COLUMBIA PLATEAU CLIMATE-GRADIENT CORRIDOR ANALYSIS ADDENDUM: PINCH-POINTS AND BARRIERS AND RESTORATION OPPORTUNITIES

WASHINGTON WILDLIFE HABITAT CONNECTIVITY WORKING GROUP

2014


Columbia Plateau, photo by Joe Rocchio

Cover photo by Joe Rocchio.

Columbia Plateau Climate-Gradient Corridor Analysis Addendum: Pinch-Points and Barriers and Restoration Opportunities

Washington Wildlife Habitat

Connectivity Working Group

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WASHINGTON WILDLIFE HABITAT CONNECTIVITY WORKING GROUP

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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Document Availability

This document and companion files are available online at:
http://waconnected.org

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Columbia Plateau, photo by Joe Rocchio

Addendum Overview

This document is an addendum to the *Washington Connected Landscapes Project: Columbia Plateau Climate-Gradient Corridor Analysis* (WHCWG 2013a; available from http://waconnected.org). It includes supplemental maps and guidance that can help prioritize and implement connectivity conservation actions that may benefit species under climate change. The analyses presented in the addendum build upon the climate-gradient corridors modeled for the Columbia Plateau Ecoregion and a surrounding buffer area (Fig. 1; WHCWG 2013a).

The supplemental products in this addendum include maps, interpretive examples, and GIS files depicting linkage pinch-points and barriers and restoration opportunities for climate-gradient corridors in the Columbia Plateau. GIS files are available from http://waconnected.org. We emphasize that we **do not** provide a full interpretation or prioritization of these products, and our results have not been verified by field studies. We **do** provide guidance for interpretation of these products for the Columbia Plateau.

Questions and Decisions these Analyses Help Inform

- Where are important areas on the landscape for maintaining connectivity in a changing climate?
- Where should further disturbance to climate-gradient corridors be avoided?
- Where along climate-gradient corridors is potential movement highly or moderately constrained?
- Are there areas where alternative climate-gradient corridors may not be available?
- Where in a climate-gradient corridor will restoration efforts have the greatest effect on climate-connectivity?
- Where can alternate climate-gradient corridors be created by restoration of key areas or removal of barriers?

Linkage Pinch-Points

Pinch-points (also known as bottlenecks or choke-points) are areas where animal movement is funneled through constricted areas within linkages. Pinch-point modeling methods are based on current flow models from electrical circuit theory. Locations where current is very strong indicates constrictions where linkages are most vulnerable to being severed (McRae et al. 2008). Pinch-points can be the result of both natural and human-made landscape features. However, this analysis only identifies pinch-points that result from human-made landscape features, because the climate-gradient corridor approach is not species-specific, but the resistance of specific natural landscape features to animal movement likely is. Pinch-points are locations where loss of a small area could disproportionately compromise connectivity because alternative movement routes are unavailable; they may therefore be considered connectivity conservation priorities. Loss of climate-gradient corridor pinch-points may sever connectivity between relatively warm and relatively cool habitat concentration areas (HCAs), which may reduce species' abilities to track shifting areas of climatic suitability. To determine the relative importance of pinch-points in different linkages, users should consider pinch-point results along with other connectivity measures (e.g., barrier and restoration opportunities or focal species pinch-points).

Barriers and Restoration Opportunities

Barriers are areas where landscape features impede wildlife movement between HCAs. Barriers may be

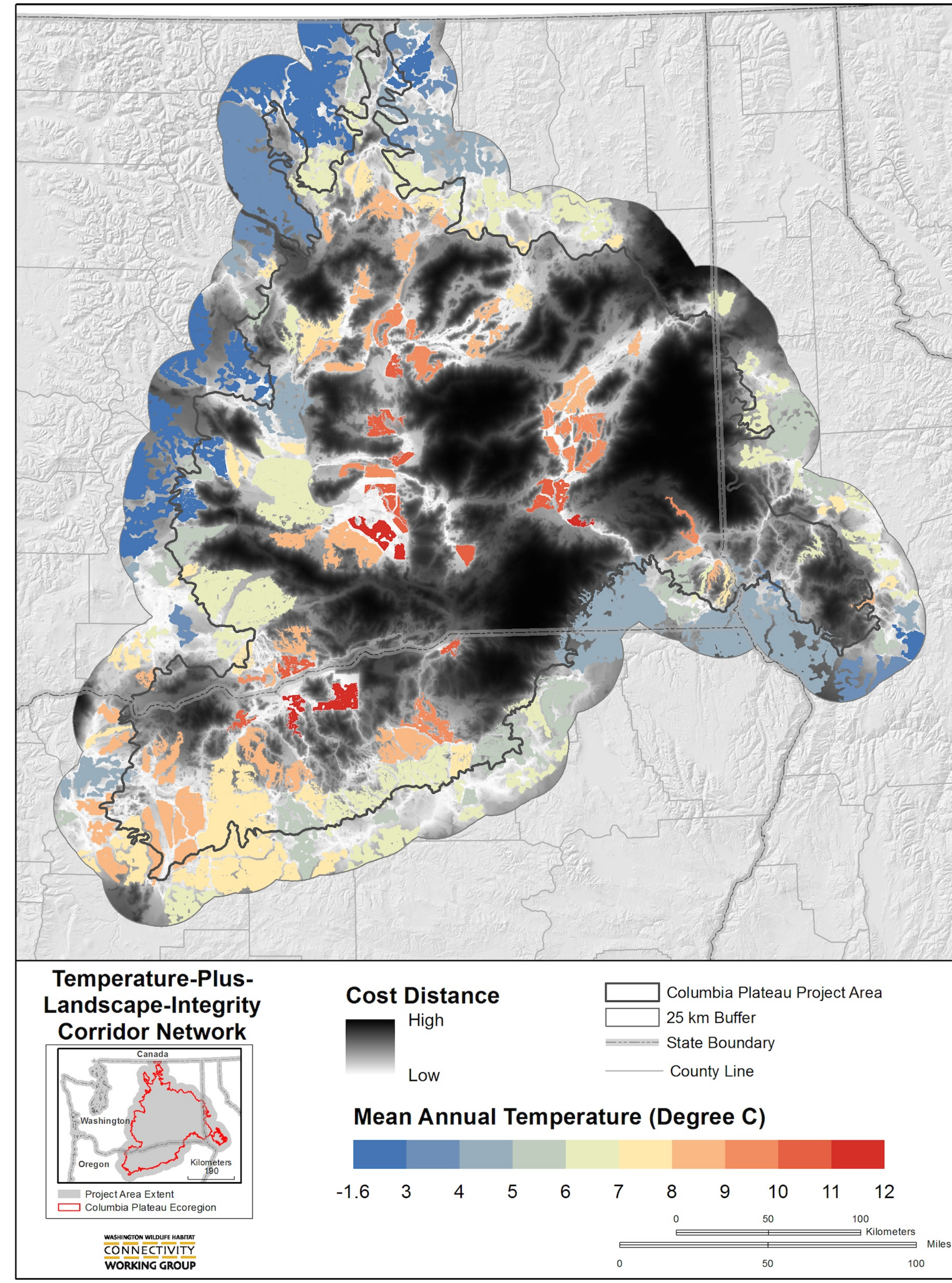


Figure 1. Temperature-plus-landscape integrity climate-gradient corridor network for the Columbia Plateau (WHCWG 2013a). Corridors connect core areas of high landscape integrity that differ in temperature by >1°C, minimizing changes in temperature and avoiding areas of low landscape integrity along the way. Corridors are shown as glowing white areas, with resistance to movement increasing as white fades to black. Core areas are shaded to reflect their mean annual temperatures.

partial or complete, and may be natural or human-made (e.g., urban areas, highways, some types of agriculture). Because we cannot reasonably remove or restore a climatic barrier (e.g., a hot valley or cold peak interrupting an otherwise gentle climatic gradient between warmer and cooler HCAs), our analysis identifies only human-made barriers. Some but not all human-made barriers may be restorable. Barrier mapping complements corridor mapping by broadening the range of connectivity conservation alternatives available to practitioners. It can help identify areas where connectivity can be restored through active barrier removal, including areas outside of the original corridor network. It can also inform decisions on trade-offs between restoration and protection; for example, purchasing an intact corridor may be substantially more expensive than restoring a barrier that blocks an alternative corridor. Barrier maps can also help identify corridors that are too degraded to provide meaningful movement opportunities (McRae et al. 2012).

Methods

We used the GIS resistance rasters, corridor rasters, and vector linkage maps produced for the Columbia Plateau Ecoregion climate-gradient corridor analysis (WHCWG 2013a) and further processed these layers as described below. Specifically, we used the Columbia Plateau landscape integrity HCA polygons and resistance surface, and the temperature-plus-landscape integrity corridor surface and least-cost path lines.

We used Pinchpoint Mapper (McRae 2012a; see more at http://www.circuitscape.org/linkagemapper) to map pinch-points in each of the linkages identified by WHCWG (2013a). For each pair of HCAs connected directly by a linkage, Pinchpoint Mapper used Circuitscape to map current flow within the linkage by injecting 1 Amp of current into one HCA and setting the other HCA to ground. Current was then allowed to flow through the linkage, concentrating in areas where the linkage was constricted. We used the same landscape integrity resistance surface that was used for mapping Columbia Plateau temperature-plus-landscape integrity corridors (WHCWG 2013a). We also used the same linkage width cutoff (WHCWG 2013a) to define which areas were inside and outside of each linkage. We produced the pinch-point map (Fig. 2) using five quantiles generated from the Pinchpoint Mapper raster output, and a 2.5 standard-deviation stretch applied in ArcGIS.

We used the Barrier Mapper Toolbox to map barrier and restoration opportunities for the Columbia Plateau climate-gradient corridor network (McRae 2012b; see more at http://www.circuitscape.org/linkagemapper; WHCWG 2013a). Barrier Mapper implements the methods described in McRae et al. (2012), which detect areas acting as influential barriers by analyzing cost-weighted distance surfaces using a circular search window. We used a variable search window radius to detect barriers at radii of 180 m, 360 m, 720 m, and 1440 m. Results gave expected percent reduction in least-cost distance of corridors per hectare restored assuming all pixels in a 100 m-wide swath across the window were changed to a resistance of 1.0. We produced the barrier map (Fig. 3) using six categories generated from a raster produced by Barrier Mapper showing the percent improvement at the center pixel for each search window. The maps identify and rank barriers by their impact and quantify the extent to which restoration may improve connectivity.

We overlaid climate-gradient corridor and focal species (WHCWG 2013b) pinch-points (Fig. 4) and barriers and restoration opportunities (Fig. 5) to identify areas important for both current and future connectivity in the Columbia Plateau. The pinch-point overlay map identifies four categories: those areas with very high to high current flow for climate-gradient corridors and any focal species (yellow), those with moderate to low current flow for climate-gradient corridors and any focal species (red), those areas with very high to high current flow for climate-gradient corridors but *not* for any focal species (blue), and those areas with moderate to low current flow for climate-gradient corridors but *not* for any focal species (pink). The barrier and restoration overlay map (Fig. 5) also identifies four categories: those areas with very high to high restoration and barrier improvement scores for climate-gradient corridors and any focal species (yellow), those with moderate to low barrier improvement scores for climate-gradient corridors and any focal species (red), those with very high to high barrier improvement scores for climate-gradient corridors but *not* for any focal species (blue), and those with moderate to low restoration and barrier improvement scores for climate-gradient corridors but *not* for any focal species (pink).

Conservation of Climate-Connectivity in the Columbia Plateau

Linkage Pinch-Points

- Most climate-gradient corridor pinch-points are found at lower elevations toward the central interior of the plateau (Fig. 2), where there is greater contrast between linkages and the surrounding landscape, and fewer options for moving between HCAs. Relatively few pinch-points are found at higher elevations at the periphery of the plateau, which is in relatively better condition and features greater numbers of HCAs and linkages, and thus fewer restrictions to movement.
- Many of the climate-gradient corridor pinch-points found toward the center of the plateau fall along riparian corridors (i.e., areas adjacent to streams and rivers; Fig. 6). This is likely because riparian areas tend to be narrow and in good condition relative to the surrounding landscape, and also fall along climatic gradients between warmer and cooler areas. Climate-gradient corridor and focal species linkage pinch-points showed high agreement along riparian corridors (Fig. 4).

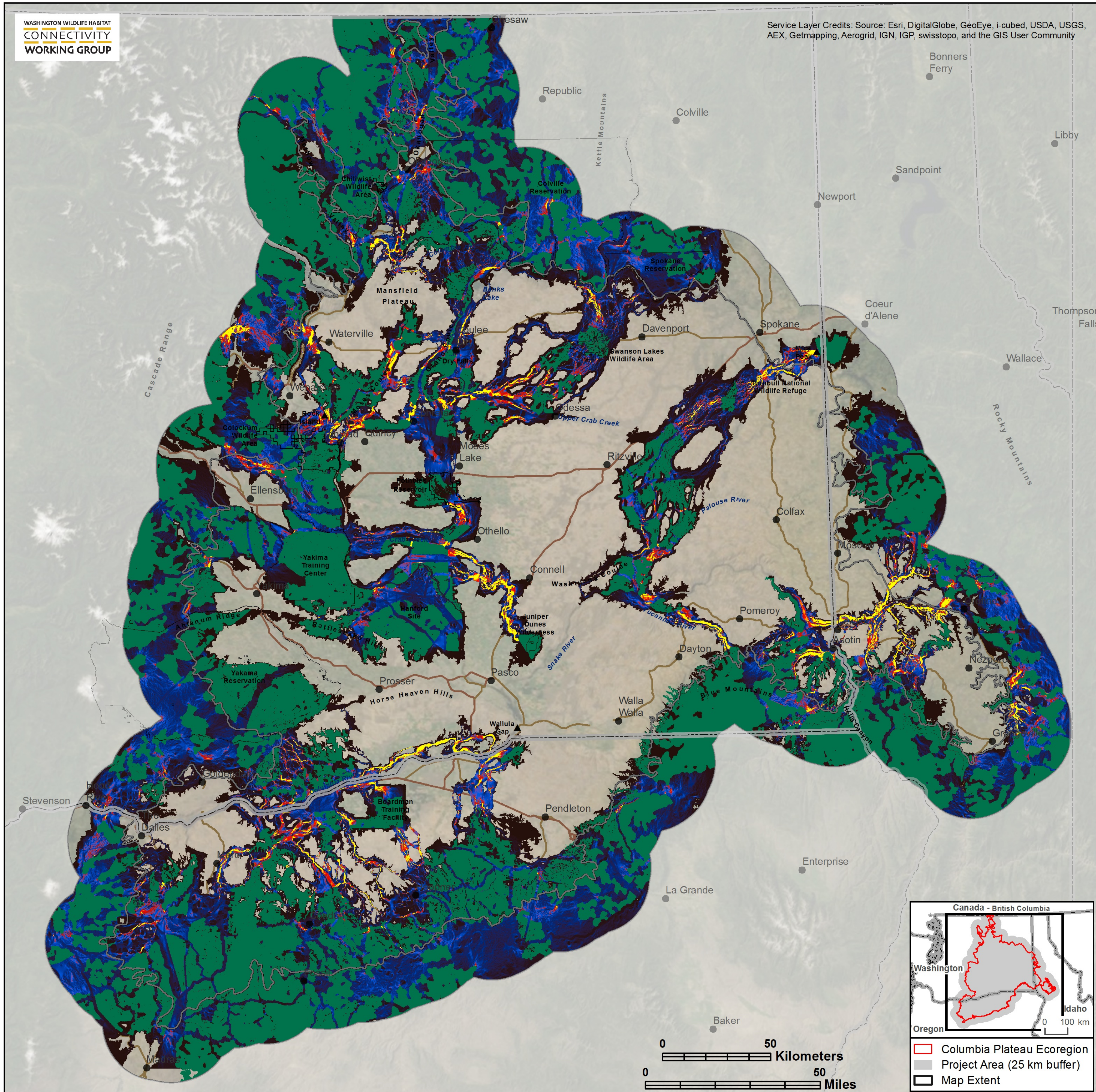
Barriers and Restoration Opportunities

- Roads posed significant barriers to climate-gradient connectivity in the plateau (Fig. 8). Increasing movement opportunities across roads (e.g., via culverts or other wildlife crossings) would dramatically improve climate-connectivity in the plateau. Climate-gradient corridors and focal species linkages showed high agreement for road-based barriers (Fig. 5).
- Development along narrow valley floors (including roads, housing, and agriculture) also presented major barriers in the Columbia Plateau, and showed high agreement with focal species barriers (e.g., the Okanagan Valley, as shown in Fig. 9).

Integrating Among These Products and Other Data Sources

- Areas identified as both linkage pinch-points and barriers and restoration opportunities represent conservation priorities, as removing barriers within pinch-points may dramatically improve movement within already narrow and/or irreplaceable linkages between HCAs (Fig. 9). Alternatively, pinch-points that do not include barriers (e.g., riparian corridors; Fig. 6) are unlikely to be significantly improved by restoration, but will require investment in connectivity maintenance.
- HCAs may include pinch-points that were not identified by our analysis, but remain vulnerable to development; it will thus be important to investigate the conservation status of core areas.
- Interpreting and applying these analyses will best be done by comparing and integrating them with a range of other data sources and conservation values (e.g., focal species data, GAP status).
- These models are intended to bring attention to places deserving a closer look for conservation action; implementation will require significant ground-truthing (e.g., high-resolution aerial imagery, on-the-ground investigation, empirical model validation).

Figure 2. Linkage Pinch-Points for Climate-Gradient Corridors



WHAT ARE PINCH-POINTS?

Pinch-points are "bottlenecks" where wildlife movement is funneled within linkages (McRae et al. 2008; McRae 2012a). This occurs when the area around the pinch-point is significantly more resistant to movement than the pinch-point itself, and there are no alternative pathways to move between two (or more) 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). This analysis identifies pinch-points that result from human-made landscape features only, as it is a coarse-filter analysis and natural barriers are more likely to be species-specific. Current flow is quantified with a pinch-point score; the greater the flow moving through a particular location, the higher the score.

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 among HCAs. Loss or degradation of habitat in these areas may sever movement routes between warmer and cooler HCAs, reducing species' abilities to track shifting areas of climatic suitability.

HOW ARE PINCH-POINTS DEPICTED ON THIS MAP?

- Habitat concentration areas (HCAs) are indicated in forest green, while climate-gradient linkages are depicted in a yellow to black color ramp.
- Yellows and reds indicate highly to moderately constrained areas for movement within linkages, whereas blues and blacks indicate areas with little to no constraint.
- Blue and black areas are not necessarily "better" areas of the linkages, but rather places where resistance is similar across broad swaths of the landscape.

TYPES OF QUESTIONS AND DECISIONS THIS MAP HELPS INFORM

- Where along climate-gradient 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.

Linkage Pinch Points

Current Flow

- Highly Constrained
- Unconstrained
- Cores

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.

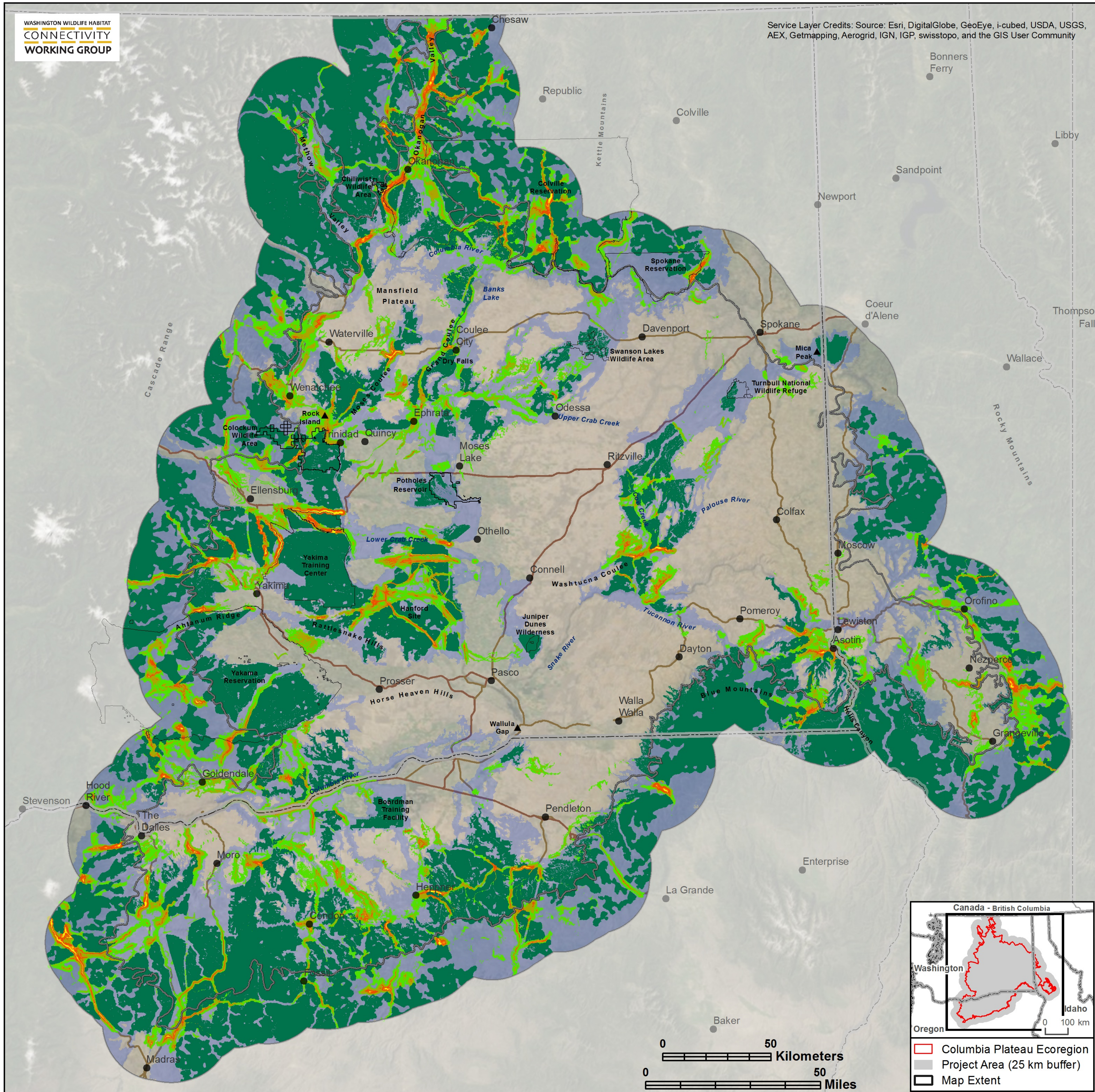


Figure 3. Barriers and Restoration Opportunities for Climate-Gradient Corridors

WHAT ARE BARRIERS AND RESTORATION OPPORTUNITIES?

Barriers are areas where landscape features impede wildlife movement between habitat concentration areas (HCAs). Barriers are identified by comparing the least-cost paths of temperature-plus-Landscape Integrity corridors to paths that would be created if particular areas were restored, thereby reducing resistance to movement (McRae et al. 2012; McRae 2012b). 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., low density housing) or complete (e.g., an urban area), and, for this analysis, are human-made only (e.g., urban areas, highways, some types of agriculture), as climatic barriers (e.g., cold peaks or hot valleys along otherwise gentle climatic gradients between two HCAs) generally cannot be restored.

HOW ARE BARRIERS AND RESTORATION OPPORTUNITIES DEPICTED ON THIS MAP?

- The Barrier Impact/Restoration Improvement 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.
- Barriers highlighted yellow or orange are thus places that, if restored or enhanced, may yield the greatest improvement in movement potential between HCAs. Yellow areas reflect improvement scores of 5-15%, orange areas scores of 4-5%, and dark orange areas scores of 3-4%.
- Restoring red or olive areas may yield only moderate improvement, while restoring light green areas may yield relatively little improvement. Red areas reflect improvement scores of 2-3%, olive areas scores of 1-2%, and light green areas scores of 1-0.05%.
- Note that the wide range for the High (yellow) category reflects the fact that we have quantified *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. We did not want these cases to overshadow restoration opportunities in longer corridors.
- Barriers identified outside linkage pathways have the potential to produce new, alternative corridors for movement between HCAs if restored.

QUESTIONS AND DECISIONS THIS MAP HELPS INFORM

- Where will restoration efforts have the greatest effect on climate-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

High

Low

Cores

Temperature-plus-LI Network

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

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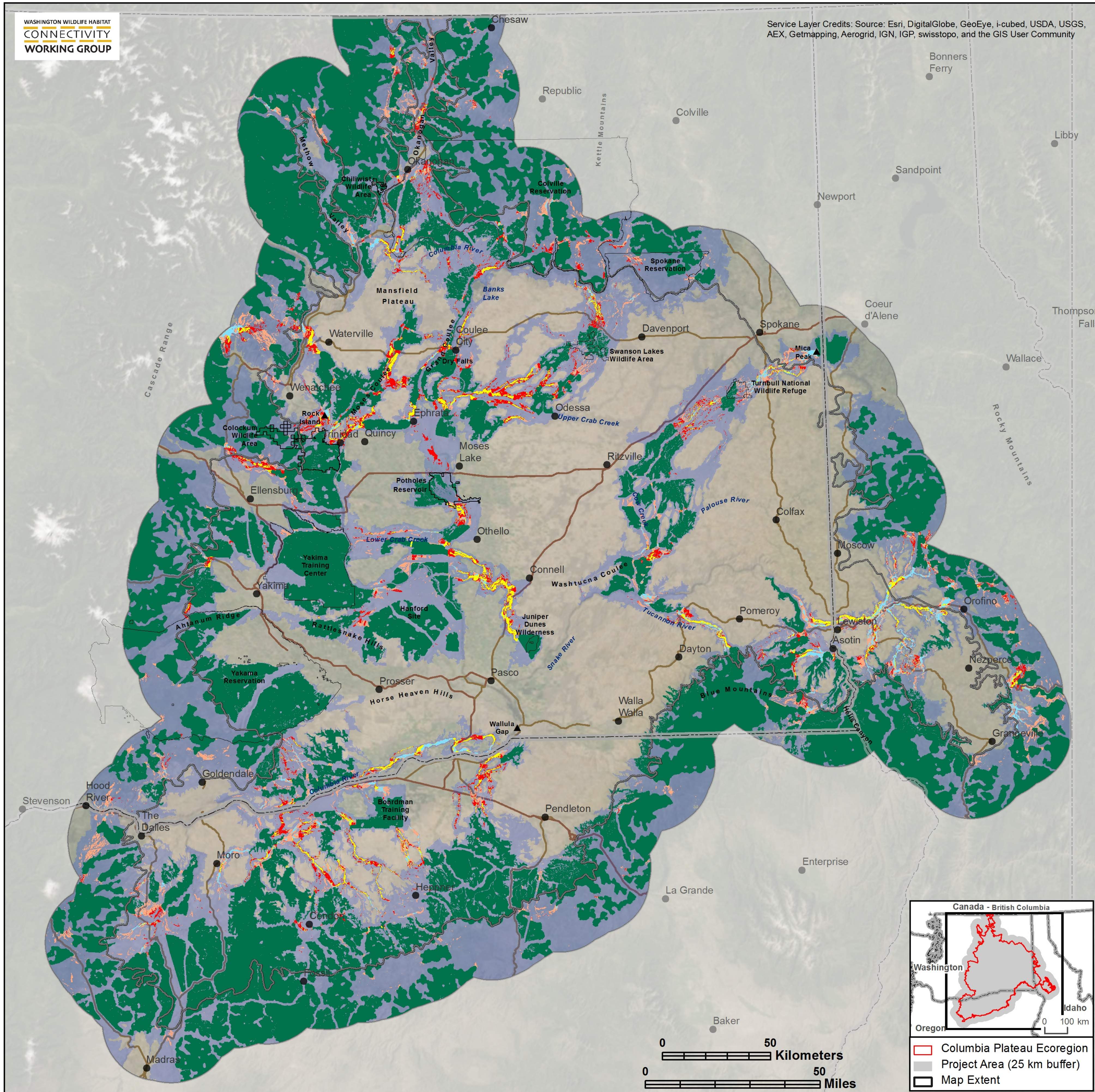

Figure 4. Overlay of Linkage Pinch-Points for Climate-Gradient Corridors and Focal Species

WHAT ARE PINCH-POINTS?

Pinch-points are "bottlenecks" where wildlife movement is funneled within linkages (McRae et al. 2008; McRae 2012a). This occurs when the area around the pinch-point is significantly more resistant to movement than the pinch-point itself, and there are no alternative pathways to move between two (or more) 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). This analysis identifies pinch-points that result from human-made landscape features only, as it is a coarse-filter analysis and natural barriers are more likely to be species-specific. Current flow is quantified with a pinch-point score; the greater the flow moving through a particular location, the higher the score.

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 among HCAs. Loss or degradation of habitat in these areas may sever movement routes between warmer and cooler HCAs, reducing species' abilities to track shifting areas of climatic suitability.

WHAT DOES THIS MAP TELL US?

This map shows areas where climate-gradient corridor pinch-points coincide with those of focal species. Such areas may be considered connectivity conservation priorities, as loss or degradation of such areas may impact current species movements as well as the ability of species ranges to move in response to climate change.

HOW IS THE OVERLAY OF CLIMATE-GRADIENT AND FOCAL SPECIES PINCH-POINTS DEPICTED ON THIS MAP?

- Yellow areas indicate places where climate-gradient pinch-points with high constraint ratings (current flow values of 0.016-0.03) overlap with those of any focal species. Blue areas indicate places where climate-gradient pinch-points with high constraint ratings do not overlap with those of any focal species.
- Red areas indicate places where climate-gradient pinch-points with medium to low ratings (current flow values of 0.010-0.016) constraint overlap with those of any focal species. Pink areas indicate places where climate-gradient pinch-points with high constraint ratings do not overlap with those of any focal species.

QUESTIONS AND DECISIONS THIS MAP HELPS INFORM

- Where along linkages is potential movement highly or moderately constrained for both climate-gradient corridors and focal 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.

Constraint Rating

Overlap / No Overlap: High, Low

Cores

Temperature-plus-LI Network

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

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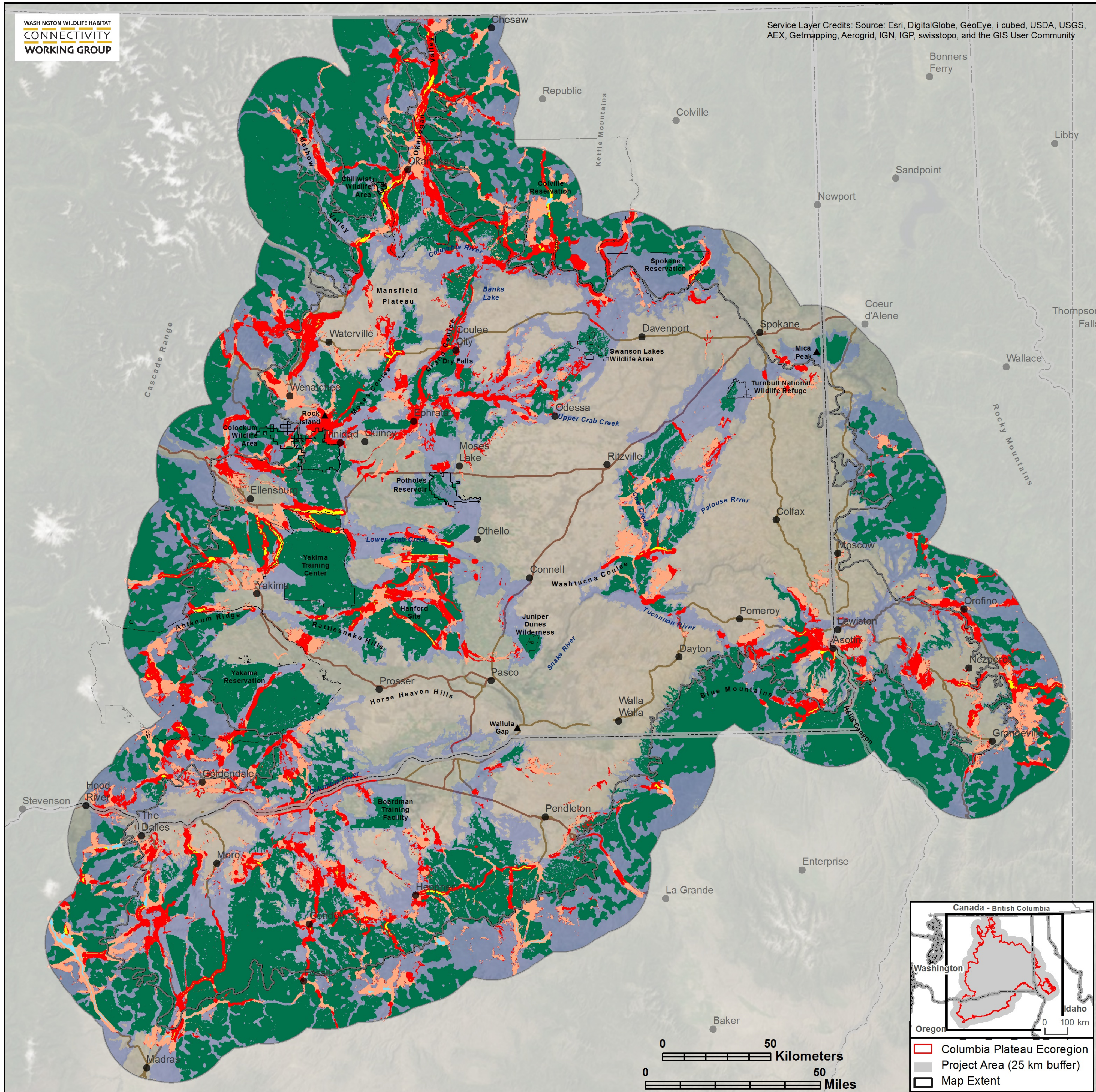

Figure 5. Overlay of Barriers and Restoration Opportunities for Climate-Gradient Corridors and Focal Species

WHAT ARE BARRIERS AND RESTORATION OPPORTUNITIES?

Barriers are areas where landscape features impede wildlife movement between habitat concentration areas (HCAs). Barriers are identified by comparing the least-cost paths of temperature-plus-Landscape Integrity corridors to paths that would be created if particular areas were restored, thereby reducing resistance to movement (McRae et al. 2012; McRae 2012b). 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., low density housing) or complete (e.g., an urban area), and, for this analysis, are human-made only (e.g., urban areas, highways, some types of agriculture), as climatic barriers (e.g., cold peaks or hot valleys along otherwise gentle climatic gradients between two HCAs) generally cannot be restored.

WHAT DOES THIS MAP TELL US?

This map shows areas where climate-gradient corridor barrier and restoration opportunities coincide with focal species barrier and restoration opportunities. Such areas may be considered connectivity conservation priorities, as their restoration may improve current species movements as well as the ability of species ranges to move in response to climate change.

HOW IS THE OVERLAY OF CLIMATE-GRADIENT AND FOCAL SPECIES BARRIERS AND RESTORATION OPPORTUNITIES DEPICTED ON THIS MAP?

- Yellow areas indicate places where climate-gradient barrier and restoration opportunities with high (3-15%) improvement scores overlap with any focal species barrier and restoration opportunities. Blue areas indicate places where climate-gradient barrier and restoration opportunities with high improvement scores do not overlap with any focal species barrier and restoration opportunities.
- Red areas indicate places where climate-gradient barrier and restoration opportunities with medium to low (0.05-3%) improvement scores overlap with any focal species barrier and restoration opportunities. Pink areas indicate places where climate-gradient barrier and restoration opportunities with high improvement scores do not overlap with any focal species barrier and restoration opportunities.

QUESTIONS AND DECISIONS THIS MAP HELPS INFORM

- Where will restoration efforts have the greatest effect on climate-connectivity as well as connectivity for focal species under current conditions?

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

Overlap
No Overlap
High
Low
Cores
Temperature-plus-LI Network

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

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Example Areas of Interest for Connectivity

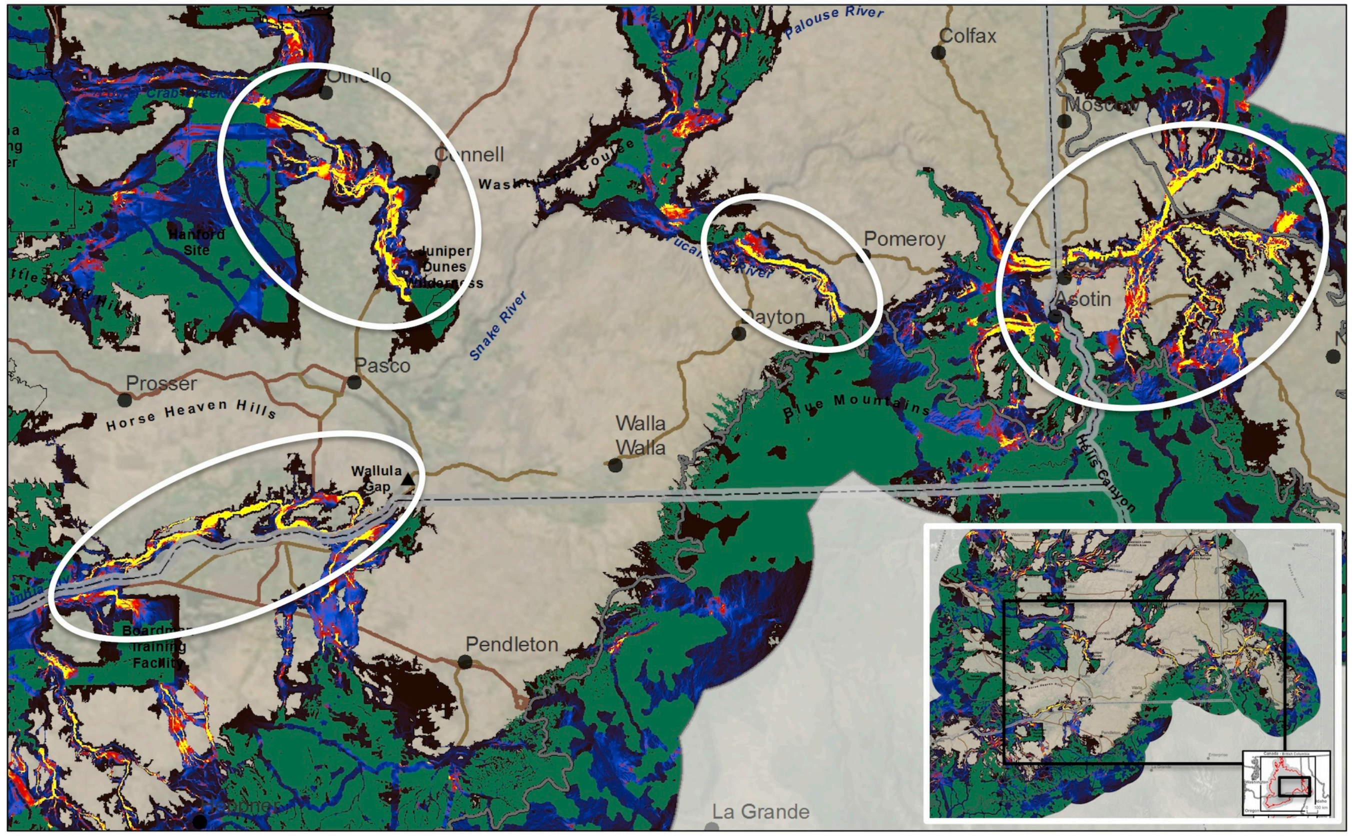

Figure 6. Many climate-gradient corridor pinch-points coincide with riparian corridors (i.e., areas beside rivers and stream; circled white).

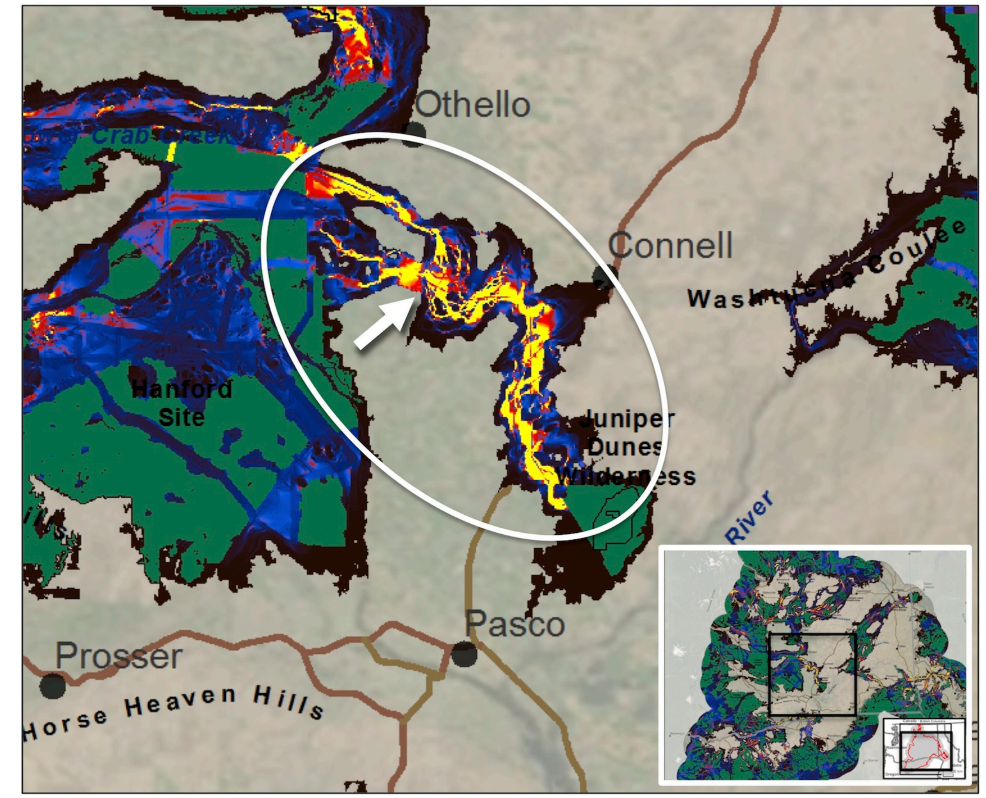

Figure 7. Climate-connectivity may be most at risk where a single, constrained linkage (e.g., portion of circled linkage to the east and south of white arrow) connects warmer to cooler HCAs.

- Many of the climate-gradient corridor pinch-points found in the relatively flat, highly-converted central interior of the Columbia Plateau are found along riparian corridors (circled areas in Fig. 6, above). This is likely because riparian areas tend to be narrow and in good condition relative to the surrounding landscape, and fall along climatic gradients linking warmer and cooler HCAs.
- Climate-gradient corridor and focal species linkage pinch-points (WHCWG 2013b) showed high agreement along riparian corridors (Fig. 4).
- None of the riparian pinch-points shown above were identified as barriers in our analysis, suggesting that wildlife movement along these corridors is unlikely to be significantly improved by restoration. Conservation action should thus be directed toward maintaining movement through these areas.

- Linkage pinch-points found within the only corridor between two HCAs are greater conservation priorities than pinch-points that constitute just one of several linkages between cores.
- For example, in the figure above (Fig. 7), a climate-gradient corridor (circled white) links the relatively warm Juniper Dunes Wilderness HCA to several cooler cores to its northwest. The portion of the linkage southeast of the white arrow is the most critical, as its loss would remove the only climate-gradient linkage out of the Juniper Dunes HCA. To the northwest of the white arrow, three linkages provide connectivity from the Juniper Dunes HCA to other HCAs; the loss of any one of these leaves two other options for movement into cooler HCAs, and thus are less of a priority than maintaining the portion of the linkage to the southeast.

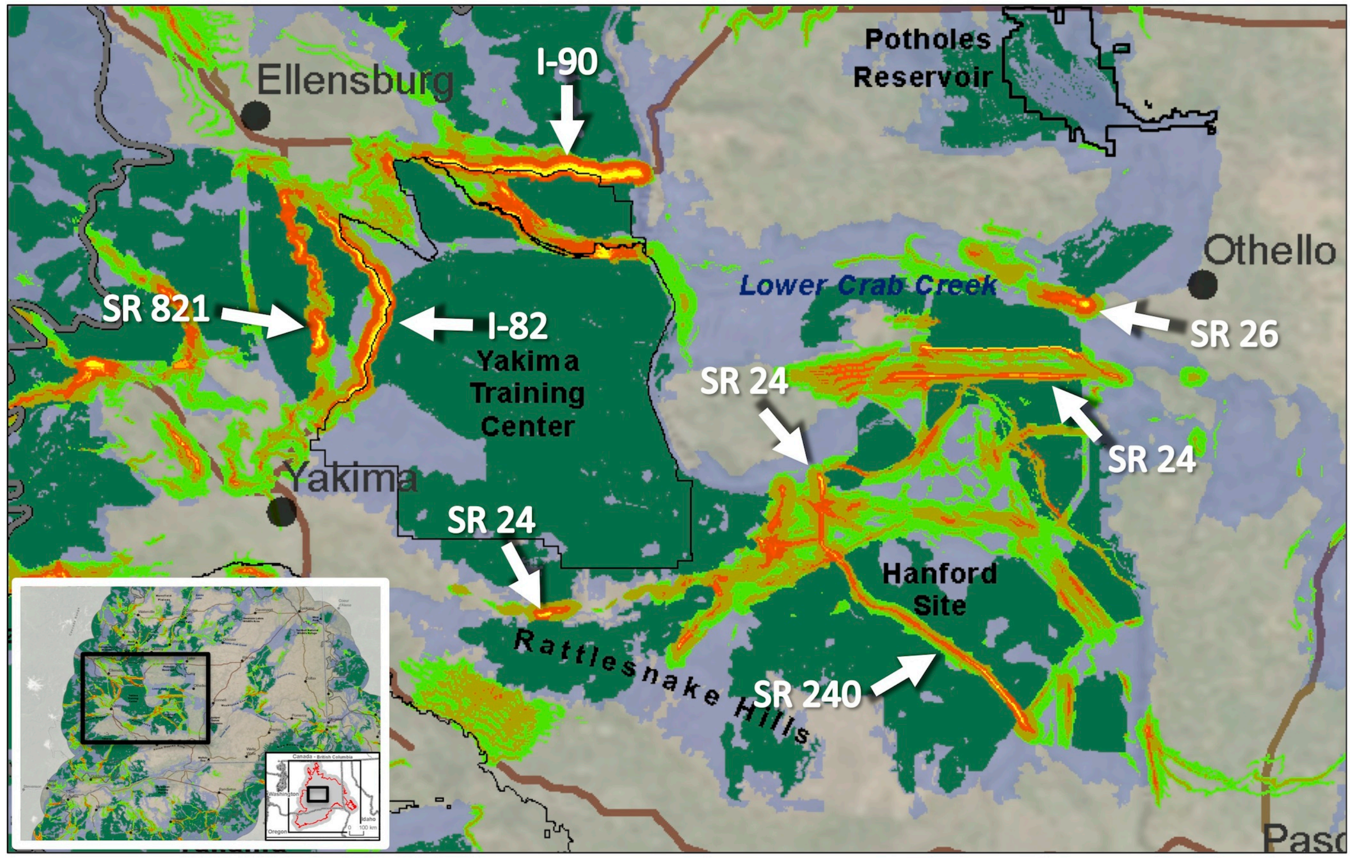

Figure 8. Roads and associated development and agriculture pose many of the barriers to climate-connectivity in the Columbia Plateau.

- Roads pose significant barriers to climate-connectivity in the Columbia Plateau (road-based barriers are highlighted by arrows in Fig 8, above, and labeled with corresponding highway). Restoring wildlife movement across roads (e.g., via culverts or other wildlife crossings) would dramatically improve climate-connectivity among HCAs.
- Road-based barriers like those highlighted above show high agreement with barriers identified in focal species analyses (Fig. 5; WHCWG 2013b), suggesting that their restoration would provide connectivity benefits now and under future climatic change.

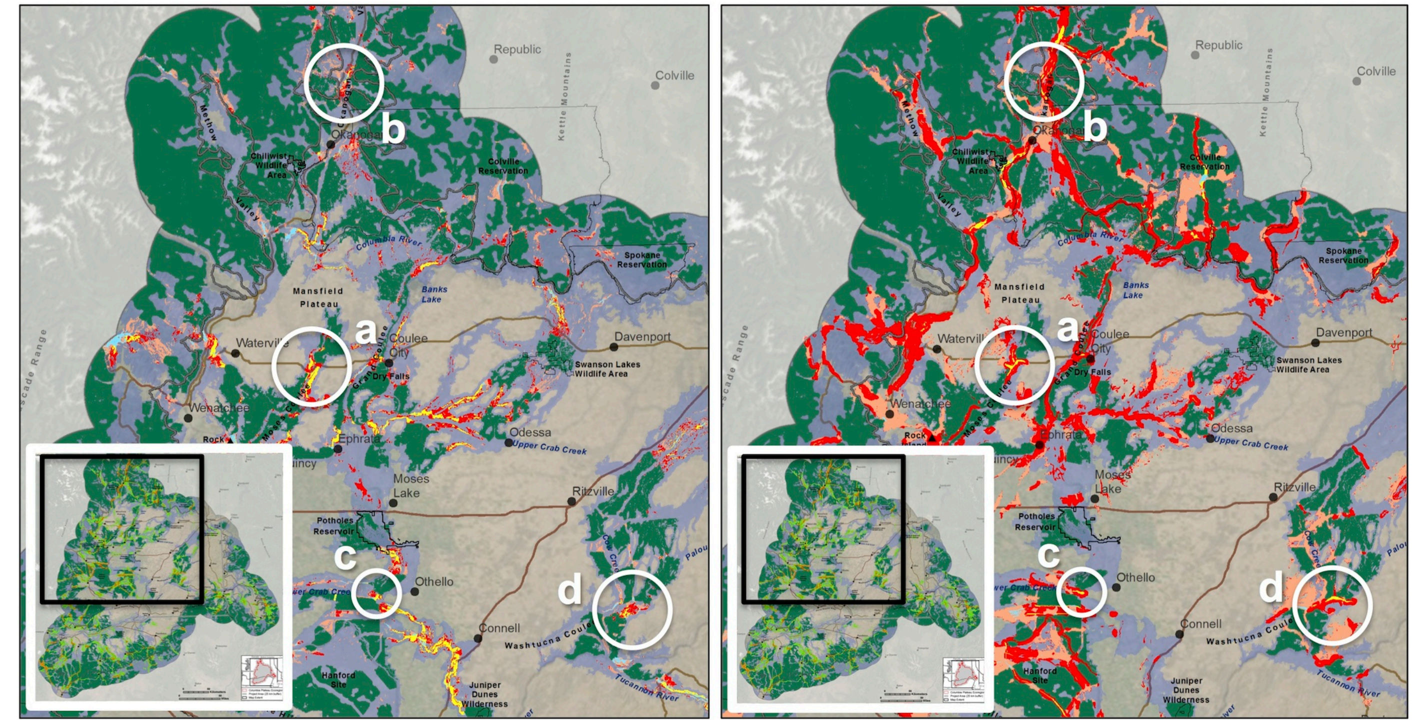

Figure 9. Areas that include pinch-points for both climate-gradient corridors and focal species linkages (map on left), *and* barriers and restoration opportunities for both climate-gradient-corridors and focal species linkages (map on right), suggest key conservation priorities for maintaining connectivity now and into the future.

- Several areas include pinch-points (map to the left in Fig. 9, above) and barriers (map to the right in Fig. 9, above) for both climate-gradient corridors and focal species linkages (WHCWG 2013b). Such areas should be considered conservation priorities because they are expected to provide critical linkages now and in the future, yet are threatened and could be dramatically improved by restoration.
- Example linkages can be found south of the Mansfield Plateau (a), in the Okanagan Valley (b), west of Othello (c), and along Washtucna Coulee (d).

Key Terms for Understanding the Analyses

Barrier — We define a barrier as a landscape feature that impedes movement between ecologically important areas, the removal of which would increase the potential for movements between those areas (McRae et al. 2012). Barriers are thus the inverse of corridors, which delineate pathways facilitating movement. Barriers can either be complete (impermeable) or partial (e.g., land-cover types that hinder movement relative to ideal conditions, but may still provide some connectivity value). Barriers may be human-made (e.g., roads, fences, or urban areas) or natural (rivers or canyons); they may be linear (e.g., highways) or span large areas (agricultural fields). Because we cannot reasonably remove or restore a climatic barrier (e.g., a hot valley or cold peak within an otherwise gentle climatic gradient between warmer and cooler HCAs), our analysis identifies only human-made barriers. Not all barriers are restorable.

Corridor **—** In this document, refers to modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife that connect HCAs. For climate-gradient corridors, these are areas predicted to be important for allowing range shifts from warmer to cooler areas as the climate warms. For focal species, these are areas predicted to be important for migration, dispersal, or gene flow.

Current Flow — For several reasons, electrical networks can be used as models of habitat networks (See McRae et al. 2008 for more details). Like the flow of electrical current, processes like dispersal often occur over multiple, diffuse pathways rather than along single, optimal routes. Even if organisms "obediently" use corridors set aside for them, unpredictable events like wildfires can destroy a corridor overnight. Therefore, building redundancy into connectivity plans is critical to conserving ecological processes over the long-term. Modeling current flow through linkages and across linkage networks can show where there are pinch-points in linkages and where HCAs and linkages are critical because alternative routes don't exist.

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. In this analysis, HCAs are areas of high landscape integrity (i.e., limited roads, dwellings, agriculture) that are thus expected to be permeable to wildlife movement. HCAs are not to be confused with "source habitat" terminology used when modeling population dynamics (i.e., habitat in which local reproductive success exceeds local mortality).

Landscape Resistance Surface — Map which covers a broad area and indicates the ease or difficulty of movement for a species across the area. In a GIS this is represented as a raster grid of resistance values corresponding to different landscape features.

Least-Cost Path — The one-pixel-wide modeled path between two HCAs with the lowest possible accumulated travel cost in terms of landscape resistance, i.e., the easiest or most efficient path for movement.

Linkage — 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). For climate-gradient corridors, these are areas identified by our models as important for movement between warmer and cooler HCAs as the climate warms. For focal species, these are corridors identified as important for wildlife movement between HCAs.

Corridor Network — System of core areas and areas important for connecting them. For our project, corridor networks represent the area encompassed by the combination of habitat concentration areas and modeled linkages.

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.

Restoration Improvement Score — In our study, we quantified the reduction in least-cost distance for linkages that could be expected if an area were restored. We measured this in terms of percent reduction in least-cost distance per hectare restored, assuming a swath across the search window area was restored to a resistance of 1.0 (i.e., lowest resistance).

Restoration Opportunities — In this document we have termed the barrier analysis results "barriers and restoration opportunities" to indicate that our models identify a spectrum of barrier types, some restorable and some not. Those persons implementing connectivity conservation can further evaluate the identified barriers to determine which offer the best opportunities for restoration.

Citations

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