Washington Connected Landscapes Project:

Columbia Plateau Climate-Gradient Corridors Analysis

Washington Wildlife Habitat Connectivity

Working Group

May 2013

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.

Full Document Citation

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2013. Washington Connected Landscapes Project: Columbia Plateau Climate-Gradient Corridors Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.

Document Availability

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

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Acknowledgements

In addition to the generous contributions of Washington Wildlife Habitat Connectivity Working Group organizations, we wish to extend appreciation to the following entities that have provided funding critical to the accomplishment of this effort:

- Bureau of Land Management
- Great Northern Landscape Conservation Cooperative
- North Pacific Landscape Conservation Cooperative
- US Fish and Wildlife Service (Washington State Recovery Funds)
- Wilburforce Foundation
- Anne Ray Charitable Trust

Introduction

Washington State is expected to see profound impacts from climate change over the coming century, from decreasing snowpack and reduced summer stream flows to increasingly frequent and severe wildfires. Climate change is also expected to impact Washington's wildlife, as the climatic conditions to which species have adapted move or disappear entirely. Historically, species have responded to such changes by adjusting their geographic ranges to track shifting areas of climatic suitability. Today, however, such responses are challenged by the rapid rate of warming and widespread human-made barriers to movement, such as those posed by roads, urban areas, and agriculture.

In few areas of Washington is this threat more of a concern than within the Columbia Plateau Ecoregion. The Columbia Plateau is expected to see relatively severe climate impacts, yet its wildlife already face numerous stressors, including extensive habitat loss and fragmentation from agriculture and exotic species invasions. For this reason, maintaining ecological connectivity within the Columbia Plateau and to neighboring areas will be critical to promoting the ecoregion's resilience to climate change.

In 2011, the Washington Wildlife Habitat Connectivity Working Group (WHCWG) released a report identifying linkages specifically intended to enhance the ability of wildlife to respond to future changes in climate. The WHCWG *Statewide Climate-Gradient Corridors Analysis* (WHCWG 2011) identified corridors that fell along the climatic gradients (specifically temperature) that species ranges are likely to follow as they move to track shifting climates. This approach is based on the assumption that if climatic gradients are conserved (e.g., as temperatures increase, higher elevations will still be relatively cooler than lower elevations even if both are eventually warmer), then species can generally be expected to move from currently warmer areas to currently cooler areas (Fig. 1). While a standard corridor might minimize the geographic distance and barriers to movement between two core areas, a climate-gradient corridor seeks to minimize changes in climate encountered between core areas of differing temperature. The corridors thus allow for movement from relatively warmer to cooler core areas, while following relatively gentle climatic gradients (e.g., avoiding crossing over cold peaks or dipping into hot valleys).

The *Statewide Climate-Gradient Corridor Analysis* (WHCWG 2011) offered a broad overview of climate-connectivity patterns across Washington, and was not intended to inform on-the-ground implementation. This *Columbia Plateau Climate-Gradient Corridors Analysis* incorporates finer-scale land use and climate spatial data layers, taking us one step closer to the information needed to guide local and regional climate-connectivity conservation action. This report: (1) provides a brief review of the methods used to identify these corridors (for more detailed methodology please refer to WHCWG 2011 and Nuñez et al. 2013), highlighting differences between the Columbia Plateau and statewide analysis approaches; (2) describes key emerging patterns and insights revealed by the analysis; (3) suggests how these map products might be appropriately interpreted and applied; and (4) identifies remaining information needs and opportunities for future analyses.

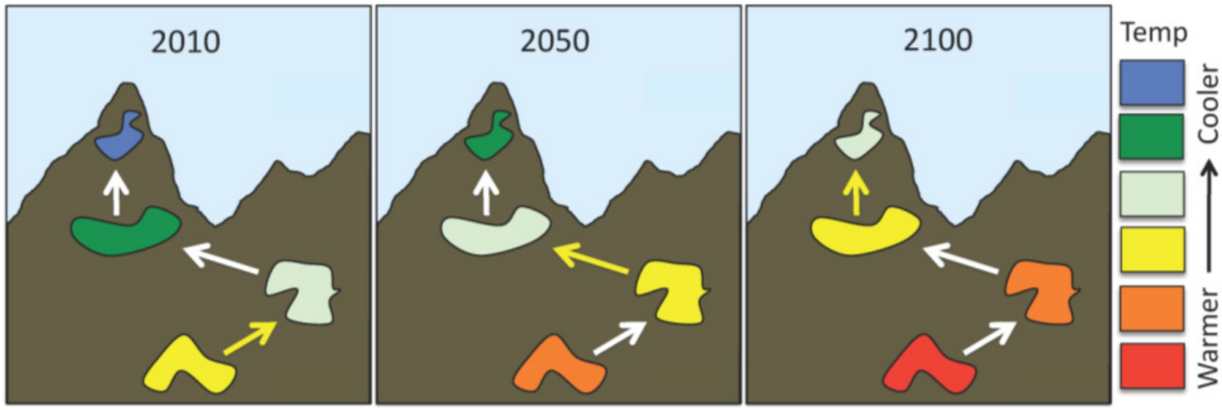

Figure 1. ***Pathways through a Changing Climate.*** As the climate warms, corridors (arrows) between relatively warmer and cooler core areas offer wildlife opportunities to track their suitable climates across the landscape. Essentially, they promote a species' ability to "run to stand still," that is, to move to new areas on the landscape in order to experience little to no change in climate.

Methods

We identified climate-gradient corridors by using cost-distance modeling to map corridors with the most unidirectional changes in temperature, and the highest landscape integrity (lowest human impact) between core areas of differing temperature. While in most instances the methods used to identify Columbia Plateau climate-gradient corridors are identical to those presented in WHCWG (2011) and Nuñez et al. (2013), there are several key differences. The most basic difference is the reduced analysis extent, which includes the Columbia Plateau Ecoregion and those lands within a 25 km buffer around the ecoregion boundary. Additional differences between the two analyses are highlighted below. The basic modeling steps were (1) selection of core areas, (2) definition of linkage rules, and (3) linkage modeling.

Core Area Selection

We used core areas identified by the landscape integrity connectivity analysis for the Columbia Plateau Ecoregion (WHCWG 2012). These core areas are large (41 to 1112 km^2), contiguous areas of land with a high degree of naturalness (i.e., areas with low levels of human impact) relative to the rest of the study area. Differences between the spatial data layers used to identify core areas in the Columbia Plateau analysis and the statewide analysis include 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 (WHCWG 2012). These changes resulted in subdividing high landscape integrity lands into more (and smaller) core areas in the Columbia Plateau analysis compared to the statewide analysis; landscape integrity core areas within the Columbia Plateau averaged 224 km^2 in the statewide analysis, vs. 140 km^2 in the ecoregional analysis. This should improve the climate-gradient corridor model by (1) reducing the climatic heterogeneity within core areas, so that the mean annual temperature of the core areas (which is used to determine which core areas are linked to which) better reflects the range of temperatures within the core areas; and (2) increasing the number of linkages among core areas, resulting in a more extensive climate corridor network.

Linkage Rules

As in the statewide analysis, we connected core areas based on:

- ***Temperature—***We connected core areas if they differed in their coldest mean annual temperatures by at least 1 °C.
- ***Distance—***We connected core areas if they were ≤50 km apart, to avoid unrealistically long linkages.

Linkage Modeling

We used *Climate Linkage Mapper* (Kavanagh et al. 2012), an ArcGIS tool developed to automate climate-gradient corridor mapping, to model least-cost corridors between core areas. As in the statewide analysis, we mapped two types of corridor networks:

- ***Temperature-Only Corridors—***These corridors find the routes of most unidirectional change in temperature between core areas, regardless of intervening land cover.
- ***Temperature-Plus-Landscape-Integrity Corridors—***These corridors find the routes of most constant change in temperature between core areas (as above), but also avoid areas of low landscape integrity (e.g., roads, agricultural areas, and urban areas).

The resistance layers used for the Columbia Plateau linkage modeling differed in two key ways from those used in the statewide analysis:

1) **Use of a 90-meter resolution temperature layer, rather than the 1000-meter resolution layer used in the statewide analysis.** This is expected to improve the climate-gradient corridor model for two reasons. First, the downscaling method used to produce the 90 m layer (Climate WNA; see Wang et al. 2012) has been shown to increase the accuracy of temperature layers in areas of complex topography, as topography is the primary driver of climate gradients in such areas. Second, using a finer-scale temperature layer removes artificially large (and costly) differences in temperature that occur between coarser-scale cells, improving the ability of climate-gradient corridors to track local temperature gradients.
2) **Use of the landscape integrity layer from the WHCWG Analysis of the Columbia Plateau Ecoregion (WHCWG 2012), rather than the landscape integrity layer used in the statewide analysis (WHCWG 2010).** The Columbia Plateau landscape integrity layer differed from its statewide counterpart due to inclusion of transmission lines, wind turbines, and railroads, and changes in how low-use roads were used in determining core areas and resistance. These changes to the landscape integrity resistance surface may be expected to influence the linkages identified by the temperature-plus-landscape-integrity corridor model.

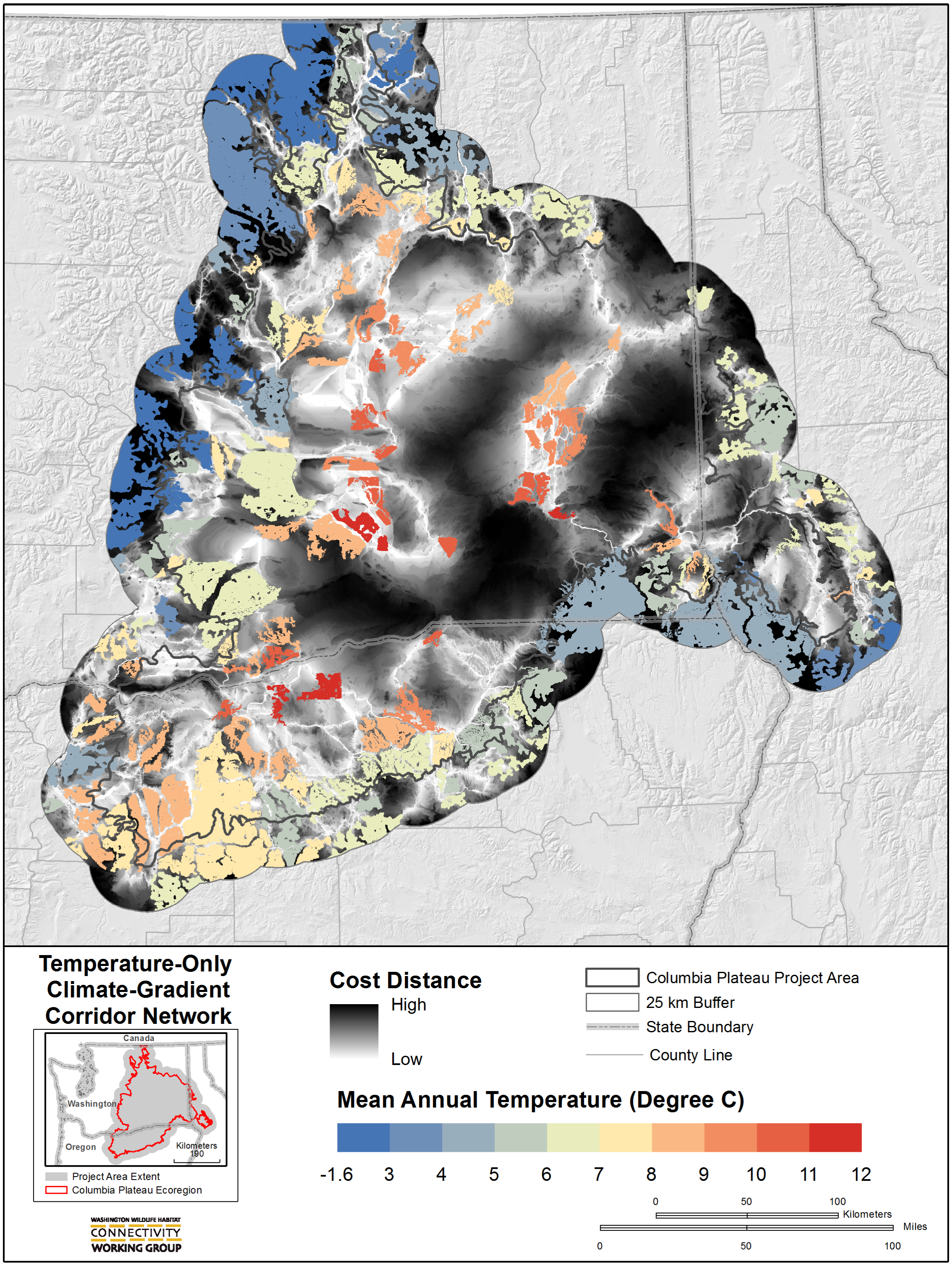

Figure 2. ***Temperature-Only Climate-Gradient Corridor Network for the Columbia Plateau Ecoregion.*** Corridors connect core areas of high landscape integrity that differ in temperature by >1 ºC, minimizing changes in temperature along the way. Corridors are represented as glowing white areas, with resistance to movement increasing as white fades to black. Polygons represent the core areas, shaded to reflect their mean annual temperatures.

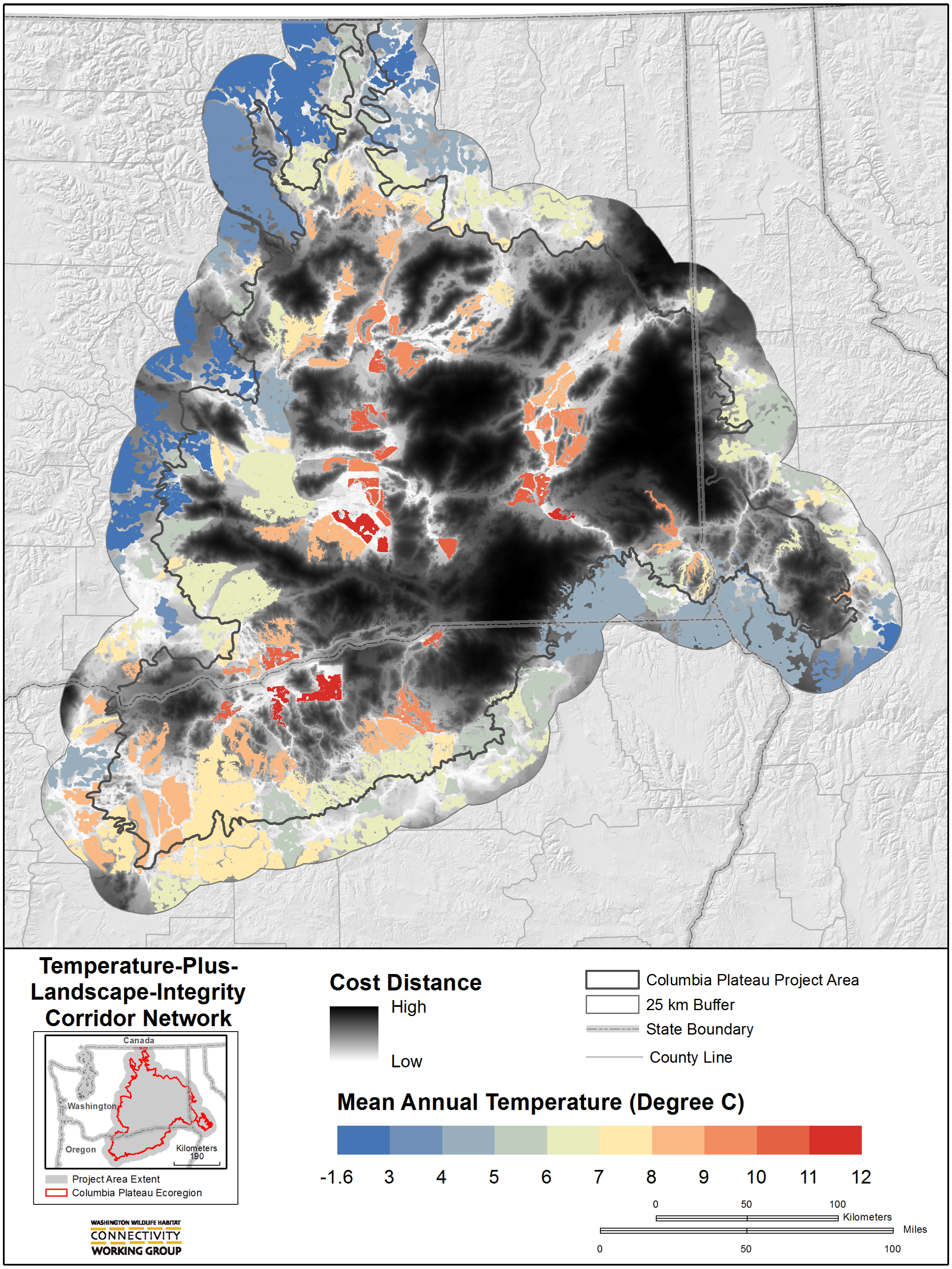

Figure 3. ***Temperature-Plus-Landscape-Integrity Corridor Network.*** In addition to minimizing changes in temperature along routes between warmer and cooler core areas, this corridor network also avoids areas of low landscape integrity (e.g., roads, agricultural areas, and urban areas). Corridors are represented as glowing white areas, with resistance to movement increasing as white fades to black. Polygons represent the core areas, shaded to reflect their mean annual temperatures.

Key Emerging Patterns and Insights

The climate-gradient corridor analysis resulted in two networks of landscape integrity core areas connected by corridors falling along the Columbia Plateau's major temperature gradients: a temperature-only corridor network (Fig. 2), and a temperature-plus-landscape-integrity corridor network (Fig. 3).

Comparisons between Two Scales of Analysis

Differences between the Columbia Plateau and the statewide climate-gradient corridor analyses (clipped to the Columbia Plateau) were driven by the three main changes to model inputs described above: (1) use of a finer-scale temperature layer, (2) use of the landscape integrity layer produced in the *Analysis of the Columbia Plateau Ecoregion* (WHCWG 2012), and (3) a smaller analysis extent. Specifically:

1) ***The use of a finer-scale temperature layer significantly affected corridor routes.*** The 90 m temperature layer better reflected the fine-scale topographic relief driving regional temperature gradients, resulting in sometimes major re-routings of climate-gradient corridors between core areas (Fig. 4). Though using the finer-scale layer required substantially more processing time, the magnitude of the resulting difference suggests that use of the finer scale layer is a worthwhile investment.

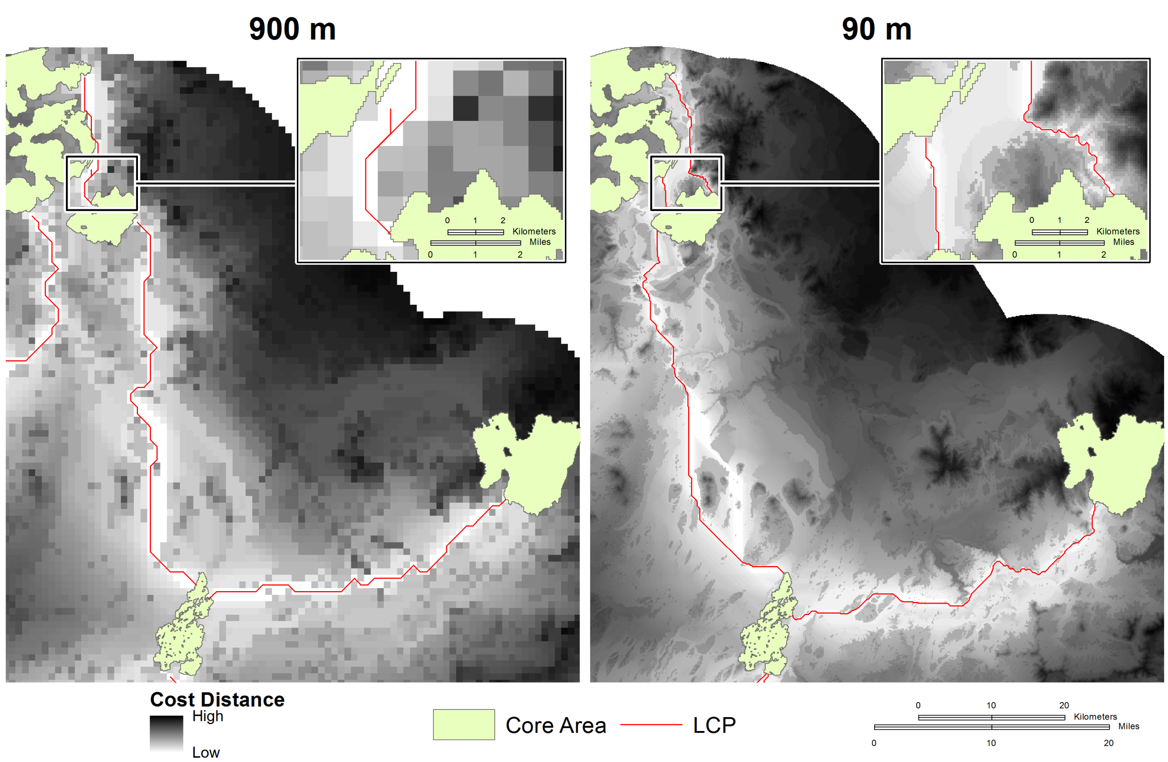

Figure 4. ***Climate-Gradient Corridors Produced Using 900 m (Left Panel) and 90 m (Right Panel) Resolution Temperature Layers.*** Red lines represent the least cost path (i.e., the one-pixel-wide optimal route) between cores, while corridors are represented as glowing white areas, with resistance to movement increasing as white fades to black. Insets show a magnification of the boxed areas to their left.

2) ***The use of the Columbia Plateau landscape integrity layer resulted in several significant changes.*** Specifically:

- **The greater number of landscape integrity core areas led to an increased number of climate-gradient corridors.** A total of 415 climate-gradient corridors was identified by the Columbia Plateau analysis vs. 223 for the statewide analysis (clipped to the Columbia Plateau). This is explained by the splitting of statewide core areas by newly identified secondary roads and other barriers, which resulted in new linkages among what were previously single, large core areas; and the presence of new core areas in areas with no core areas in the statewide analysis (e.g., due to the lowering of the resistance of those agricultural lands under permanent herbaceous vegetation cover, which are expected to be more wildlife-friendly than other agricultural lands), leading to new corridors linking these to other core areas (e.g., Fig. 5, Panels "a" and "b," circles labeled "1").

- **The smaller size of landscape integrity core areas led to reduced climatic heterogeneity within core areas.** This difference was minimal—the average standard deviation of mean annual temperature within a core area was 0.67 for the Columbia Plateau analysis, compared to 0.69 for core areas within the Columbia Plateau in the statewide analysis—but is expected to improve the accuracy of the model by linking core areas whose mean annual temperatures (which determine which core areas are linked to which) better reflect the range of temperatures found within the core areas.

- **Use of the improved landscape integrity resistance surface resulted in both the gain and loss of key linkage areas relative to the statewide climate-gradient corridor analysis.** These gains and losses are distinct from those stemming from changes to the landscape integrity core areas. For example, some linkages were lost where statewide corridors traversed newly identified barriers such as transmission lines and secondary roads, resulting in new linkages through areas of relatively lower resistance (e.g., Fig. 5, Panels "a" and "b," circles labeled "2" and "3").

- **The clipping of the statewide analysis extent to the Columbia Plateau bisected many large core areas in the Columbia Plateau buffer, leading to changes in relative temperatures among core areas, and subsequent changes to linkages.** As described above, the breaking up of large, climatically heterogeneous core areas changed the mean temperatures of these core areas, and subsequently which core areas were linked to which. Because many of the core areas in the Columbia Plateau buffer region were, in the statewide analysis, part of much larger core areas which included cold, high-elevation areas beyond the buffer, clipping generally increased the mean temperatures of these core areas (e.g., see the change from deeper to paler blues and yellows for core areas in the buffer area of Panel "a" vs. Panel "b" in Fig. 5). Thus, linkages to and among these smaller core areas are likely to better reflect the range of temperatures immediately available to wildlife moving out of the Columbia Plateau's warm interior to cooler peripheral core areas.

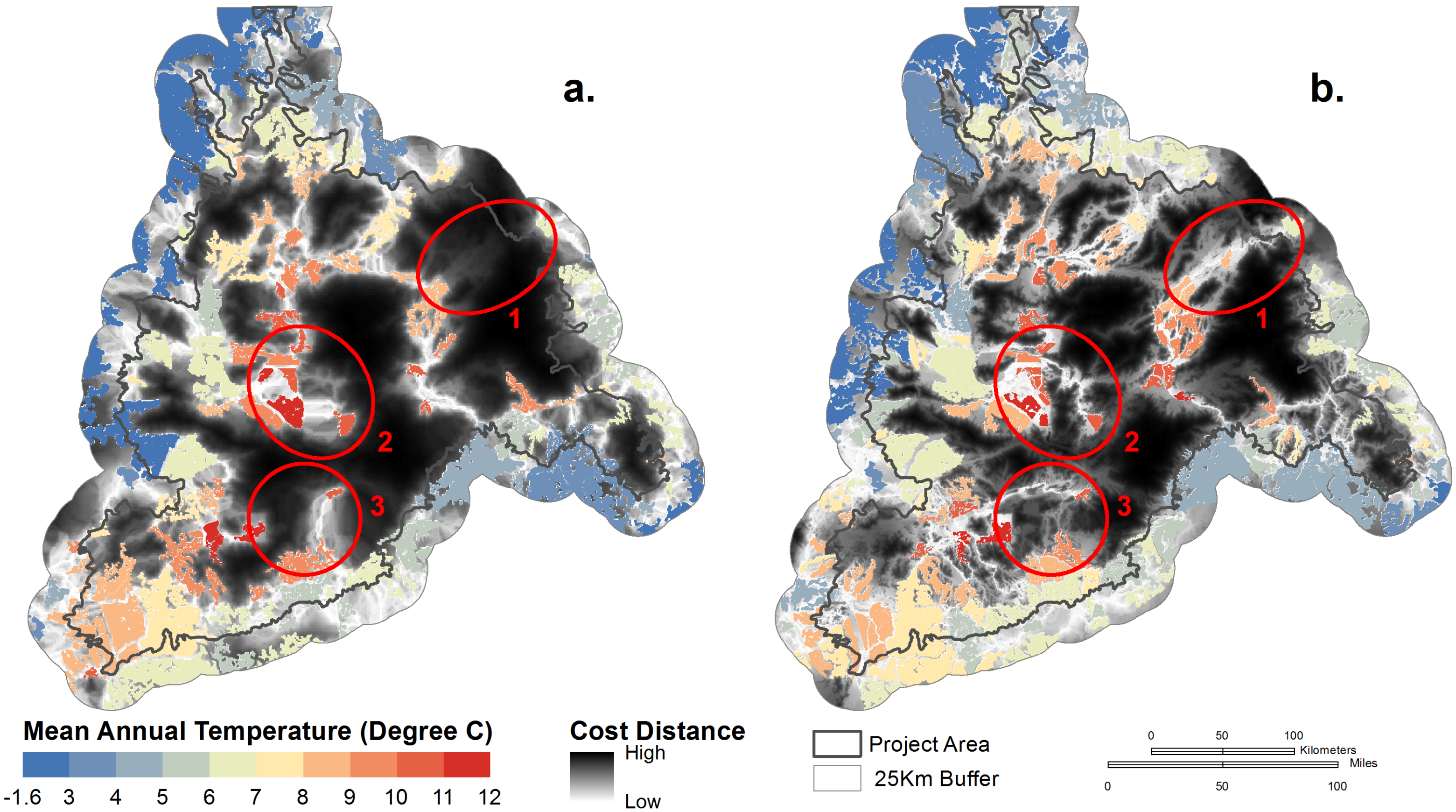

Figure 5. ***Statewide (Panel a) and Columbia Plateau (Panel b) Temperature-Plus-Landscape-Integrity Climate-Gradient Corridor Networks for the Columbia Plateau Ecoregion.*** See text above for further information.

Comparisons among Temperature-Only, Temperature-Plus-Landscape-Integrity, and Landscape-Integrity-Only Analyses

In the statewide climate-gradient corridor analysis, relatively gentle climate gradients and relatively intense land use within the Columbia Plateau Ecoregion led to distinct differences between the temperature-only and temperature-plus-landscape-integrity models. The Columbia Plateau climate-gradient corridor analysis refines these two models by including finer-scale temperature and land-use input layers, and allows for a more in-depth comparison of the models' differences and what they might suggest for model application. In addition, including the landscape-integrity-only model (referred to as simply "Landscape Integrity" in WHCWG 2012) in our comparisons is critical to understanding the relative influence of climate and land use in determining climate-gradient corridor networks, and thus their appropriate interpretation. Specifically:

- **Temperature-only corridors in the Columbia Plateau are relatively wide in flat, lower elevation areas in the interior and relatively narrow in the steeper, higher elevation areas at the periphery.** As noted in the statewide analysis, because climate gradients are shallow in the relatively flat interior of the Columbia Plateau, temperature-only corridors here are relatively wide (Fig. 2), as most routes between core areas are of equally low cost. But, because climate-gradient corridors in high-elevation areas are more likely to encounter large, costly changes in temperature, temperature-only corridors at the ecoregion's periphery are relatively narrow (Fig. 2).
- **The temperature-plus-landscape-integrity corridor network is virtually identical to the landscape-integrity-only corridor network in the relatively flat, lower elevation areas toward the interior of the Columbia Plateau.** High intensity land-use in the Columbia Plateau leads to steep cost differences between the relatively few areas of high landscape integrity and those with low landscape integrity. On the other hand, cost differences due to temperature changes are relatively small because of shallow climatic gradients in this area. Thus, the temperature-plus-landscape-integrity corridor network is virtually identical to the landscape-integrity-only corridor network (Fig. 6).
- **Differences between the temperature-plus-landscape-integrity and landscape-integrity-only corridor networks are primarily caused by climate-gradient corridor linkage rules.** Since climate-gradient corridors connect only core areas that differ in temperature, differences between the two models result primarily from the loss of landscape integrity corridors that link core areas of similar temperature (Fig. 6, pale pink areas where the landscape-integrity-only network does not overlap the temperature-plus-landscape-integrity network).

Insights from Model Comparisons

- **The temperature-plus-landscape-integrity model allows for the identification (and prioritization) of landscape integrity linkages that connect warm core areas to cool ones.** Temperature-plus-landscape-integrity linkages in the Columbia Plateau are, for the most part, landscape integrity linkages that connect core areas of differing temperature.

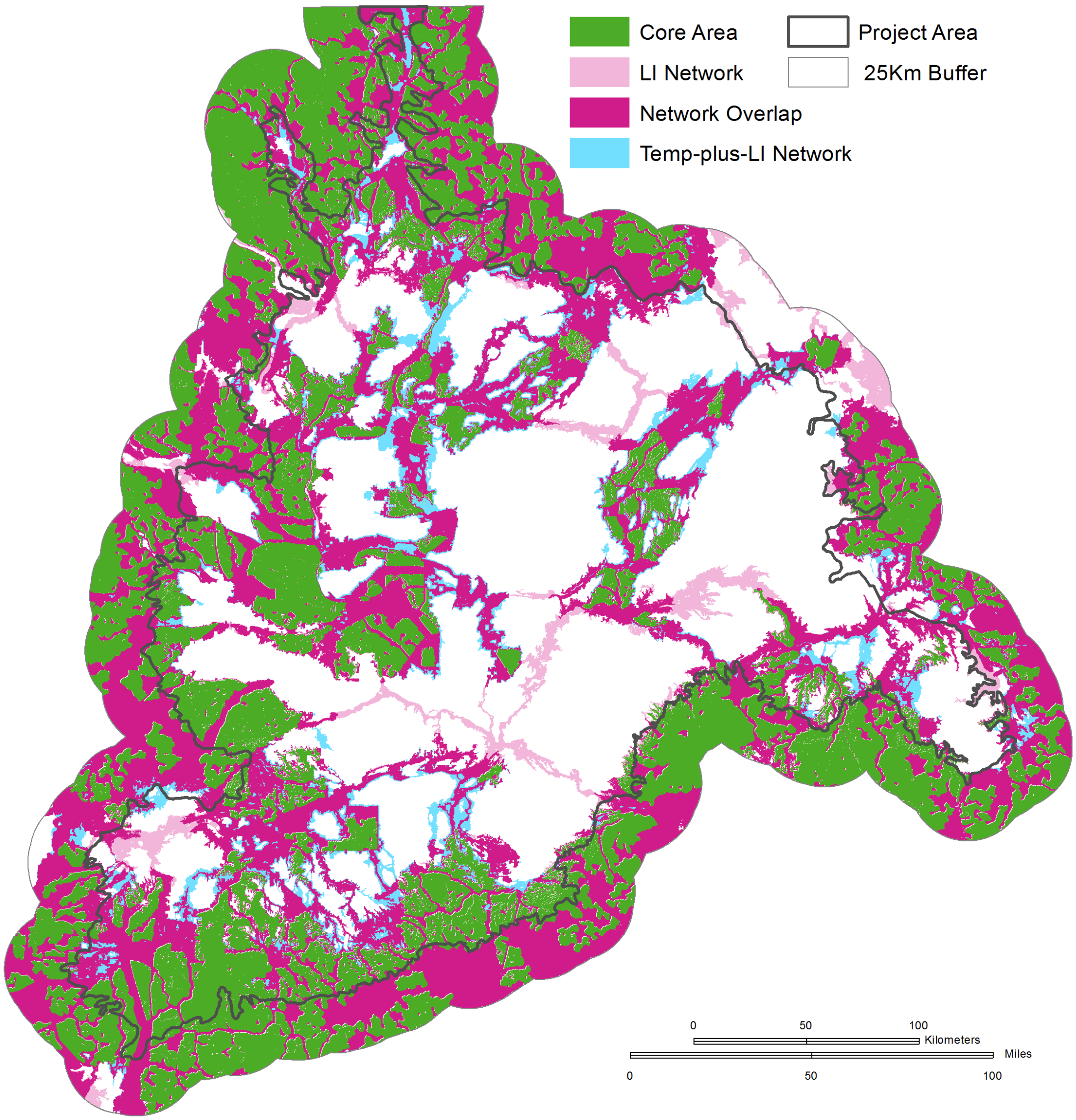

Figure 6. ***Overlay of Landscape Integrity-Only and Temperature-plus-Landscape-Integrity Climate-Gradient Corridor Networks.***

Since the temperature-only model links the same core areas as the temperature-plus-landscape-integrity model, but does not consider intervening land use, it offers a complementary view of climate-connectivity needs within the Columbia Plateau. Specifically:

- **The temperature-only model allows for the identification of climate-connectivity restoration opportunities within the Columbia Plateau.** Temperature-only corridors follow least-cost climate paths between core areas of differing temperature, but intensive land use in the Columbia Plateau removes them from the temperature-plus-landscape-integrity network. Consequently, these corridors identify opportunities for restoring the most climatically direct routes between warmer areas and cooler ones.

Suggested Interpretation and Application of the Analysis

Ultimately, the relatively small differences in temperature among core areas within the Columbia Plateau, and the relatively shallow climatic gradients among them suggest the following overarching take-home messages from the analysis:

- **Toward the interior of the Columbia Plateau, climate-gradient corridors provide only limited added value to landscape integrity and focal species corridors in identifying connectivity priorities for promoting biological resilience to climate change.** The relatively homogenous climate in the interior of the Columbia Plateau suggests that climate-gradient corridors are of limited utility in this area. Efforts to build biological resilience to climate change via connectivity conservation should instead focus on maintaining and enhancing connectivity priorities identified using models of current condition (e.g., focal species and landscape integrity).

- **Toward the periphery of the Columbia Plateau, climate-gradient corridors provide significant added value to landscape integrity and focal species models in identifying connectivity priorities for promoting biological resilience to climate change.** The presence of strong climatic gradients and core areas of increasingly cool temperatures toward the Columbia Plateau's periphery leads to climate gradient corridors that identify critical climate-connectivity conservation opportunities that would otherwise go unrecognized by analyses focused on current conditions. Given limited available refugia from warming within the flat, warm interior of the plateau, climate-gradient corridors may offer valuable access to higher elevation areas toward the periphery of the Plateau and beyond, increasing the resilience of wildlife within the plateau.
- **Areas of overlap between temperature-only and temperature-plus-landscape-integrity linkages identify potentially low-cost opportunities for maintaining climate-connectivity.** Since the only difference between the two models is the inclusion of land-use, temperature-plus-landscape-integrity corridors that overlap with temperature-only corridors identify areas that provide the most direct climatic routes between warm and cool core areas while also avoiding areas of low landscape integrity, and thus may suggest priority areas for climate-connectivity conservation (Fig. 7, magenta areas of network overlap).
- **Areas where temperature-only corridors do not agree with temperature-plus-landscape-integrity corridors highlight climate-connectivity restoration opportunities.** These areas represent the most direct climate-gradient corridors between warm areas and cool, yet have low landscape integrity, as indicated by the absence of temperature-plus-landscape-integrity corridors. This suggests that these corridors present good starting points for evaluating climate-connectivity restoration activities (Fig. 7, pale pink areas).
- **Areas where climate-gradient and focal species connectivity networks overlap highlight potential priority areas for climate-connectivity conservation efforts (Fig. 8).** Overlaying climate-gradient corridor networks with focal species connectivity networks offers additional opportunities for guiding climate-connectivity conservation decisions. As areas of overlap are valuable for both current and future connectivity, they suggest priority areas for

connectivity maintenance and restoration. However, because climate-gradient corridor networks include landscape integrity core areas as well as climate-gradient corridors, such overlays may be most powerfully interpreted and applied by analyzing them together with other climate-gradient corridor map products (e.g., Figs. 3, 7, and 9), to better understand the underlying reasons for network overlap and implications for implementation. Future analyses (see *Conclusions and Future Work*, below) may offer additional guidance and products regarding this approach.

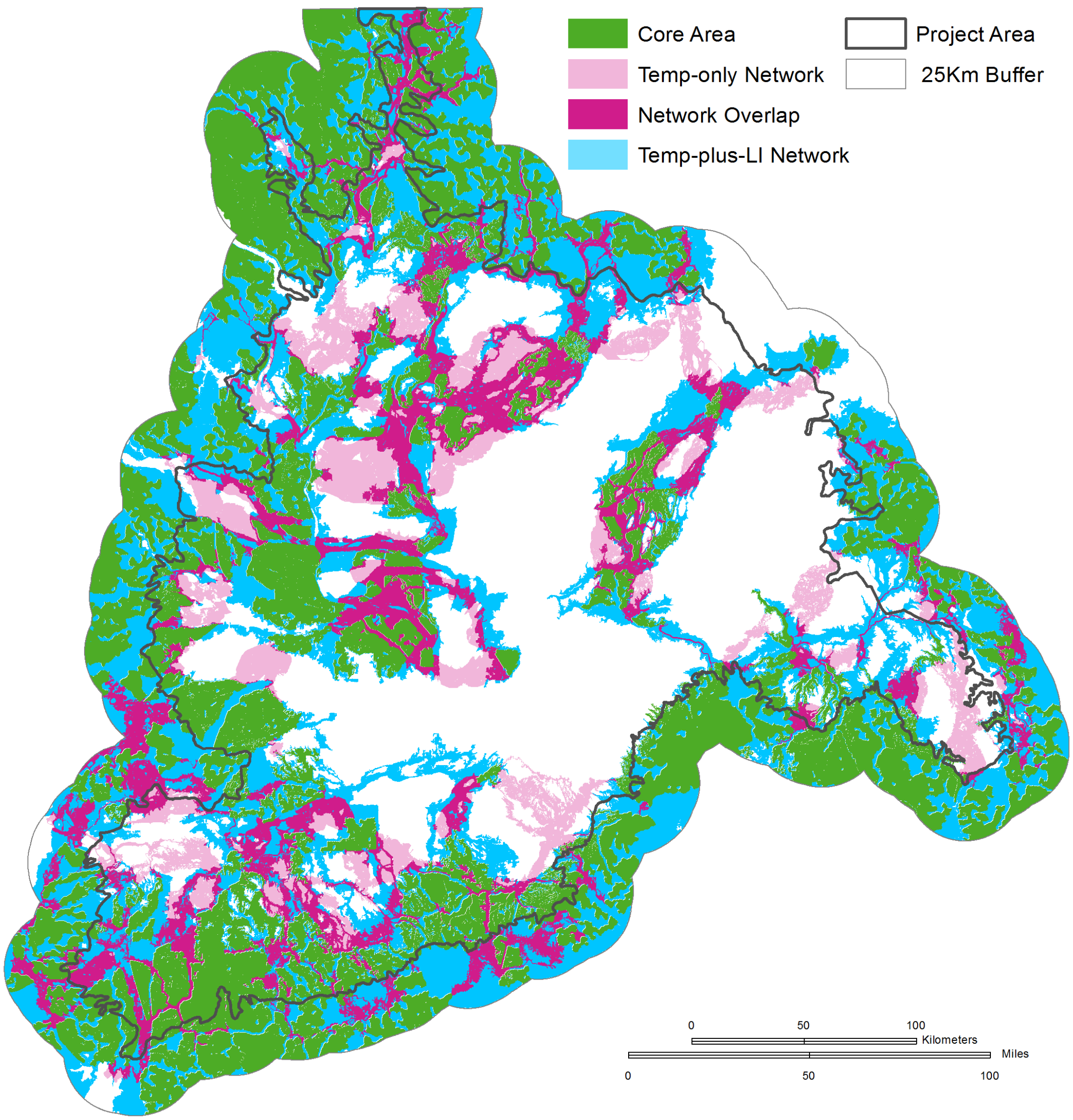

Figure 7. ***Overlay of Temperature-only and Temperature-plus-Landscape Integrity Climate-Gradient Corridor Networks.***

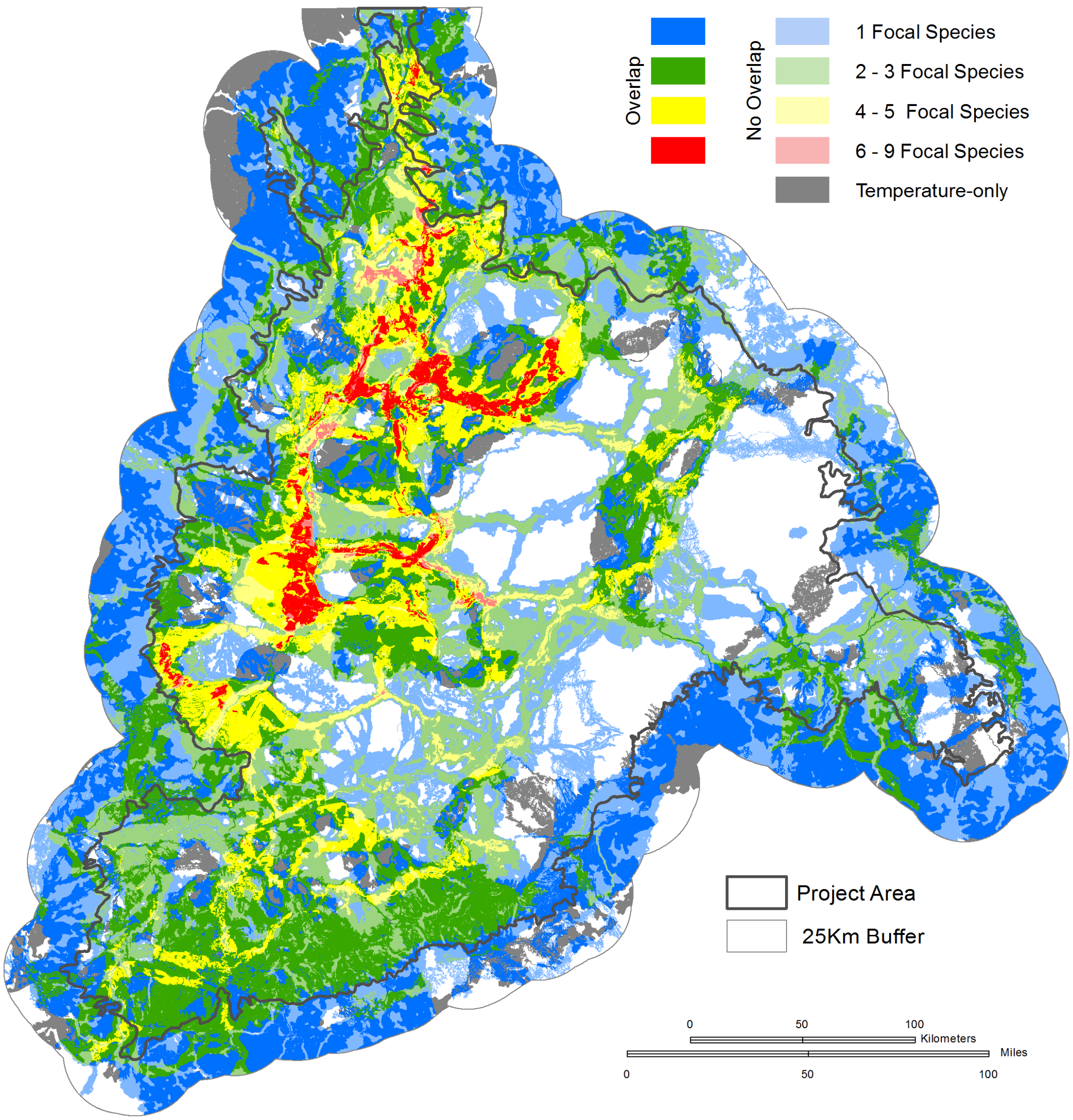

Figure 8. ***Overlay of the Temperature-only Climate-Gradient Corridor Network and Focal Species Networks from the Analysis of the Columbia Plateau Ecoregion (WHCWG 2012).***

A Vision for a Climatically-Connected Columbia Plateau Ecoregion

The WHCWG *Analysis of the Columbia Plateau Ecoregion* (WHCWG 2012) suggested a vision for a connected Columbia Plateau, which identified several key connectivity zones for focal species and landscape integrity within the Plateau and out to surrounding areas. Incorporating climate-gradient corridors into this vision draws attention to additional linkage zones whose primary added value is in facilitating the movement of wildlife out of the warm heart of the Columbia Plateau and up into the cooler, higher elevation areas at its periphery (Fig. 9). As discussed above, because core areas toward the interior of the ecoregion feature relatively similar temperatures, with intervening climate gradients that are relatively shallow, some key connectivity areas identified by focal species and landscape integrity networks—most notably the southern half of the Braided Scablands Swath—are missing from the climate-gradient corridor network. For such areas, maintaining connectivity still offers a critical tool for promoting biological resilience to climate change, but linkages based on current conditions represent the best available indicator of connectivity needs in those areas.

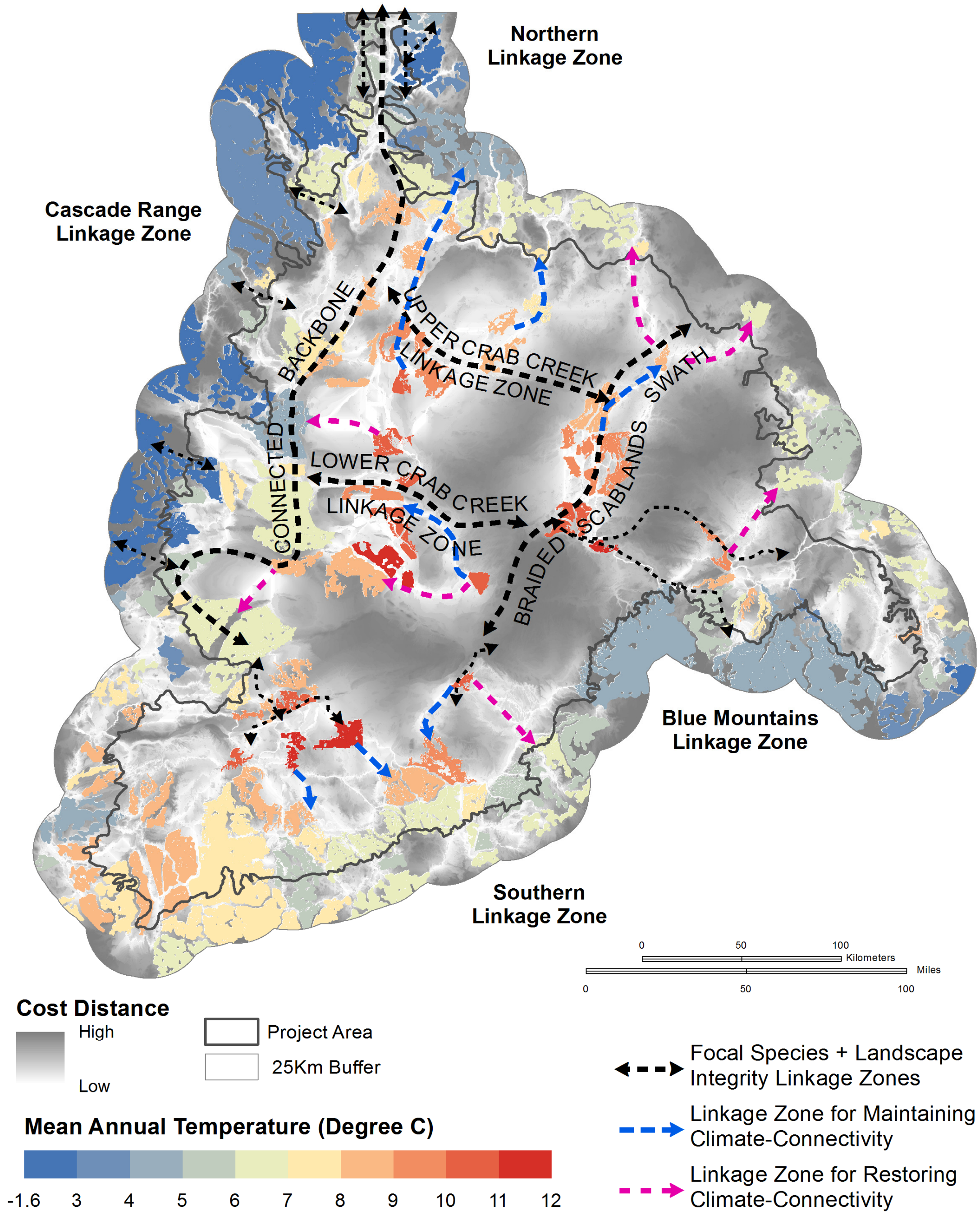

Figure 9. ***A Vision for a Climatically-Connected Columbia Plateau Ecoregion.*** Black lines correspond to linkage zones identified for focal species and landscape integrity (WHCWG 2012), blue lines correspond to climate-gradient corridors that overlap with landscape integrity corridor networks, and

magenta lines correspond to climate gradient corridors that do not overlap with landscape integrity corridor networks.

Appropriate Use of Climate-Gradient Corridor Map Products

As with the statewide analysis, users should be aware of the following caveats regarding appropriate use of the climate-gradient corridor analysis:

- **Corridors identified by this analysis are most useful for guiding relatively large-scale conservation decisions**. The assumption that current climate gradients will be maintained into the future is most robust at scales above several kilometers and below several hundred kilometers. Thus, climate-gradient corridors identified by this analysis are most appropriate for guiding connectivity conservation decisions over relatively large areas. Zooming in on individual corridors to guide local-scale (<5 km), specific land-use decisions (e.g., individual parcel acquisition) would violate the underlying assumptions of the model. Instead, the climate-gradient corridor network is best used for identifying relatively large-scale climate-connectivity priority areas, within which local-scale connectivity conservation actions can be made using on-the-ground information.
- **Climate-gradient corridors should not be overlaid with species habitat layers to identify species-specific climate-gradient corridors.** As habitat distributions are expected to shift in the future, it would be inappropriate to use individual species distribution maps as sources or destinations for species-specific climate-gradient corridors. Species distribution maps may, however, be used to prioritize climate-gradient corridors, such as by identifying and prioritizing climate-gradient corridors that overlap multiple focal species connectivity networks (discussed above, see Fig. 9).

Opportunities for Future Analysis

Climate-Connectivity Needs of Wildlife Moving into the Columbia Plateau

This analysis only addresses climate-related movement needs for wildlife currently living within the Columbia Plateau, which are likely to require access to cooler areas as the climate warms. It is less likely to facilitate the movement of wildlife into the Columbia Plateau Ecoregion from other ecoregions, simply because topography is the primary driver of climate-gradient corridors in our region, and the Columbia Plateau is at a lower elevation than immediately-surrounding areas. Climate-connectivity models aimed at facilitating the movement of wildlife moving northward into the Columbia Plateau may require additional analyses explicitly incorporating latitudinal gradients, for example, to complement the relatively local climate gradients we examined.

Prioritizing Corridors and Conservation Actions

Currently, this analysis provides minimal guidance regarding the relative importance of any particular corridor in the network. Possible approaches for prioritization include conducting analyses to identify areas where loss of landscape integrity would most compromise climate-induced movement across the landscape. This could be achieved using tools such as Circuitscape (McRae & Shah 2009) to detect “pinch-points” in corridors, or by conducting centrality analyses to identify core areas and corridors whose loss would lead to a dramatic reduction in overall network connectivity (e.g., Carroll et al. 2012). Additionally, the use of new tools to identify pinch-points and restoration opportunities within corridors (as has been done for focal species in the Columbia Plateau; see WHCWG 2013) could help to determine appropriate actions for conserving the corridors we have mapped.

Conclusions and Future Work

This report complements the earlier statewide climate-gradient corridor analysis (WHCWG 2011) by using finer-scale data at the ecoregional extent of the Columbia Plateau. In the coming year, the WHCWG will release additional products that will further support prioritization of climate-gradient corridors identified in this report and provide additional guidance for on-the-ground implementation. Together, these maps and interpretation tools aim to inform regional wildlife management and land-use planning decisions targeting the movement needs of wildlife and the habitats they rely on, now and into the future.

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