connectivity conservation in the Columbia Plateau.
- As part of our efforts to identify linkages that may improve species’ abilities to adapt to climate change, we will be (1) re-running the Climate Gradient Corridor analysis (WHCWG 2011) using the ecoregional-scale Columbia Plateau landscape integrity network, (2) synthesizing the statewide and Columbia Plateau Climate Gradient Corridor networks with focal species networks and other relevant layers, and (3) developing interpretation materials to help guide implementation of these new products. These climate change related portions of the WHCWG’s work are being led by researchers at the University of Washington.

IMPLEMENTATION

- The Arid Lands Initiative will use our results to inform priority areas for implementing conservation strategies directed at “*conserving and restoring a viable, well-connected system of eastern Washington’s arid lands and related freshwater habitats, sustaining native plant and animal communities, and supporting compatible local economies and communities*.”

5.2. Conclusions

The goal of the Connectivity Analysis of the Columbia Plateau Ecoregion was to identify the most important areas for maintaining and enhancing wildlife habitat connectivity across the ecoregion. We achieved this goal through a landscape modeling effort that produced connectivity networks for 11 focal species—selected to represent the main vegetation types in the Columbia Plateau—and a composite landscape integrity network based on four models that differed in the relationship between landscape integrity and resistance to movement of species or processes (such as fire or seed dispersal). The main highlights of the Connectivity Analysis of the Columbia Plateau are:

- This ecoregional analysis confirms and refines the general findings of the statewide connectivity analysis, bringing them a step closer to directly informing on-the-ground efforts to conserve connectivity, by providing information to prioritize regions most important for maintaining and enhancing connectivity across the ecoregion. This replication and refinement allows us to articulate a vision for a connected landscape with confidence and to highlight particular areas in need of specific attention.
- Our results identify areas that play an important role in keeping arid lands in Washington connected. The convergence of results from the focal species and landscape integrity

approaches suggest that the identification of these important connectivity areas is robust to the underlying assumptions of the analysis.

- Building from these important connectivity areas, we articulate a vision for a connected landscape across Washington's arid lands. This vision includes two broad regions—the Connected Backbone and the Braided Scablands Swath—and critical complex linkage zones that connect these regions to one another and to neighboring jurisdictions and ecoregions.
- The vision for a connected Columbia Plateau has yet to be achieved, but provides an important foundation for developing connectivity conservation strategies in the Columbia Plateau Ecoregion. Though the focus of this analysis is based on current conditions, we recognize that conserving and restoring connectivity in this region may be especially important in light of a changing and uncertain climate.
- We provide some recommendations as examples of how to use these results to inform decisions targeting the conservation and restoration of habitat connectivity in the Columbia Plateau. Entities and stakeholders in particular areas are best suited to identify what actions should be implemented in pursuit of these recommendations.
- This report is not prescriptive. We encourage users interested in incorporating connectivity into their efforts to consider the wealth of information provided by this project, to determine how these results can best help them achieve their goals, objectives, and priorities.
- Users interested in directly applying these results to their local area should evaluate whether the information provided here is sufficiently detailed and validated to support informed decisions at the local scale. Where it is insufficient, users should consider collaborating with other interested stakeholders to validate the results, or to develop fine-scale linkage designs to identify specific sites in which to implement particular actions.
- We consider the focal species and landscape integrity approaches to be complementary. As stated above, the general similarity in spatial patterns resulting from these approaches suggests they are robust to differences in the underlying assumptions of each approach. In this landscape, and at this scale, the focal species networks provide a level of specificity and depth to the results that we expect will be extremely useful not only to entities interested in conservation of these particular species, but more broadly to those interested in species with similar habitat needs and movement capabilities. We recognize, however, that focal species analyses are both time- and data-intensive, and that entities interested in understanding connectivity in other landscapes and at other scales may not have the necessary resources available. The WHCWG, through this effort and the statewide analysis (WHCWG 2010), are providing numerous datasets for fruitful comparison between these approaches at two different scales. Such comparisons are critical to determine under what conditions the less resource-intensive landscape integrity approach could provide sufficient specificity on its own to help guide connectivity conservation decisions.
- A few notable differences between focal species and landscape integrity results allow us to pose important questions about the connectivity functions provided by mixed native and agricultural areas. Field validation of the focal species models and efforts to better

understand the value of agricultural landscapes may become the foundation for innovative approaches to simultaneously achieve production and conservation objectives.

We are already moving forward with further work based on the results of the Columbia Plateau analysis to validate the models, and providing these results to inform the conservation decisions that different entities are making across this landscape. We also support and encourage current and future efforts to (1) improve our understanding of the value agricultural landscapes provide for connectivity and (2) develop linkage designs where needed to guide local collaborations and action. Our over-arching goal is to provide the information needed to effectively conserve habitat connectivity so that Washingtonians can continue enjoying healthy and diverse wildlife populations in this modern world and into an ever-changing future. We expect this analysis to support the development and implementation of innovative strategies and efficient and effective efforts to help fulfill the vision of a connected Columbia Plateau in Washington.

Acronyms

ALI — Arid Lands Initiative

BLM — United States Department of the Interior Bureau of Land Management

CCT — Colville Confederated Tribes

CDL — Cropland Data Layer

CNW — Conservation Northwest

CRP — Conservation Reserve Program

CWD — cost-weighted distance (See Glossary)

CWD:EUC — Cost-weighted distance to Euclidean distance ratio (See Glossary)

CWU — Central Washington University

DNR — Washington Department of Natural Resources

EAS/MSA — Environmental Assessment Services/Mission Support Alliance

EVT — Landfire Existing Vegetation

GAP — Gap Analysis Program

GIS — Geographic Information System

GOV — Governor's Executive Policy Office

HCA — habitat concentration area (See Glossary)

IDFG — Idaho Fish and Game

ISU — Idaho State University

LCC — least-cost corridor (See Glossary)

LCD — least-cost distance (See Glossary)

LCP — least-cost path (See Glossary)

LI — landscape integrity

MAHV — minimum average habitat value

NAU — Northern Arizona University

NCASI — National Council for Air and Stream Improvement

NED — National Elevation Dataset

NGO — Non Governmental Organization

NHD — National Hydrography Dataset

NLCC — normalized least-cost corridor, (See Glossary)

NPS — National Parks Service

NRCS — Natural Resources Conservation Service

NVCS — National Vegetation Classification Standard

NWR — National Wildlife Refuge

NWWC — Northwest Wildlife Consultants

OSU — Oregon State University

ODFW — Oregon Department of Fish and Wildlife

SGCN — Species of Greatest Conservation Need

SLWA — Swanson Lakes Wildlife Area

SP — Shrubsteppe Partnership

SSURGO — Soil Survey Geographic Database

STATSGO — U.S. General Soil Map

TNC — The Nature Conservancy

UI — University of Idaho

UIL — University of Illinois

USDA-NASS — United States Department of Agriculture's National Agricultural Statistical Service

USFS — United States Forest Service

USFS-PNW — United States Forest Service Pacific Northwest Research Station

USFWS — United States Fish and Wildlife Service

USGS — United States Geological Survey

UW — University of Washington

WCSI — Washington Conservation Science Institute

WDFW — Washington Department of Fish and Wildlife

WHCWG — Washington Wildlife Habitat Connectivity Working Group

WHROW — Wildlife-Habitat Relationships in Oregon and Washington

WSDOT — Washington Department of Transportation

WTI — Western Transportation Institute

WWU — Western Washington University

YNW — Yakama Nation Wildlife

YTC — Yakima Training Center

Glossary

Alienation — Avoidance of an area by wildlife due to factors such as noise, harassment, human activity, etc.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape (Carroll 2010).

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 1993). Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape integrity.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Cost — See Resistance.

Cost-weighted Distance — Each cell in a raster map can be attributed with a relative cost or resistance reflecting the energetic cost, difficulty, or mortality risk of moving across that cell. In our models, resistance is determined by characteristics of each cell, such as land cover, housing density, elevation, etc. Cost-weighted distance analyses produce maps of total movement resistance accumulated as animals move away from specific HCAs or core areas.

Cost-weighted/Euclidean Distance Ratio — Ratio of cost-weighted to Euclidean distance between two habitat concentration areas or core areas. Higher ratios mean least-cost corridors are longer or have higher resistance.

Cost-weighted/Non-Weighted Path Length Ratio — Ratio of cost-weighted distance to the non-weighted least-cost path length. This is equivalent to the average per-cell resistance encountered moving along the least-cost route between two habitat concentration areas or core areas. High values indicate pathways that pass through low quality movement habitat or across barriers.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Ecoregion — Area in which climate, topography, and soil types are sufficiently uniform to support major vegetation communities with similar characteristics.

Euclidean Distance — Distance between two points as measured on a plane. In our modeling and analyses, Euclidean distances are the straight-line distances between closest points on the edges of neighboring HCAs.

Focal Species — As originally defined by Lambeck (1997), taxa targeted for management through vegetation-restoration efforts because they are the ones most influenced by threatening processes. For example, focal species might be the most area-sensitive, dispersal-limited, resource-limited, and ecological-process limited in a landscape. The concept is to manage a landscape for a suite of focal species, each of which is thought to be sensitive to a particular threatening process (Lindenmayer et al. 2002). We applied this definition to the context of connectivity conservation by highlighting species sensitive to habitat modification and developing selection criteria for focal species that considered how strongly species represented different threat classes, the scale of typical dispersal movements, and the effects of habitat modification on dispersal. We also sought to select a suite of focal species that represented all major vegetation types in the analysis area, and that had complementary characteristics.

Fracture Zone — An area of reduced permeability between HCAs or core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Concentration Area (HCA) — Habitat areas that are expected or known to be important for focal species based on actual survey information or habitat association modeling. We used HCAs as locations between which linkage analyses were conducted to identify important connectivity pathways. Not to be confused with "source habitat" terminology used when modeling population dynamics (i.e., habitat in which local reproductive success exceeds local mortality).

Habitat Connectivity — See Connectivity.

Habitat Value Model — A raster GIS grid with cell values depicting the relative habitat suitability for a particular species on a scale of 0 to 1, with 1 being ideal habitat. Habitat value models are derived by individually assigning one or more raster GIS data layers a habitat value score on a scale of 0 to 1 and then multiplying the values for all layers together.

Landscape Connectivity — See Connectivity.

Landscape Integrity — A relative measure of the level of human-caused change on a landscape that combines information on land conversion, human population density, and road use and density. We used landscape integrity-based models to map large, intact core areas and natural linkages between them. Areas that have low levels of human modification and are in relatively natural or semi-natural condition have high relative landscape integrity scores and low resistances in our models.

Least-cost Corridor (LCC) — A raster map depicting modeled movement routes of varying difficulty that connect two HCAs or core areas. Least-cost corridors are produced by first mapping the cost-weighted distance (CWD) from each HCA to every grid cell. The CWD layers for a pair of HCAs are then added to identify the least-cost corridor (the path between two HCAs or core areas with the lowest possible travel cost; i.e., the easiest or most efficient path). Each grid cell in the resulting map represents the minimum possible cost accumulated by an animal moving from one HCA to the other while passing through that grid cell.

Least-cost Distance (LCD) — The minimum cost-weighted distance an animal can accumulate moving from one HCA or core area to another. This is the total resistance accumulated moving along the least-cost corridor.

Linkage — See Linkage Zone.

Linkage Design — Detailed, site-specific plan meant to conserve connectivity in a linkage zone. Typically identifies a continuous swath of land which should, if conserved, maintain or restore the ability of wildlife and ecological processes to move between HCAs or core areas.

Linkage Dweller — A species that disperses between HCAs over the course of multiple generations by living and reproducing within a linkage zone.

Linkage Mapping Cutoff — Cost-weighted distance value that allows inclusion of all movement paths that are similar, in cost-weighted distance, to the least-cost corridor connecting two HCAs.

Linkage Network — System of habitats and areas important for connecting them. For our project, linkage networks represent the area encompassed by the combination of all habitat concentration areas and modeled linkages for a focal species (or core areas and modeled linkages for landscape integrity models). Composite linkage networks for groups of focal species (e.g., connectivity guilds) can be formed as the union of all species-specific linkage networks. Similarly, for landscape integrity modeling, composite linkage networks can be formed by the union of linkage networks representing different levels of sensitivity to human modification.

Linkage Zone — Area identified as important for maintaining movement opportunities for organisms or ecological processes (e.g., for animals to move to find food, shelter, or access to mates). In our report, these are areas identified by our models as important for movement between HCAs or core areas.

Metapopulation — A group of spatially separated populations of the same species, typically linked by dispersal of individuals from one population to another (Levins 1969).

Movement Corridor — See Corridor.

Moving Window — Spatial analysis procedure in which a function (e.g., proportion, sum) is applied to a collection of grid cells neighboring a focus cell in a raster map. The value of the function is written to an output raster at the spatial location of the focus cell. The procedure is typically implemented across all rows and columns of a raster using a circular or square neighborhood centered on each focus cell.

Non-weighted Least-Cost Path Length — Length of the least-cost movement route, without accounting for cost.

Normalized least-cost corridor (NLCC) — Raster map showing modeled movement routes of varying difficulty connecting two HCAs or core areas. Similar to least-cost corridors, except that all grid cells have scores relative to the best (least-cost) path. NLCCs range in value from 0 (the least-cost corridor) on up; in our linkage maps, NLCCs are displayed according to the relative resistances of routes within each linkage, using a color ramp. The color ramp varies from yellow, representing low resistance routes (routes similar in cumulative resistance to the least-cost corridor), to blue, representing high resistance routes. Note that the color scheme provides an indication of relative cumulative resistance of different movement routes within a linkage, rather than between linkages. That is, yellow is best for that linkage, but yellow in one linkage cannot be compared with yellow in another. To compare between linkages, users must refer to linkage statistics in Appendix B.

Permeability — The opposite of resistance or travel cost; grid cells with lower permeability have higher resistance. A perfectly permeable raster grid cell would have a resistance of 1 in our resistance maps. Also refers to the ability of an entire landscape to support movement of plants, animals, or processes.

Pinch Point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Raster — GIS spatial data structure containing cells arranged in a two-dimensional array or grid with each cell containing a value.

Resistance — Resistance of a raster grid cell represents its suitability for movement, with increasing values corresponding to increasing movement difficulty. A resistance of 1 is equivalent to optimal movement habitat for a species. Conceptually, for focal species, we defined the resistance contributed by each landscape feature as the number of additional grid cells of ideal habitat a given species would move through to avoid one grid cell of the feature being considered. For each landscape feature, we estimated the additional resistance to movement imposed by the feature relative to “ideal” habitat, ranging from zero for ideal habitat to 10,000 for complete barriers. The final resistance layer for each species was then derived by summing the resistances from each input layer and adding one (to account for Euclidean distance). In landscape integrity models, resistance represents the relative reluctance of organisms to move across human-changed landscapes. Higher resistance values represent conditions that result in higher avoidance of human-altered landscapes. Landscape integrity resistance values were scaled and calibrated to the resistance values used in focal species models. Synonyms are cost and friction. Antonym is permeability.

Resistance Surface — A raster grid of resistance values.

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Appendices

Appendix A.1. Connectivity for Sharp-tailed Grouse in the Columbia Plateau

Appendix A.2. Connectivity for Greater-Sage Grouse in the Columbia Plateau

Appendix A.3. Connectivity for Black-tailed Jackrabbit in the Columbia Plateau

Appendix A.4. Connectivity for White-tailed Jackrabbit in the Columbia Plateau

Appendix A.5. Connectivity for Townsend's Ground Squirrel in the Columbia Plateau

Appendix A.6. Connectivity for Washington Ground Squirrel in the Columbia Plateau

Appendix A.7. Connectivity for Least Chipmunk in the Columbia Plateau

Appendix A.8. Connectivity for Mule Deer in the Columbia Plateau

Appendix A.9. Connectivity for Western Rattlesnake in the Columbia Plateau

Appendix A.10. Connectivity for Beaver in the Columbia Plateau

Appendix A.11. Connectivity for Tiger Salamander in the Columbia Plateau

Appendix B. Focal Species and Landscape Integrity Habitat Concentration Areas, Core Areas, and Linkage Data

Appendix C. Focal Species and Landscape Integrity Model Values

Appendix D. GIS Data Layer Development and Data Sources

Appendix E. Focal Species Selection

Focal species of the Columbia Plateau Ecoregion: LEFT COLUMN black-tailed jackrabbit (Michael A. Schroeder), Western rattlesnake (James Rosindell), Townsend's ground squirrel (Ryan Shaw), white-tailed jackrabbit (Doug Backlund), CENTER COLUMN Sharp-Tailed Grouse (Gregg Thompson), tiger salamander (Gary M. Stolz), Washington ground squirrel (Rich Finger), least chipmunk (Kelly McAllister), RIGHT COLUMN beaver (Ginger Holser), Greater-Sage Grouse (R. E. Bennetts), mule deer (Woodrow Myers)