# Chapter 13. Network Centrality, Pinch-Points, and Barriers and Restoration Opportunities: Focal Species Composite Maps

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This chapter is an addendum to the *Washington Connected Landscapes Project: Analysis of the Columbia Plateau Ecoregion* (WHCWG 2012). It includes supplemental maps that, by combining information from the connectivity maps for the 11 focal species, can help prioritize and implement conservation actions that benefit multiple species or ecological systems. These composite maps build on the synthesis of focal species and landscape integrity results of the *Analysis of the Columbia Plateau Ecoregion* (Fig. 13.1; see Chapter 3 and Appendix C, WHCWG 2012, available from http://waconnected.org).

*See page vi for photo credits*

## Composite Connectivity Maps

We focus on combining results from the 11 focal species (See Chapters 2–12), guided by two main questions: How can we identify connectivity areas important for multiple focal species, given the current trend towards multiple-species habitat management? How can the different types of information provided by centrality, pinch-point, and barrier analyses be combined to better inform decisions on maintaining and improving habitat connectivity?

To answer the first question on ways to identify connectivity areas important for multiple focal species, we created maps showing (1) ***composite centrality*** for habitat concentration areas (Fig. 13.2) and linkages (Fig. 13.3), developed by normalizing and summing centrality values across species; (2) ***composite linkage pinch-points***, developed by summing linkage pinch-point scores across species (Fig. 13.4), and also by tallying how many species have high pinch-point scores in a given area (Fig. 13.5); and (3) ***composite barriers***, which were similarly developed by summing barrier scores across species (Fig. 13.6) and also by tallying the number of species with high barrier scores in a given area (Fig. 13.7).

To answer the second question on how best to combine these different analyses to inform decisions, we created maps illustrating how these modeling products can be combined to support conservation decisions (e.g., those described in the conceptual flowchart shown in Fig. 13.8) given a user's specific objectives and criteria for defining the importance of a site. These ***synthesis*** maps (Figs. 13.9–13.12) highlight examples on the landscape where conservation and restoration efforts may be high priorities across multiple focal species. We also provide examples of how these maps can inform decision-making processes with different objectives (Figs. 13.8, 13.13, and 13.14).

Details on how these maps were produced can be found in the Methods section at the end of this chapter and in the sidebar text of Figures 13.2–13.7.

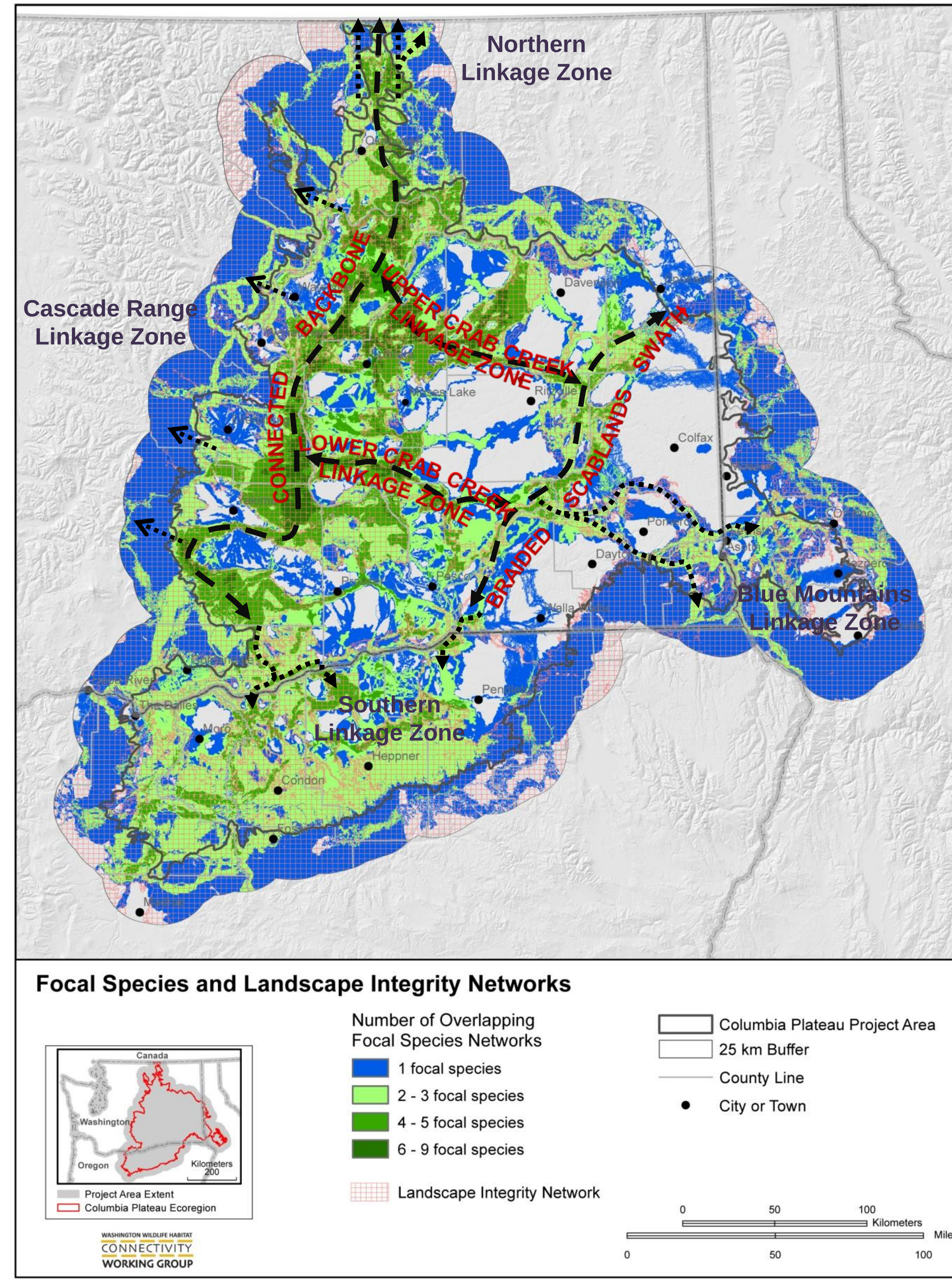
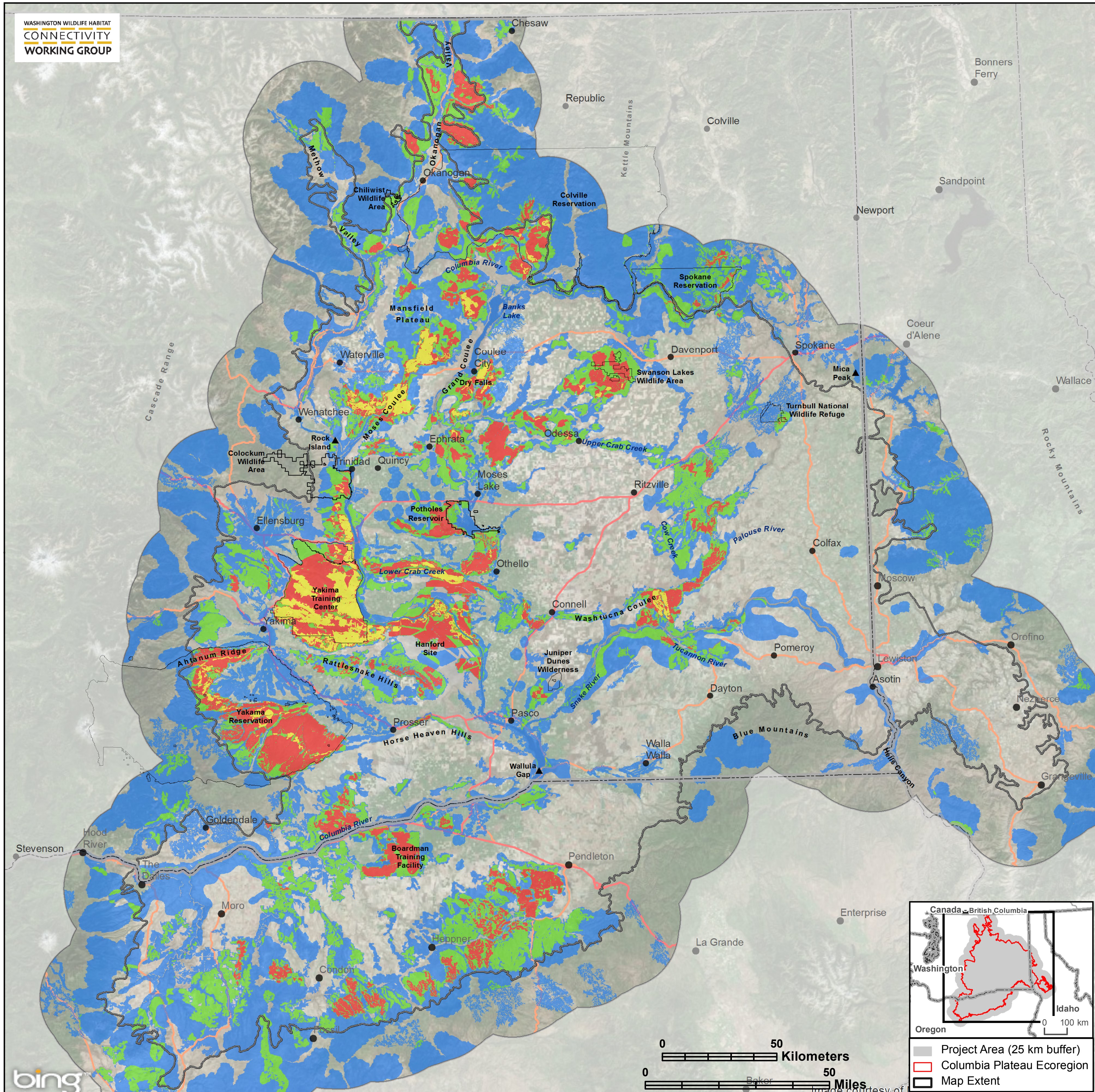



**Figure 13.1.** A vision for a connected Columbia Plateau in Washington: composite of focal species and landscape integrity linkage networks for the Columbia Plateau Ecoregion (from WHCWG 2012). Prominent connectivity patterns within the Columbia Plateau are indicated by large dashes, and connections to areas outside of the Columbia Plateau are indicated with short dashes.




# Figure 13.2. Composite of Habitat Concentration Area (HCA) Centrality.

***WHAT IS THE COMPOSITE OF HCA CENTRALITY?***

Habitat concentration area (HCA) centrality is a measure of how important particular HCAs are for keeping a network connected. HCA centrality was evaluated for each species (Chapters 2–12) using the Linkage Mapper Toolbox (see more at http://www.circuitscape.org/linkagemapper). HCA centrality scores were then summed across the 11 focal species to determine the composite HCA centrality score.

***WHY IS CENTRALITY IMPORTANT?***

Each species' connectivity network is comprised of habitat concentration areas (HCAs) and linkages that enable movement of wildlife between them. HCAs where centrality is high are important for maintaining a connected network, and can be thought of as "gatekeepers" for connectivity. For example, if an HCA with high centrality is degraded or lost, the network might be severed into separate, smaller sub-networks.

***WHAT DOES THE COMPOSITE OF HCA CENTRALITY TELL US?***

Areas with high *composite* HCA centrality are places on the landscape that represent either highly central HCAs for one or two species or areas that are part of moderate to highly central HCAs for multiple focal species. This composite map of HCA centrality therefore highlights areas that can be thought of as "gatekeepers" for connectivity for one or more focal species, reflecting important areas for keeping the underlying ecological systems connected.

***HOW IS COMPOSITE HCA CENTRALITY DEPICTED ON THIS MAP?***

In this map, HCA centrality scores are summed across species. Individual species centrality scores were first normalized in a 100 to 200 range and summed results were ranked as follows: summed values above 600 = Very High (areas depicted yellow), values 400 to 600 = High (areas depicted red), values 200 to 400 = Medium (areas depicted green), and values less than 200 = Low (areas depicted blue).

***QUESTIONS AND DECISIONS THIS MAP HELPS INFORM***

- Where are important areas on the landscape for maintaining connectivity for multiple species?
- Where should further disturbance to connectivity be avoided?
- Which areas on the landscape might be important for multiple species recovery efforts (e.g., sites for translocations and augmentations of populations)?

*Notes: (1) This map depicts modeled HCAs (see more at http://waconnected.org). While we've used the best available data layers, field review is necessary to ensure the HCAs are viable. (2) We included areas in Oregon and Idaho to help understand transboundary connectivity; however, our products may be less accurate in these adjoining areas.*

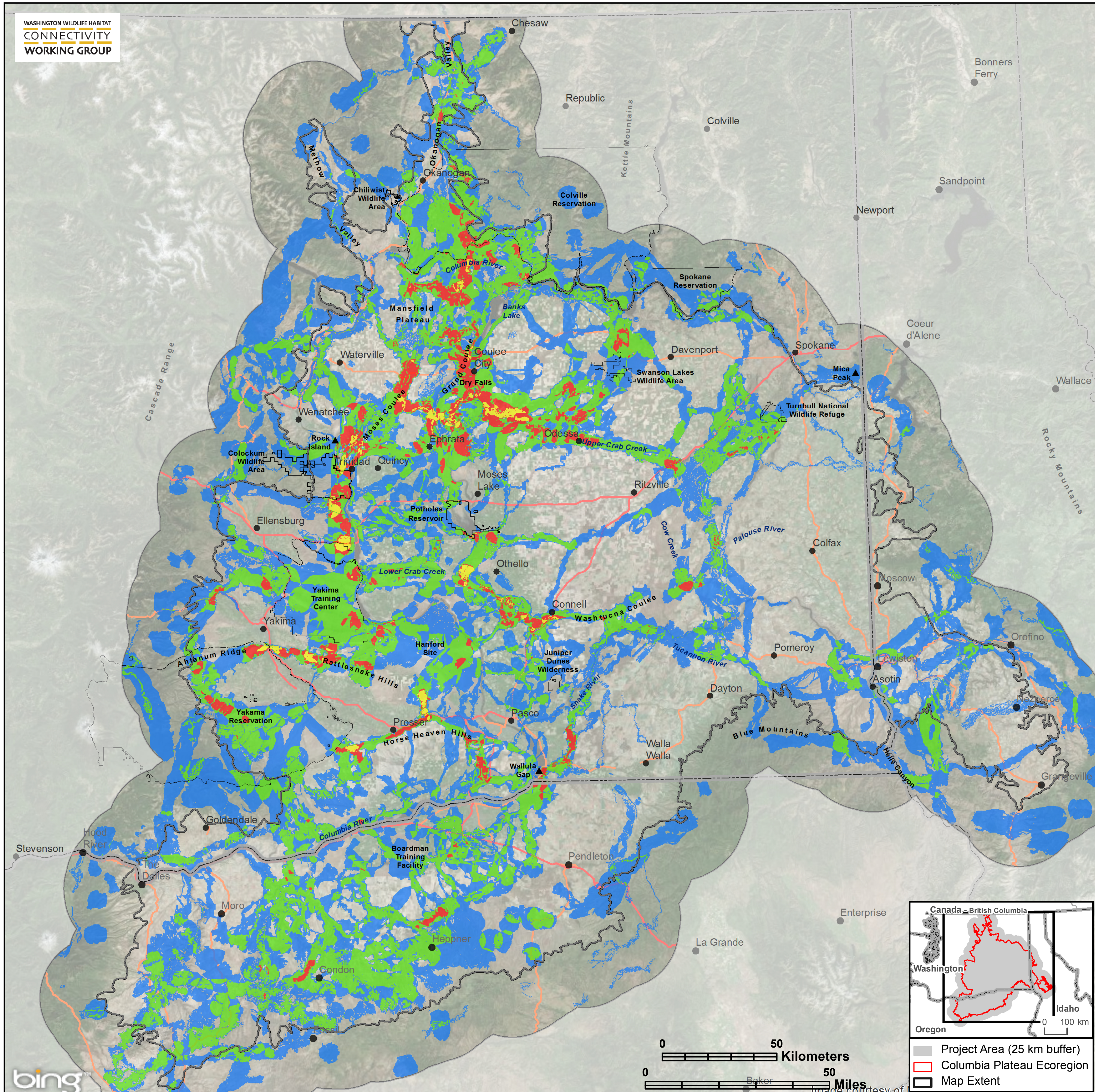
**Cumulative Rating**

Very High | Medium
High | Low

**Boundaries and Population Centers**

- Columbia Plateau Project Area
- Columbia Plateau Project Area 25 km Buffer
- State or Provincial Border
- Freeway
- Major Highway
- City or Town
- Important Site

**The data portrayed on this map are subject to use constraints as described in WHCWG metadata documentation.**




# Figure 13.3. Composite of Linkage Centrality.

***WHAT IS THE COMPOSITE OF LINKAGE CENTRALITY?***

Linkage centrality is a measure of how important particular linkages are for keeping a network connected. Linkage centrality was evaluated for each species (Chapters 2–12) using the Linkage Mapper Toolbox (see more at http://www.circuitscape.org/linkagemapper). Linkage centrality scores were then summed across the 11 focal species to determine the composite linkage centrality score.

***WHY IS CENTRALITY IMPORTANT?***

Each species' connectivity network is comprised of habitat concentration areas (HCAs) and linkages that enable movement of wildlife between them. Linkages where centrality is high are important for keeping a network connected, and can be thought of as "gatekeepers" for connectivity. For example, if a linkage with high centrality is severed, a species may lose an important "highway" for movement across the ecoregion.

***WHAT DOES THE COMPOSITE OF LINKAGE CENTRALITY TELL US?***

Areas with high *composite* linkage centrality are places on the landscape that are part of highly central linkages for multiple focal species or areas that are part of moderate to highly central linkages for multiple focal species. This composite map of linkage centrality therefore highlights areas that are expected to be connectivity "gatekeepers" for multiple focal species, reflecting important areas for keeping the underlying ecological systems connected.

***HOW IS COMPOSITE LINKAGE CENTRALITY DEPICTED ON THIS MAP?***

In this map, linkage centrality scores are summed across species. Individual species centrality scores were first normalized in a 100 to 200 range and summed results were ranked as follows: summed values above 600 = Very High (areas depicted yellow), values 400 to 600 = High (areas depicted red), values 200 to 400 = Medium (areas depicted green), and values less than 200 = Low (areas depicted blue).

***QUESTIONS AND DECISIONS THIS MAP HELPS INFORM***

- Where are important areas on the landscape for maintaining connectivity for multiple species?
- Where should further disturbance to connectivity be avoided?
- Which areas on the landscape might be most important for multiple species recovery efforts?

*Notes: (1) This map depicts modeled linkages (see more at http://waconnected.org). While we've used the best available data layers, field review is necessary to ensure the linkages are viable. (2) We included areas in Oregon and Idaho to help understand transboundary connectivity; however, our products may be less accurate in these adjoining areas.*

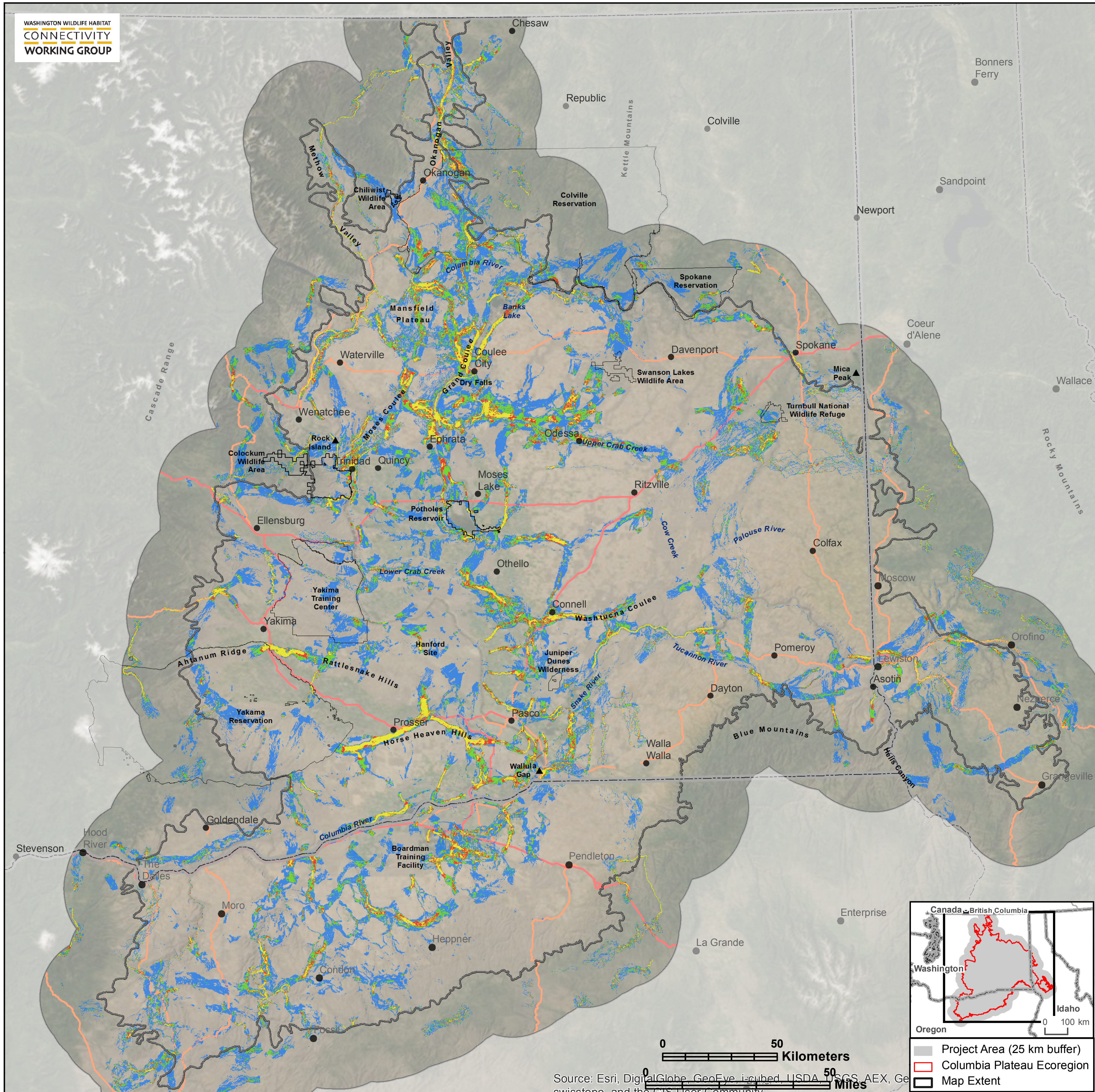
**Cumulative Rating**

Very High
Medium
High
Low

**Boundaries and Population Centers**

Columbia Plateau Project Area
Columbia Plateau Project Area 25 km Buffer
State or Provincial Border
Freeway
Major Highway
City or Town
Important Site

**The data portrayed on this map are subject to use constraints as described in WHCWG metadata documentation.**




# Figure 13.4. Composite of Linkage Pinch-Points: Cumulative Constraints.

***WHAT IS THE COMPOSITE OF LINKAGE PINCH-POINTS?***

Pinch-points are "bottlenecks" where animal movement is funneled within linkages (McRae et al. 2008; McRae 2012c). This occurs when the area around the pinch-point is significantly more resistant to animal movement than the pinch-point itself, and there are no alternative pathways for animals to move between those particular HCAs. Pinch-point modeling methods are based on electrical circuit theory. If movement is represented by an electric current running among HCAs, the flow of current will concentrate in some locations, or be dispersed in others, depending on the landscape characteristics. Locations where current flow is concentrated are constrictions within linkages, and represent areas where the impact of future habitat loss or degradation is expected to be greatest (see more at http://www.circuitscape.org/linkagemapper). Pinch-points can be the result of both natural and human-made landscape features.

Current flow is quantified with a pinch-point score; the greater the flow moving through a particular location the higher the score. For this map the *composite* of linkage pinch-points was developed by *summing the top 50% of each species pinch-point scores* across the 11 focal species. Those composite scores representing the top 50% for each species are included, while those in the lower 50% (these have current flow values less than 0.02) are not.

***WHY ARE PINCH-POINTS IMPORTANT?***

Linkage pinch-points indicate potential priority areas for connectivity conservation, as loss or degradation of a small amount of habitat could disproportionately compromise connectivity due to a lack of alternative movement routes. Loss or degradation of habitat in these areas may sever movement routes, or impact other important movement needs.

***WHAT DOES THE COMPOSITE OF LINKAGE PINCH-POINTS TELL US?***

Composite linkage pinch-points developed by summing the pinch-point scores across all focal species highlight areas that either act as strong pinch-points for a few focal species, or moderate to strong pinch-points for several species.

***HOW ARE COMPOSITE LINKAGE PINCH-POINTS DEPICTED ON THIS MAP?***

This map displays linkage pinch-point scores (i.e., current flow values) summed across species. Summed pinch-point scores are broken down into the following categories: Very High (current flow values greater than 0.08, depicted yellow), High (0.06 to 0.08, depicted red), Medium (0.04 to 0.06, depicted green), and Low (0.02 to 0.04, depicted blue).

***QUESTIONS AND DECISIONS THIS MAP HELPS INFORM***

- Where along linkages is potential movement highly or moderately constrained?
- Are there areas where alternative movement routes may not be available?

*Notes: (1) This map depicts modeled linkage pinch-points (see more at http://waconnected.org). While we've used the best available data layers, field review is necessary to ensure the linkages are viable. (2) We included areas in Oregon and Idaho to help understand transboundary connectivity; however, our products may be less accurate in these adjoining areas.*

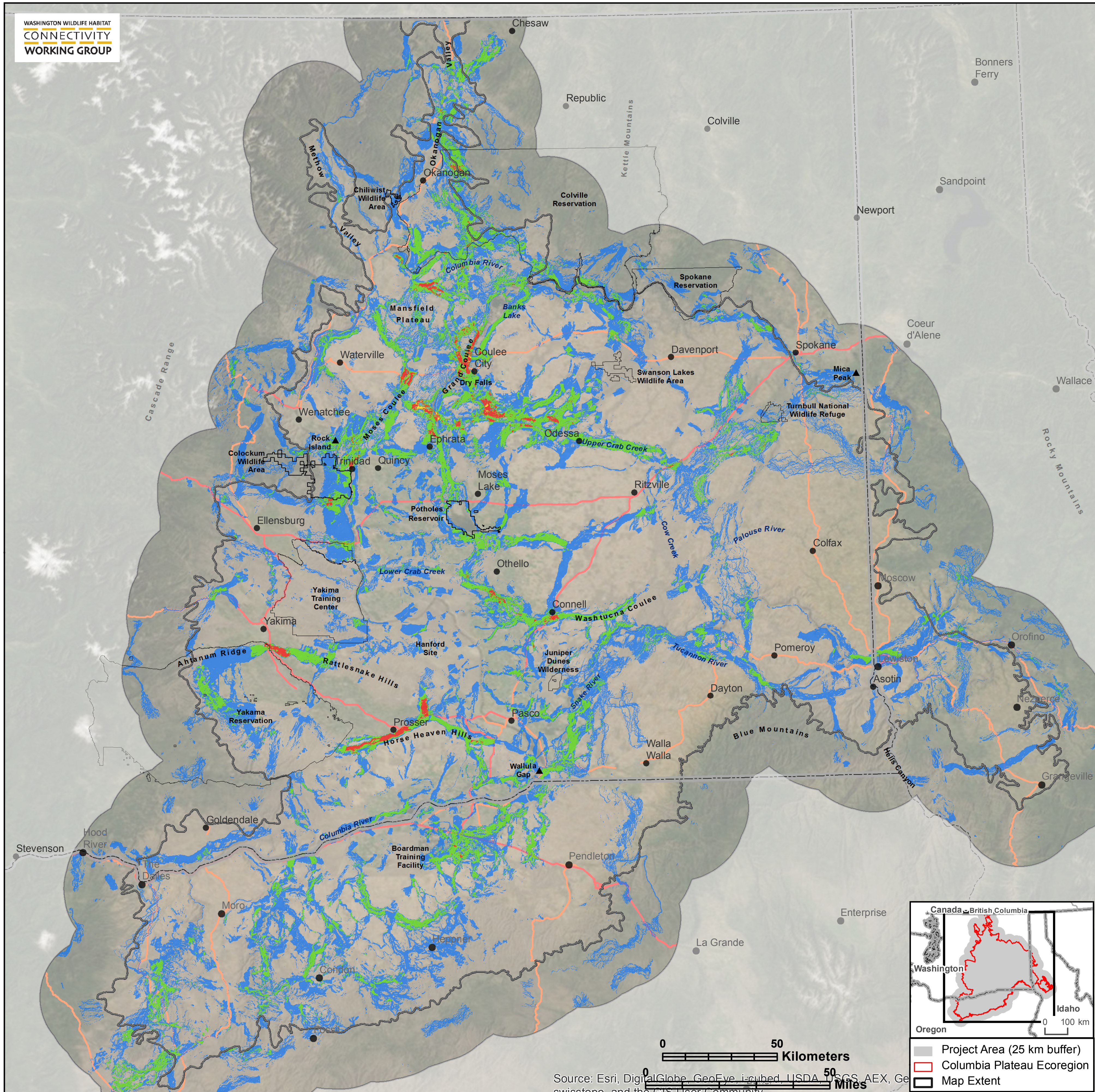
**Constraint Rating**

- Very High
- Medium
- High
- Low

**Boundaries and Population Centers**

- Columbia Plateau Project Area
- Columbia Plateau Project Area 25 km Buffer
- State or Provincial Border
- Freeway
- Major Highway
- City or Town
- Important Site

**The data portrayed on this map are subject to use constraints as described in WHCWG metadata documentation.**




# Figure 13.5. Composite of Linkage Pinch-Points: Number of Species.

***WHAT IS THE COMPOSITE OF LINKAGE PINCH-POINTS?***

Pinch-points are "bottlenecks" where animal movement is funneled within linkages (McRae et al. 2008; McRae 2012c). This occurs when the area around the pinch-point is significantly more resistant to animal movement than the pinch-point itself, and there are no alternative pathways for animals to move between those particular HCAs. Pinch-points can be the result of both natural and human-made landscape features.

Pinch-point modeling methods are based on electrical circuit theory. If movement is represented by an electric current running among HCAs, the flow of current will concentrate in some locations, or be dispersed in others, depending on the landscape characteristics. Locations where current flow is concentrated are constrictions within linkages, and represent areas where the impact of future habitat loss or degradation is expected to be greatest (see more at http://www.circuitscape.org/linkagemapper).

Current flow is quantified with a pinch-point score; the greater the flow moving through a particular location, the higher the score. For this map the *composite* of linkage pinch-points was developed by counting the *number of focal species* that had pinch-point scores in the top 50% of the species' values at each location.

***WHAT DOES THE COMPOSITE OF LINKAGE PINCH-POINTS TELL US?***

Composite linkage pinch-points based on the number of species highlights areas where movement of multiple species is constrained at a pinch-point (using species' top 50% of pinch-point score values).

***HOW ARE COMPOSITE LINKAGE PINCH-POINTS DEPICTED ON THIS MAP?***

Results are depicted on the map as follows: areas with 6 to 8 species (depicted yellow), 4 or 5 species (depicted red), 2 or 3 species (depicted green), and 1 species (depicted blue). No location had pinch-points for more than 8 species.

***QUESTIONS AND DECISIONS THIS MAP HELPS INFORM***

- Where across the landscape is potential movement along linkages highly constrained for multiple species?
- Are there areas where alternative movement routes may not be available for multiple species?

*Notes: (1) This map depicts modeled linkage pinch-points (see more at http://waconnected.org). While we've used the best available data layers, field review is necessary to ensure the linkages are viable. (2) We included areas in Oregon and Idaho to help understand transboundary connectivity; however, our products may be less accurate in these adjoining areas.*

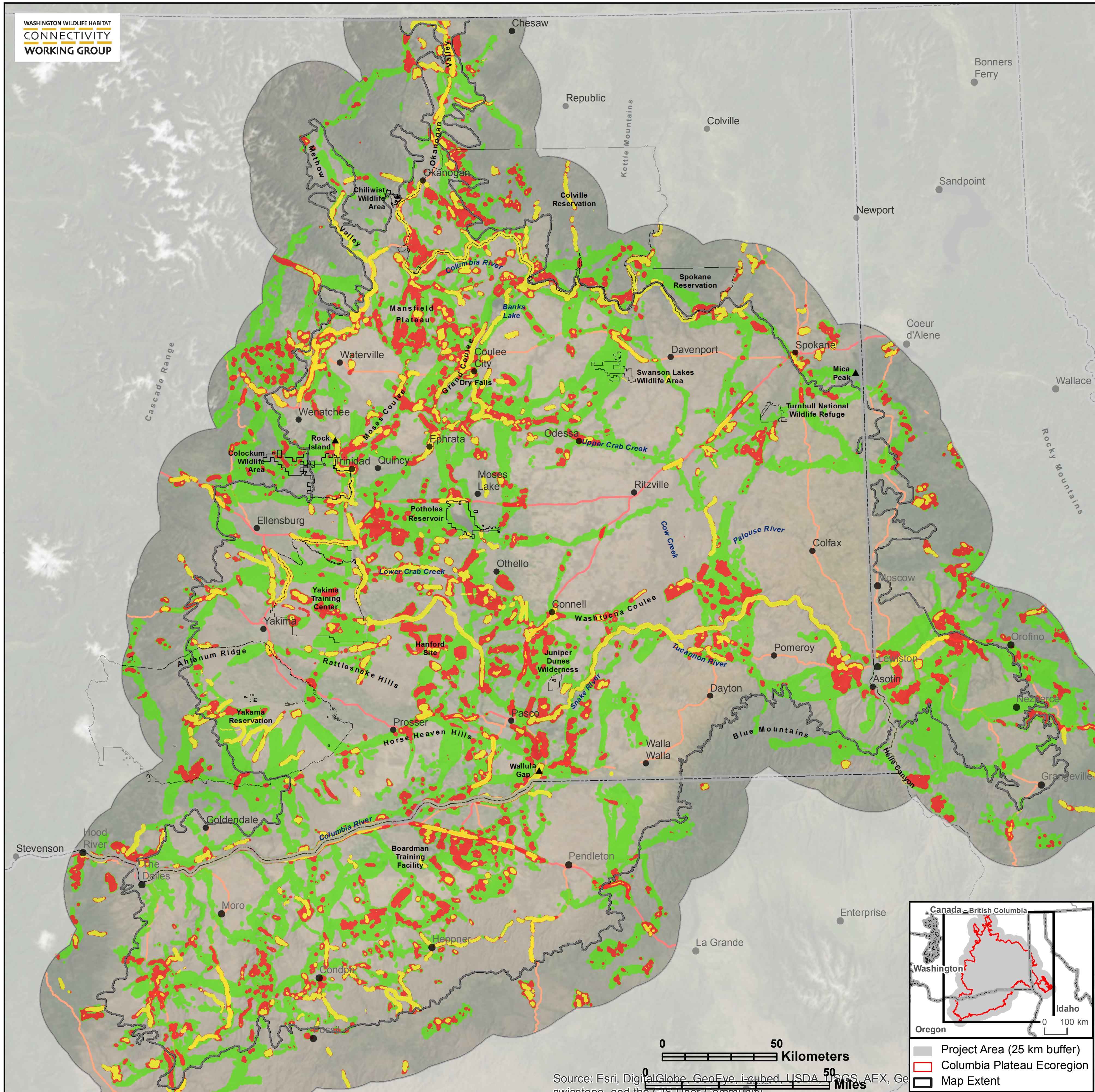
**Number of Species at the Pinch-Point**

6 - 8
2 - 3
4 - 5
1

**Boundaries and Population Centers**

Columbia Plateau Project Area
Freeway
Columbia Plateau Project Area 25 km Buffer
Major Highway
State or Provincial Border
City or Town
Important Site

**The data portrayed on this map are subject to use constraints as described in WHCWG metadata documentation.**




# Figure 13.6. Composite of Barriers and Restoration Opportunities: Cumulative Impact.

***WHAT IS THE COMPOSITE OF BARRIERS AND RESTORATION OPPORTUNITIES?***

Barriers are areas where landscape features impede animal movement between habitat concentration areas (HCAs). Barriers are identified by comparing the least-cost paths under present conditions to paths that would be created if particular areas were restored, thereby reducing resistance to movement (McRae et al. 2012; McRae 2012a). Through this comparison, barriers are identified and ranked based on the extent to which restoring them would improve connectivity (see more at http://www.circuitscape.org/linkagemapper). Barriers may be partial (e.g., suboptimal habitat types) or complete (e.g., an urban area), and they may be natural (e.g., rivers, cliffs) or human-made (e.g., urban areas, highways, some types of agriculture). It is important to note that not all barriers are restorable.

For this composite map barriers are identified and ranked by *adding* barrier impact/restoration improvement scores across the 11 focal species. Highlighted areas show where barriers either strongly impede the movement of one or a few species, or moderately to strongly impede movement of a large number of focal species.

***HOW ARE COMPOSITE BARRIERS AND RESTORATION OPPORTUNITIES DEPICTED ON THIS MAP?***

This map shows the sum of barrier impact/restoration scores across species. Each score reflects the percent reduction in corridor resistance per hectare restored. For example, restoring 1 hectare across a barrier with a score of 1.0 would make a linkage 1% shorter measured in terms of total corridor resistance. Yellow areas reflect summed improvement scores between 1.7% and 57%, red areas between 0.4% and 1.7%, and green areas less than 0.4%. Yellow and red areas are thus places that, if restored or enhanced, may yield the greatest improvement in movement potential between HCAs for one or more species. Restoring green areas may yield moderate improvement. Note that the wide range for the Highest (yellow) category reflects the fact that we are summing scores that quantify *percent* improvement in a corridor per hectare restored. Some linkages are very short (e.g., connecting two HCAs separated only by a highway). In such cases, a barrier can have a disproportionately high *percent* improvement score, because the total cost-weighted distance of the linkage is low. Additionally, many strong barriers are not restorable (e.g., rivers). We did not want these cases to overshadow real restoration opportunities in longer corridors.

***QUESTIONS AND DECISIONS THIS MAP HELPS INFORM***

- Where will restoration efforts have the greatest effect on multi-species connectivity?

Since **all types** of barriers to movement are identified on this map, users must further evaluate the feasibility of each restoration opportunity.

*Notes: (1) This map depicts modeled linkages (see more at http://waconnected.org). While we've used the best available data layers, field review is necessary to ensure the HCAs are viable. (2) We included areas in Oregon and Idaho to help understand transboundary connectivity; however, our products may be less accurate in these adjoining areas.*

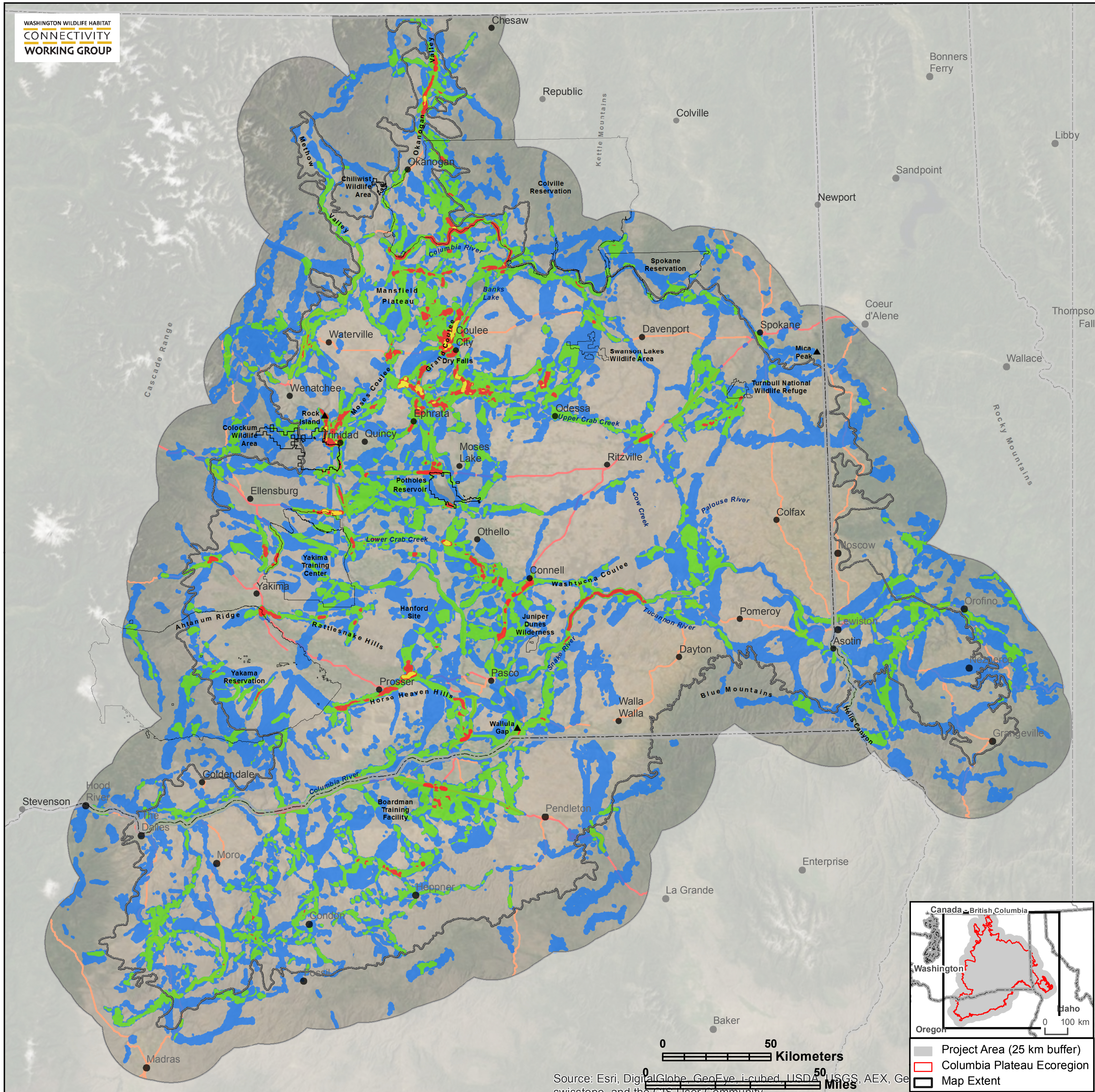
**Barrier Impact / Restoration Improvement Score**

Highest | High | Medium

**Boundaries and Population Centers**

- Columbia Plateau Project Area
- Columbia Plateau Project Area 25 km Buffer
- State or Provincial Border
- Freeway
- Major Highway
- City or Town
- Important Site

**The data portrayed on this map are subject to use constraints as described in WHCWG metadata documentation.**




# Figure 13.7. Composite of Barriers and Restoration Opportunities: Number of Species.

***WHAT IS THE COMPOSITE OF BARRIERS AND RESTORATION OPPORTUNITIES?***

Barriers are areas where landscape features impede animal movement between habitat concentration areas (HCAs). Barriers are identified by comparing the least-cost paths under present conditions to paths that would be created if particular areas were restored, thereby reducing resistance to movement (McRae et al. 2012; McRae 2012a). Through this comparison, barriers are identified and ranked based on the extent to which restoring them would improve connectivity (see more at http://www.circuitscape.org/linkagemapper).

Barriers may be partial (e.g., suboptimal habitat types) or complete (e.g., an urban area), and they may be natural (e.g., rivers, cliffs) or human-made (e.g., urban areas, highways, some types of agriculture).

It is important to note that not all barriers are restorable, and this analysis does not distinguish those that can be restored from those that cannot. Consideration of restoration feasibility is needed to make that distinction.

For this map composite barriers are identified and ranked based on the *number* of focal species for which a particular location is a barrier, and where restoration, if feasible, would substantially improve connectivity between adjacent HCAs.

***HOW ARE COMPOSITE BARRIERS AND RESTORATION OPPORTUNITIES DEPICTED ON THIS MAP?***

Results are depicted on the map as follows: areas with 6 to 8 species (depicted yellow), 4 or 5 species (depicted red), 2 or 3 species (depicted green), and 1 species (depicted blue). No location had barriers for more than 8 species.

***TYPES OF QUESTIONS AND DECISIONS THIS MAP HELPS INFORM***

- Where will restoration efforts improve connectivity for multiple focal species?

Since **all types** of barriers to movement are identified on this map users must further evaluate the feasibility of each restoration opportunity.

*Notes: (1) This map depicts modeled linkages (see more at http://waconnected.org). While we've used the best available data layers, field review is necessary to ensure the HCAs are viable. (2) We included areas in Oregon and Idaho to help understand transboundary connectivity; however, our products may be less accurate in these adjoining areas.*

**Number of Species at the Barrier**

6 - 8
2 - 3
4 - 5
1

**Boundaries and Population Centers**

Columbia Plateau Project Area
Columbia Plateau Project Area 25 km Buffer
State or Provincial Border
Freeway
Major Highway
City or Town
Important Site

**The data portrayed on this map are subject to use constraints as described in WHCWG metadata documentation.**

## Synthesis Maps Highlighting Areas of Interest for Connectivity

In this section we combine centrality, pinch-point, and barrier analyses to highlight areas predicted to be important for multi-species connectivity. We start with a conceptual flowchart (Fig. 13.8) outlining decisions users might make when deciding how to use these metrics to inform the selection of priority areas to meet user-specific objectives. We then define areas predicted to be important for multi-species connectivity by first summing centrality values across species, and then combining areas of high centrality with areas that have high pinch-point and barrier metric values.

### High Network Centrality Areas

- The synthesis map for network centrality shows areas with high summed centrality scores for habitat concentration areas (HCAs) and/or linkages (Fig. 13.9). These areas form the basis for maps shown in Figures 13.10–13.12.
- For areas where the summed HCA or summed linkage centrality scores were within the top 30% of values (Fig. 13.9), we tallied the number of focal species that had high centrality scores (Fig. 13.10).

### Linkage Pinch-Points with High Centrality

- The pinch-point/centrality synthesis map (Fig. 13.11) combines multi-species pinch-point information with multi-species centrality information. It shows how many species have strong pinch-points that overlap the top 30% centrality areas shown in Figure 13.9.

### Barriers and Restoration Opportunities with High Centrality

- The barrier/centrality synthesis map (Fig. 13.12) combines multi-species barrier information with multi-species centrality information. It shows how many species have strong barriers that overlap the top 30% centrality areas shown in Figure 13.9.

### Example Applications of Composite Maps to Inform Targeted Conservation Actions

- Figures 13.13 and 13.14 illustrate how different maps could be incorporated into decision-making processes with different objectives (e.g., the process illustrated in Fig. 13.8). These maps give examples of how composite barrier maps can be overlaid with maps depicting agricultural lands and roads to highlight opportunities for specific restoration actions.
- Maps combining results for multiple species may inform a variety of decisions related both to efforts to maintain and restore connectivity, as well as efforts to develop infrastructure and obtain benefits from lands in ways that minimize their impacts on wildlife habitat and movement.

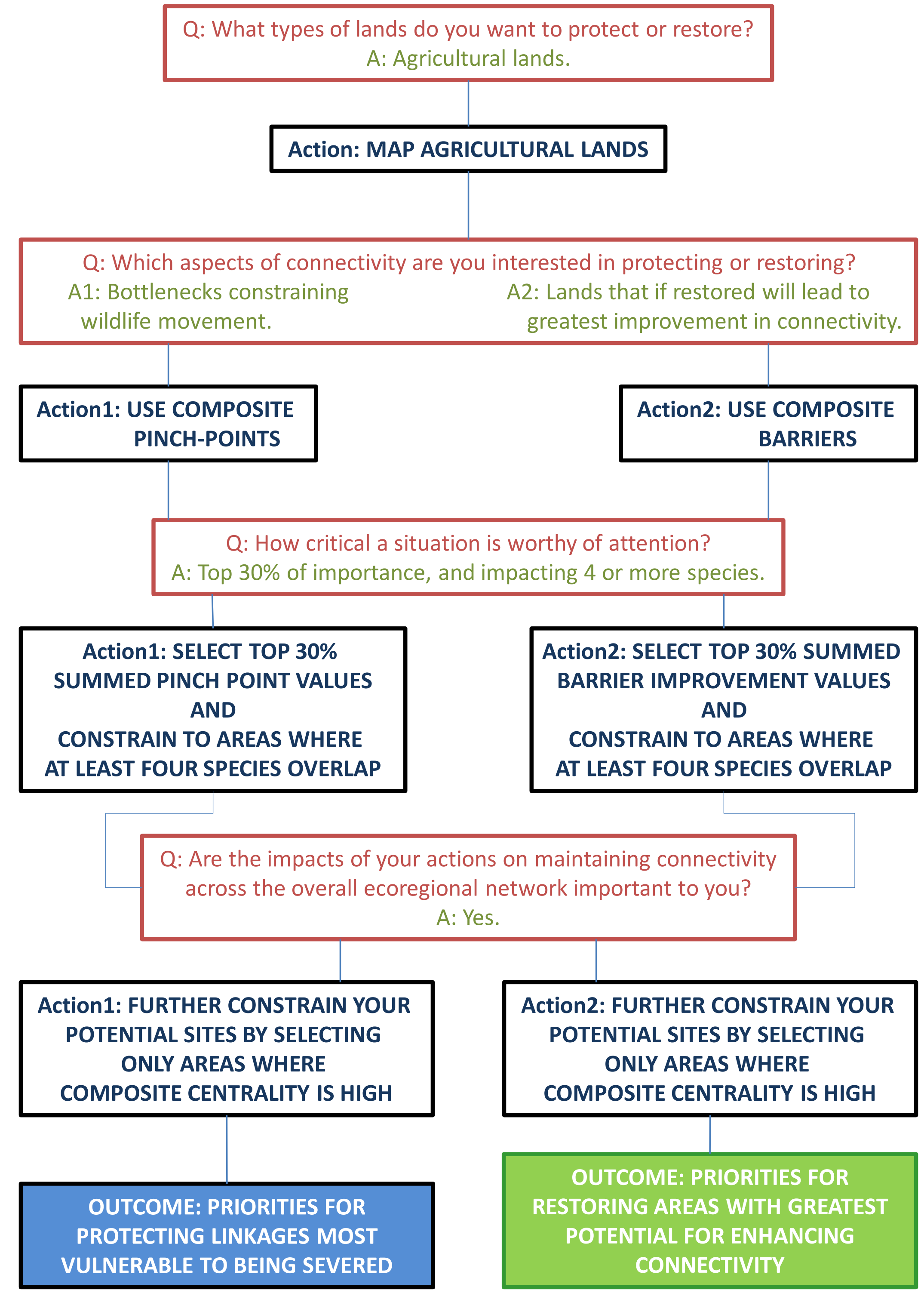



**Figure 13.8.** Conceptual flowchart for how to combine connectivity analyses to help inform selection of areas for conservation actions. The structure of this figure reflects the questions (Q) managers would ask themselves, example answers (A) given their objectives, and the actions (Action) they would take to inform their decisions. ***Note:*** this flowchart is simply an example to show how these products can be used; users would need to evaluate their priorities on the ground and in their socio-economic context to determine if their planned actions would indeed be feasible and effective.

### High Network Centrality Areas

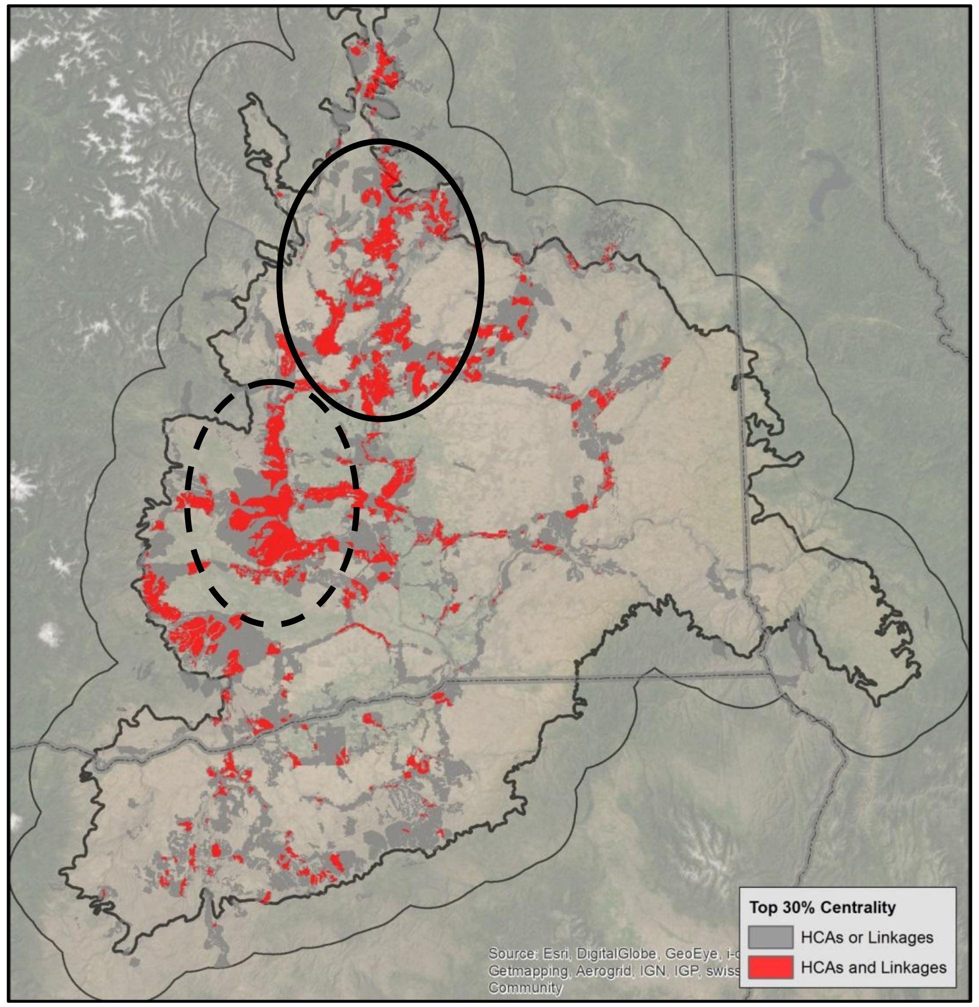



**Figure 13.9.** Network centrality synthesis map showing areas of high centrality: top 30% summed centrality areas across all focal species for either HCA or linkage centrality (depicted gray), or areas where high centrality HCAs and linkages overlap (depicted red).

- Relatively un-fragmented areas such as the Yakima Training Center act as highly central HCAs and linkages within multiple species' networks (dashed oval in Fig. 13.9).
- The northern Columbia Plateau (including areas within Douglas and Grant counties) contains the largest cluster of high-centrality areas for multiple species, including areas with both high HCA centrality and high linkage centrality (solid oval in Fig. 13.9).

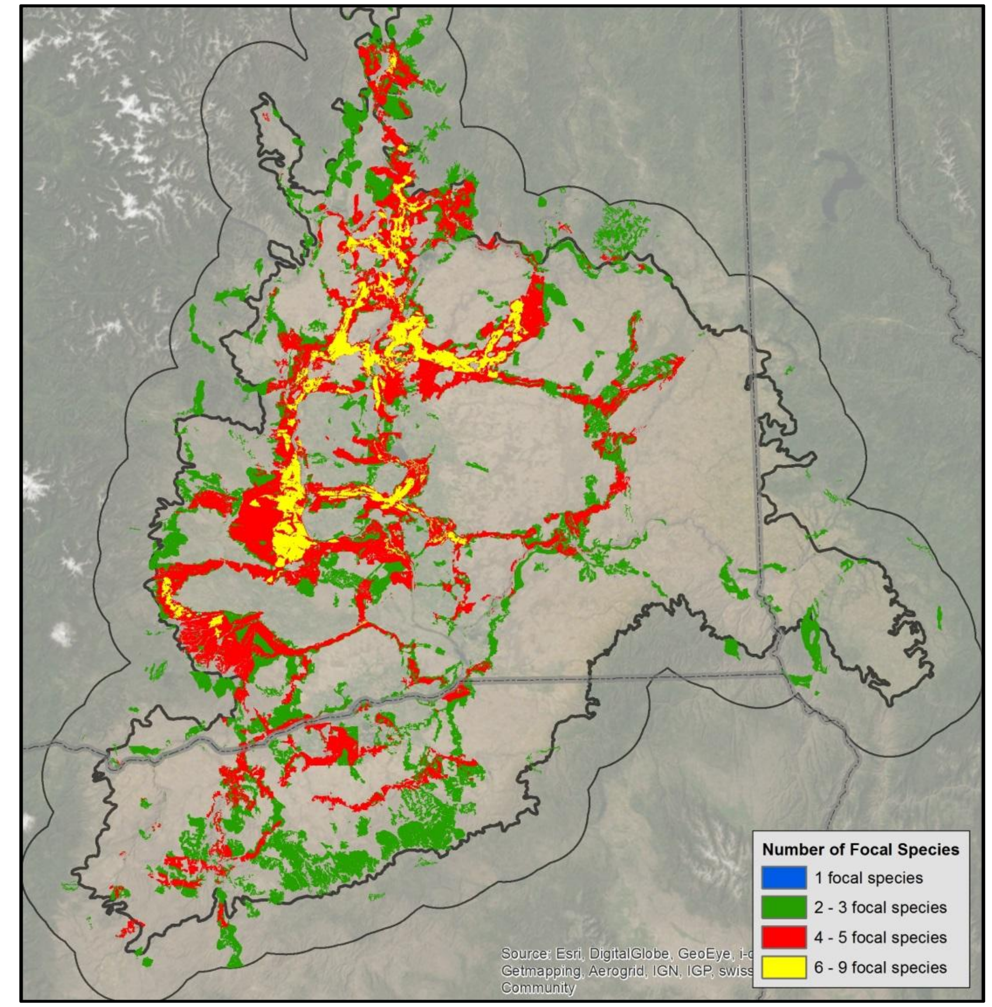



**Figure 13.10.** Network centrality synthesis map showing the number of focal species that have their top 30% centrality values in any location falling within the top 30% summed centrality areas from Figure 13.9.

- The areas where high species tallies overlap high summed centrality areas (areas depicted red and yellow in Fig. 13.10) are predicted to be crucial for network centrality for many of the focal species.
- A linkage for one species may overlap an HCA for another. Areas that are part of both central HCAs and central linkages for multiple species (areas that are both depicted red in Fig. 13.9, and red and yellow in Fig. 13.10) are contributing to habitat, to connectivity among HCAs, and to the overall connectedness of the combined network.
- The extensive overlap between areas that have high centrality for six or more species (areas depicted yellow in Fig. 13.10) and the main connectivity regions in central Washington (the Connected Backbone and the western end of the Upper Crab Creek Linkage Zone, labeled in Fig. 13.1) reinforces the importance of the connectivity regions identified in the analysis of the Columbia Plateau Ecoregion (Fig. 13.1; WHCWG 2012).

## Linkage Pinch-Points with High Centrality

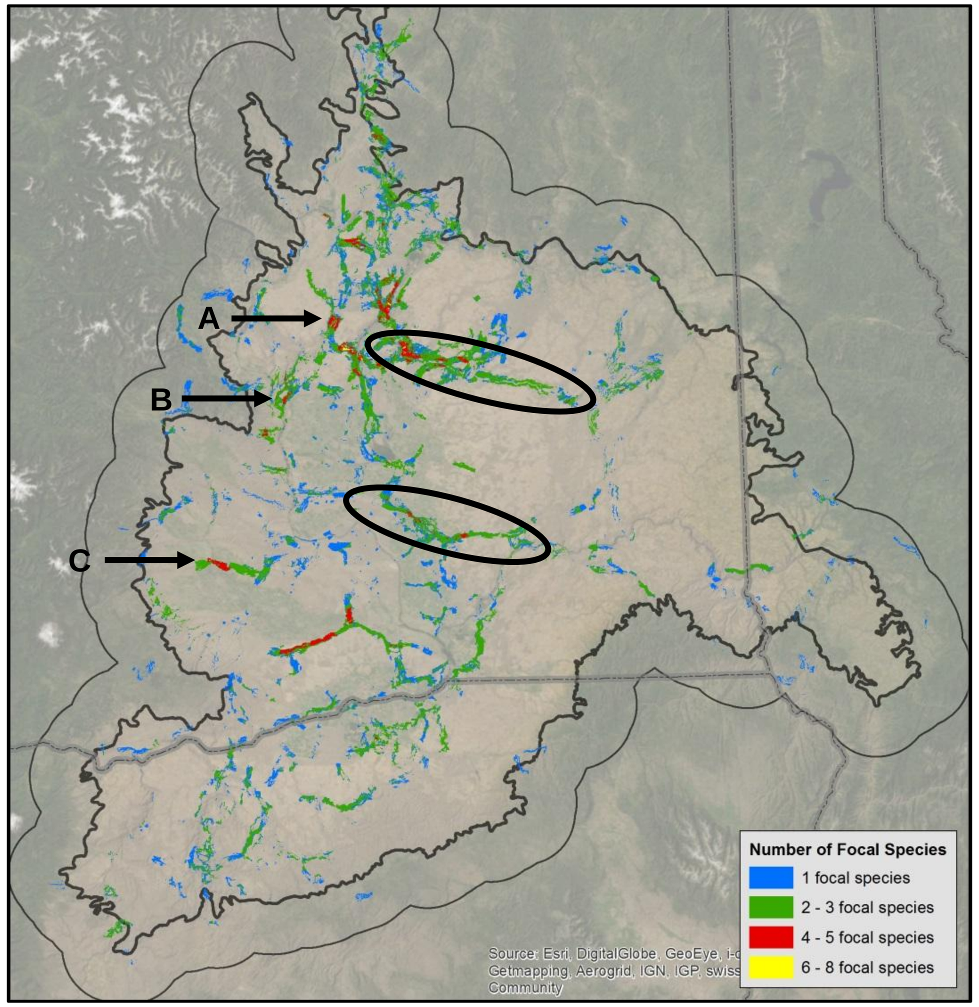



**Figure 13.11.** Pinch-point/centrality synthesis map showing the number of focal species with strong pinch-points (grid cells falling within the top 15% of pinch-point values for each species) in any location falling within the top 30% summed centrality areas from Figure 13.9.

- Notable pinch-points in the Connected Backbone (labeled in Fig. 13.1) occur in Moses Coulee, the crossing of the Columbia River near Trinidad, and Ahtanum Ridge (arrows labeled "A" to "C" respectively in Fig. 13.11). Further degradation or loss of these areas could have significant impact by severing movement routes along the Connected Backbone.
- The Crab Creek linkage zones (ovals in Fig. 13.11; labeled in Fig. 13.1) have multiple pinch-points for two or more species; connectivity here is vulnerable to further conversion or degradation. These pinch-points occur in areas that also have high centrality for either HCAs, linkages, or both. Maintaining or improving conditions that enable east–west movement along the Crab Creek linkage zones is therefore critical for overall connectivity across the ecoregion.

## Barriers and Restoration Opportunities with High Centrality

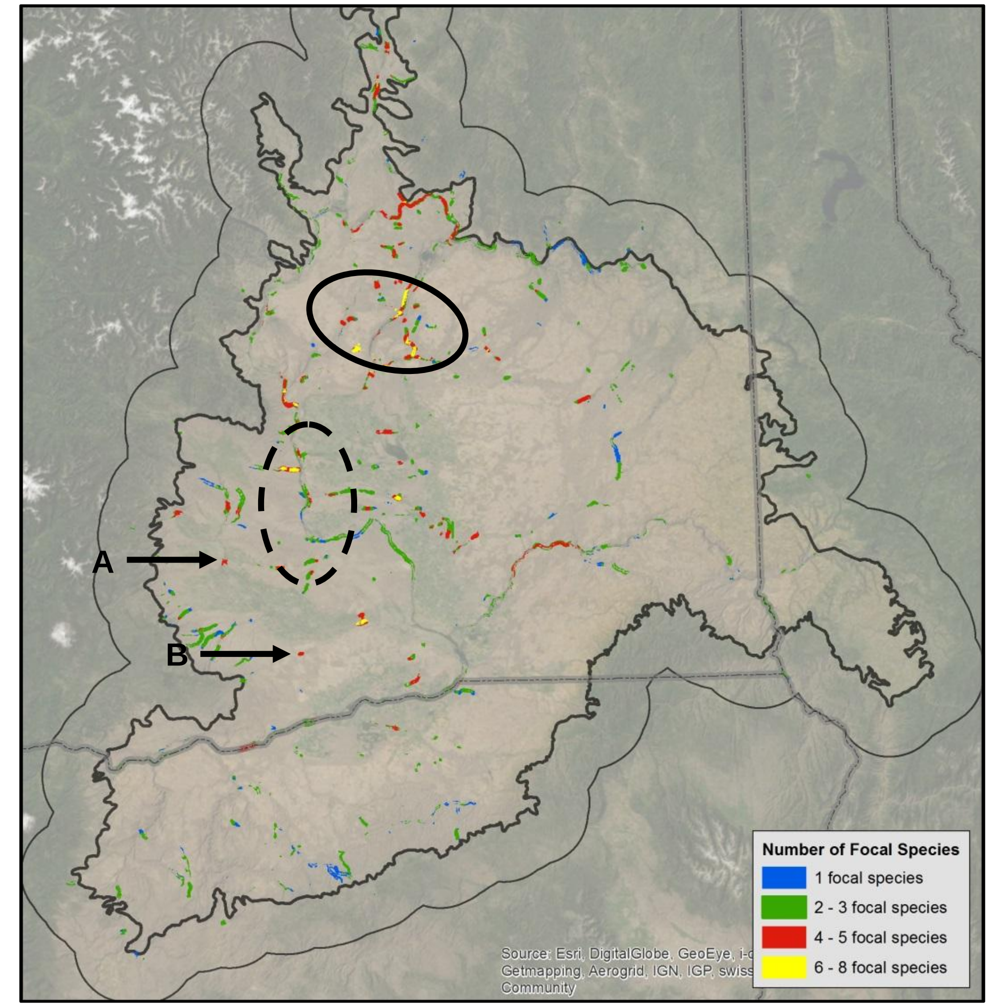



**Figure 13.12.** Barrier/centrality synthesis map: number of focal species with strong barriers (areas falling within the top 30% of barrier values for each species) in any location falling within the top 30% summed centrality areas from Figure 13.9.

- High impact barriers for multiple species appear to concentrate near the intersection of the Connected Backbone and the Upper Crab Creek Linkage Zone (solid oval in Fig. 13.12; see also Fig. 13.7). Restoration in this area may be important for maintaining/enhancing ecoregional connectivity.
- Linkages for several species circle around and across the Yakima Valley to connect to the rest of the backbone further north (dashed oval, Fig. 13.12). Barriers identified along Ahtanum Ridge and the Horse Heaven Hills may be of particular importance (arrows labeled "A" and "B" respectively, Fig. 13.12).
- Some identified pinch-points also appear as barriers for multiple species (e.g., Union Gap near Ahtanum Ridge; arrow labeled A, Fig. 13.12; see also Fig. 1.12, Chapter 1). This suggests that these linkages may not currently be fully functional for some species. Conservation efforts to improve connectivity in the vicinity of these pinch-points may also require restoring barriers, if feasible.

## Example Applications of Composite Maps to Inform Targeted Conservation Actions

### AGRICULTURAL LANDS

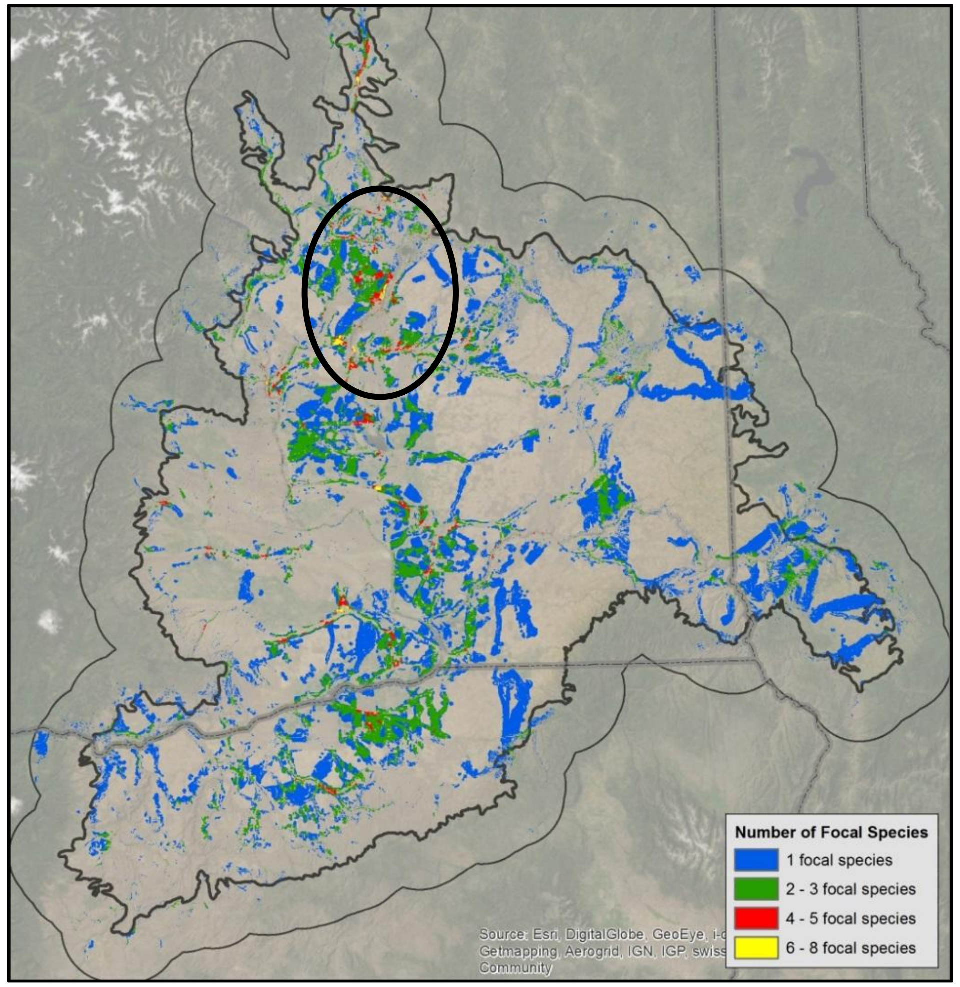



**Figure 13.13.** Agricultural lands example: barrier analysis applied only to agricultural lands.

- Agricultural lands pose resistance to movement for some species, and are a land-use type where restoration to native habitat may be feasible. Where can such restoration lead to greatest improvement in connectivity for wildlife? Limiting the barrier/restoration opportunity analysis to agricultural lands (Fig. 13.13) suggests, for example, that there is a concentration of such lands in the northern Columbia Plateau, including areas in Douglas and Grant counties (area in oval), an area which also has high centrality for multiple species.
- Entities interested in working with landowners to establish native vegetation in agricultural fields could use this type of information to help implement Farm Bill programs or other incentives.

### ROADS

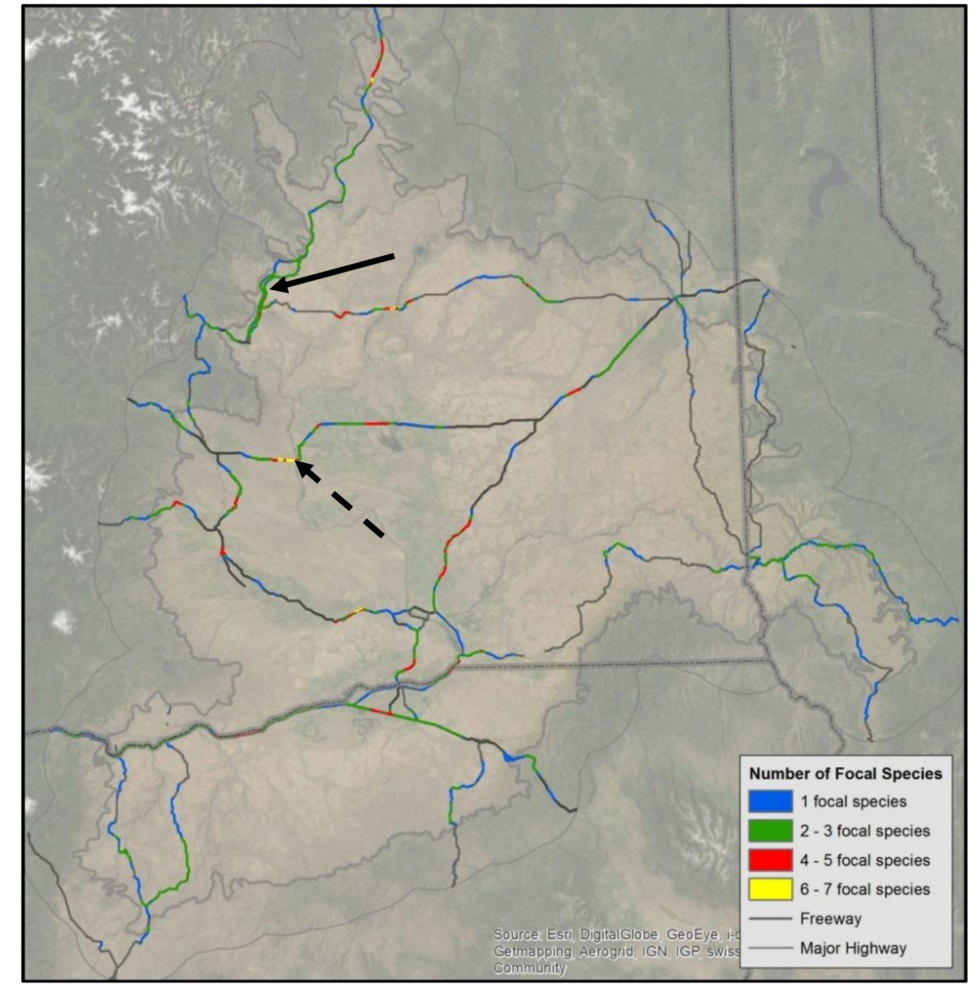



**Figure 13.14.** Roads example: overlap of composite barrier/restoration opportunity results with freeways and major highways.

- Roads can pose significant resistance to movement for many species through increased mortality or behavioral avoidance of road crossings. The Washington State Department of Transportation has an interest in reducing the effects of state highways on wildlife movements and reducing collision risks to make highways safer for travelers. Identifying barriers associated with highways (Fig.13.14) can inform highway projects that seek to improve overall connectivity for multiple wildlife species.
- For example, barriers associated with US Highway 97 (solid arrow in Fig. 13.14) are important for multiple species, though they likely reflect a combination of highway effects, the Columbia River, and a railway line, all of which run parallel to one another. Investing in a more permeable highway at this location must be weighed against the natural barrier formed by the Columbia River. This differs from the barrier posed by I-90 west of the Columbia River and the town of Vantage (dashed arrow in Fig. 13.14). Here, the interstate is a significant barrier to wildlife movements and crossing structures are tools that can increase the highway’s permeability. In addition, this section of I-90 is in an area with high centrality values; placing crossing structures here could improve overall connectivity across the landscape.

## Methods

We focused on combining results from the 11 focal species (See Chapters 2–12) at two levels, guided by two main questions: How can we identify connectivity areas important for multiple species, given the current trend towards multiple-species habitat management? How can the different types of information provided by centrality, pinch-point, and barrier analyses be used together to help make informed decisions relating to maintaining and improving habitat connectivity? To address these questions we created: (1) composite maps, and (2) synthesis maps.

### *1) Composite Maps—Areas important for multiple species*

To answer the first question on ways to identify connectivity areas important for multiple focal species, we combined the single-species network centrality, pinch-point, and barrier results presented in Chapters 2–12, in two ways. First, we summed outputs for each analysis across the 11 focal species (illustrated in Fig.13.15a). Summing the outputs provides a measure of the composite conservation or restoration value of a site. Because centrality scores are sensitive to the number of HCAs in a network, we normalized centrality scores to account for the maximum possible score given the total number of HCAs in each species network before adding scores across species.

Second, because high summed values may represent relatively high values for a few species or low-to moderate values for up to nine species (note that though we summed across 11 species, in no case were there more than nine overlapping species in a particular grid cell), we tallied the number of species contributing to summed scores for barriers and pinch-points. For barriers, we tallied the number of species with positive barrier impact scores at any given grid cell. For pinch-points, we first identified grid cells with pinch-point scores in the top 50% of scores for each species. We then tallied these across species, so that each grid cell value represented a count of species experiencing moderate to high movement constraint in the grid cell (illustrated in Fig 13.15b). Sum- and tally-based maps are shown in Figures 13.2–13.7.

### *2) Synthesis Maps—Combining different analyses to inform decisions*

To answer the second question on how best to combine these different analyses to inform decisions, we used overlays to show where areas with high multi-species pinch-point or barrier scores overlapped with areas of high overall centrality (grid cells in the top 30% of summed centrality values; Figs. 13.9–13.12). This helps to show which multi-species barriers and pinch-points occur in areas of particularly high connectivity importance. For barriers, we tallied the number of species with barrier scores in the top 30% for each species at each grid cell; for pinch-points, we tallied the number of species with pinch-point scores in the top 15% (i.e., top 30% areas of those areas with high summed pinch-point values, which were themselves the top 50% of summed values) for each species at each grid cell. We ignored grid cells that did not fall within the top 30% of summed centrality values.

In addition to highlighting important areas for conservation and restoration, these maps are also meant to show how the different metrics can be combined to help focus and prioritize actions given a user's specific objectives and criteria for defining the importance of a site.

Note that for the composite analyses we did not first select or map areas where particular conservation actions are expected to be feasible. Decision-makers interested in using these maps will therefore need to overlay or constrain the results based on their own evaluation of feasibility.

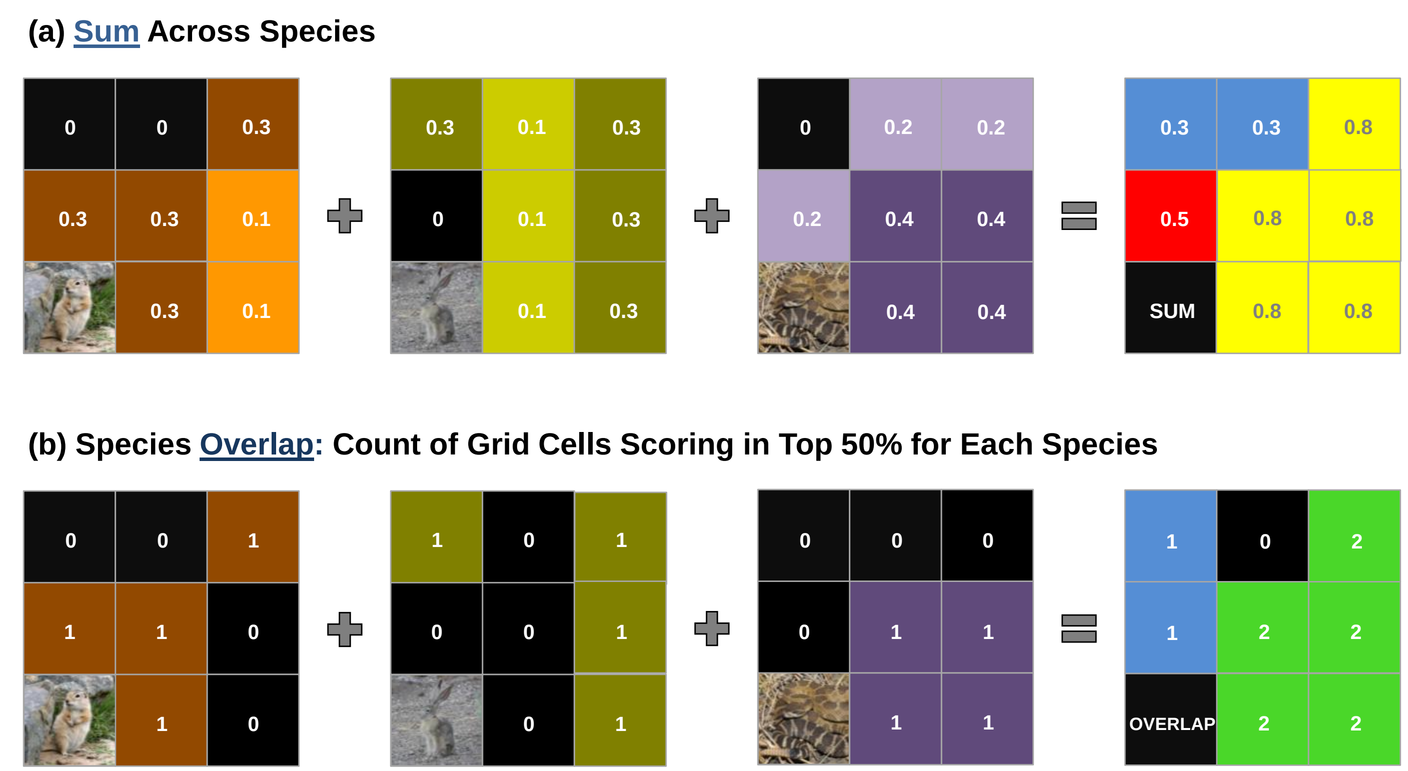



**Figure 13.15.** Methods for developing composite maps. Panel (a) shows how metric values (0.0–1.0) are summed across species, and panel (b) shows how many species had a metric value above a given threshold (in this case within the top 50% of grid cells for each species). Actual thresholds used for species tallies in this report ranged from grid cells in the top 50% for each species to grid cells within the top 15% for each species, depending on the metric and objective. *Photo credits: Washington ground squirrel (Bob Davies), black-tailed jackrabbit (Michael A. Schroeder), Western rattlesnake (James Rosindell).*

## Citations


Carroll, C., B. H. McRae, and A. Brookes. 2011. Use of linkage mapping and centrality analysis across habitat gradients to conserve connectivity of gray wolf populations in western North America. Conservation Biology 26(1):78–87.

McRae, B. H. 2012a. Barrier Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle Washington. Available from http://www.circuitscape.org/linkagemapper.

McRae, B. H. 2012b. Centrality Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle Washington. Available from http://www.circuitscape.org/linkagemapper.

McRae, B. H. 2012c. Pinchpoint Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle Washington. Available from http://www.circuitscape.org/linkagemapper.

McRae, B. H., B. G. Dickson, T. H. Keitt, and V. B. Shah. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 10: 2712–2724.

McRae, B. H., S. A. Hall, P. Beier, and D. M. Theobald. 2012. Where to restore ecological connectivity? Detecting barriers and quantifying restoration benefits. PLoS ONE 7(12): e52604. doi:10.1371 /journal.pone.0052604.

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2012. Washington Connected Landscapes Project: Analysis of the Columbia Plateau Ecoregion. Washington's Department of Fish and Wildlife, and Department of Transportation, Olympia, Washington. Available from http://www.waconnected.org.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*Focal species and the Columbia Plateau Ecoregion: Columbia plateau landscape photos (Joe Rocchio); Focal Species, LEFT COLUMN, black-tailed jackrabbit (Michael A. Schroeder), Townsend's ground squirrel (Ryan Shaw), white-tailed jackrabbit and greater sage-grouse (Michael A. Schroeder), beaver (Ginger Holser), CENTER COLUMN mule deer (Woodrow Myers), sharp-tailed grouse (Gregg Thompson), least chipmunk (Kelly McAllister), tiger salamander (William Leonard), RIGHT COLUMN Western rattlesnake (James Rosindell), mule deer (Michael A. Schroeder), Washington ground squirrel (Bob Davies)*