The Washington Connected Landscapes Project: Providing Analysis Tools for Regional Connectivity and Climate Adaptation Planning

Final Report
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Submitted to the North Pacific Landscape Conservation Cooperative by Brad McRae, The Nature Conservancy

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Partners: The Washington Wildlife Habitat Connectivity Working Group (WHCWG) is a science-based collaboration of land management agencies, NGOs, universities, and Washington Treaty Tribes. The group is co-led by Washington State Departments of Fish and Wildlife (WDFW) and Transportation (WSDOT), with active participation from The Nature Conservancy (TNC), Conservation Northwest (CNW), Washington Department of Natural Resources (DNR), US Forest Service (USFS), US Fish and Wildlife Service (USFWS), Western Transportation Institute (WTI), and University of Washington (UW).

Cooperators: Joanne Schuett-Hames (WDFW), Darren Kavanagh (UW), Brian Cosentino (WDFW), Sonia Hall (Independent Researcher), and Joshua Lawler (UW).

Project Summary: The Washington Connected Landscapes Project is a highly leveraged effort to provide scientific analyses and tools necessary to conserve wildlife habitat connectivity. In support of the project, we 1) developed tools necessary to reliably identify and prioritize areas important for connectivity conservation and restoration under current conditions and for allowing species range shifts under climate change; 2) tested and refined these tools by applying them in a Great Northern LCC (GNLCC)-funded effort to identify essential habitats and linkages for the Columbia Plateau Ecoregion where the WHCWG is currently engaged (connectivity and climate tools) and across Washington State (climate tools); and 3) released these tools as freely available GIS toolboxes. We have published two papers on novel methods developed for this project, have released two reports applying the tools, and are writing follow-up papers building on the methods.

Background and Need: Managing for well-connected landscapes is a key strategy to enhance resilience and ensure the long-term viability of plant and animal populations. Connectivity conservation is also the single most frequently cited climate adaptation strategy (Heller & Zavaleta 2009); many species will require highly permeable, well-connected landscapes both to maintain dispersal and gene flow as vegetation patterns and disturbance regimes change and to allow adaptive range shifts.

Despite these needs, only a handful of regional conservation planning efforts have included connectivity. Moreover, despite numerous calls to increase connectivity across climatic gradients to accommodate climate-drive range shifts, there has been a lack of approaches proposed to rigorously map the areas needed to accomplish this (Beier et al. in 2011).

The WHCWG statewide connectivity analysis identified broad-scale priority areas for connectivity conservation (WHCWG 2010). More detailed, finer-scale ecoregional analyses were needed give land managers sufficient information to prioritize and implementing conservation actions. Specifically, analyses were needed that could address the following questions

- Where along linkages is potential movement constrained? Are there areas that should be prioritized because alternative movement routes are not available?
- Given a network of core areas connected by corridors, which core areas and corridors are most important to maintaining overall network connectedness?
- Where in a linkage will restoration efforts (i.e., removal of barriers) have the greatest connectivity benefit? And where can alternate linkage pathways be created by restoration?

Tools to answer these questions were unavailable prior to this project.

Lastly, as part of our statewide analysis, the WHCWG had developed new approaches to map important connectivity areas that span climatic gradients for climate change adaptation (WHCWG 2011). These analyses were extremely labor-intensive, however, and they could not be replicated easily in new geographies or at finer scales without automation.

Objectives

We sought to provide novel analysis tools to help land managers address the above needs. The tools we developed assist with identification and prioritization of areas important for wildlife habitat connectivity under current conditions and for climate adaptation, thus advancing planning efforts across the NPLCC and the adjacent GNLCC.

Objective #1. Develop spatial analysis tools for ecoregional connectivity analyses and climate adaptation planning. Our first objective was to enhance existing corridor mapping tools to 1) identify choke points (areas where corridors narrow, creating bottlenecks where connectivity could be easily severed); 2) identify areas where restoration could most greatly enhance connectivity; 3) prioritize linkages and core areas with high network centrality (those which are particularly important for connectivity across an overall network of core habitat areas); and 4) automate methods to identify areas important for species range shifts along climatic gradients. The latter methods had been piloted at a coarse, statewide scale (Fig. 3), but automation was necessary to make them readily applicable to ecoregional-scale analyses and to analyses in new geographies.

Objective #2. Test and refine analysis tools as part of GNLCC-funded Columbia Plateau connectivity analysis. Our second objective was to test and apply the enhanced connectivity analysis tools in the Columbia Plateau Ecoregion, which, along with the Puget Trough-Willamette Valley, was identified as being the most fragmented in our statewide analysis (WHCWG 2010). This project sought to build upon our broad-scale statewide products by 1) completing a more detailed connectivity analysis of the Columbia Plateau Ecoregion using the enhanced connectivity modeling methods described above, and 2) providing a more detailed analysis of areas expected to be important for species range shifts under climate change. These analyses allowed us to test and refine our tools while directly informing conservation decisions, resulting in a template for connectivity and climate analyses in other regions.

Objective #3. Release above spatial analysis tools for public use. To facilitate application of our methods in new geographies, our third objective was to provide fully documented and open-source GIS tools for future use by the WHCWG and by conservation practitioners in the NPLCC, GNLCC, and in other regions.

Results and Accomplishments

Objective #1. Develop spatial analysis tools. To accomplish our first objective, we built upon two connectivity modeling platforms: *Linkage Mapper*, an open-source ArcGIS toolbox we created for our statewide analysis (McRae and Kavanagh 2011) and *Circuitscape* (McRae and Shah 2009). We developed four new tools:

- ***Pinchpoint Mapper*** integrates *Linkage Mapper* and *Circuitscape* to identify choke-points (a.k.a. bottlenecks or pinch-points) in corridors produced by *Linkage Mapper* (Fig. 1).
- ***Barrier Mapper*** implements a novel method for detecting important movement barriers, which can be used to facilitate restoration planning (Fig. 1; details on the method can be found in a new manuscript).
- ***Centrality Mapper*** uses a network version of *Circuitscape* to analyze core and corridor centrality in networks produced by *Linkage Mapper*. This can help prioritize important corridors (Fig. 2).
- ***Climate Linkage Mapper*** maps corridors following climatic gradients to facilitate species range shifts under climate change (Fig. 3). These novel methods first identify natural areas that differ in temperature or moisture. They then use anisotropic cost-distance analyses to map corridors that avoid both areas with high human impact and areas with unsuitable climates by using layers of development and underlying climatic gradients as separate input layers (Fig 3). More details on the method can be found in a second manuscript.

Objective #2. Test and refine analysis tools. The WHCWG conducted two connectivity analyses of the Columbia Plateau Ecoregion. "Phase I" (WHCWG 2012) applied the same core-corridor mapping approach used in the Statewide analysis (WHCWG 2010). "Phase II" (WHCWG 2013) applied the new tools described above.

We worked closely with WHCWG members completing the Columbia Plateau Ecoregional connectivity analysis, supporting their efforts by providing and revising tools as connectivity analyses were completed. We refined our tools based on WHCWG feedback and based on feedback from two workshops and multiple meetings and calls with members of the Arid Lands Initiative (ALI).

Reports from this work can be found at http://waconnected.org/climate-change-analysis/ and http://waconnected.org/columbia-plateau-ecoregion/.

Add new reports- phase II, climate pinch,

Objective #3. Release tools for public use. We released enhanced versions of *Linkage Mapper* and *Circuitscape* that add functionality described above. We also released *Climate Linkage Mapper* as a new tool to automate climate corridor mapping. Each new module was released as open-source software with its own user guide. *Linkage Mapper*, *Climate Linkage Mapper*, and *Circuitscape* are now hosted in public code repositories complete with version control, issue tracking, and user support groups.

Linkage Mapper (which now includes *Pinchpoint Mapper, Barrier Mapper, Centrality Mapper, and Climate Linkage Mapper* modules) can be downloaded here: http://code.google.com/p/linkage-mapper/

Circuitscape can be downloaded here: http://www.circuitscape.org/

Both tools have seen a high volume of traffic since their release. Each is downloaded more than 100 times per month, which we are very excited about.

Lastly, we released a set of utilities based on code we developed for LCC projects to facilitate creating inputs for connectivity modeling: http://www.circuitscape.org/gnarly-landscape-utilities

Project Deliverables (all complete)

Objective 1: Develop spatial analysis tools

-Prototype integration of Linkage Mapper and Circuitscape for choke-point detection
Status: complete.

-Prototype tools to identify connectivity restoration opportunities
Status: complete. A manuscript describing the method was published in December 2012 in *PLoS ONE*: http://www.plosone.org/article/info:doi/10.1371/journal.pone.0052604.

-Prototype of Circuitscape with network analysis capability for centrality measures
Status: complete.

-Prototype of Climate Linkage Mapper
Status: complete. The code was used in a manuscript published this year in *Conservation Biology*: http://onlinelibrary.wiley.com/doi/10.1111/cobi.12014/abstract

Objective 2: Test and refine tools (Funds for this portion covered in FY11 GNLCC funding request)

-Two Arid Lands Initiative workshops to obtain enhanced linkage modeling feedback
Status: both workshops were held, providing significant feedback on our methods. On May 23, 2012 we presented the Columbia Plateau connectivity products and enhanced connectivity tools to the subcommittee of the Arid Lands Initiative working on defining spatial priorities, and participated in a question and answer session to help them understand the products and their usefulness to the ALI. The connectivity data and all the new tools were deemed very valuable by the ALI, and we incorporated feedback into our Columbia Plateau analysis.

On December 20, 2012, draft Phase II products were reviewed with both the Arid Lands Initiative and US Fish and Wildlife Service (USFWS) to ensure these products were understood and to modify them as needed so that they would be most useful in these two groups' spatial priorities work. The ALI Spatial Priorities Subcommittee decided to use several connectivity data sets as fundamental layers in their analysis. The USFWS will be combining their work into a mutual methodology with ALI based on these data. Additional support for interpretation will continue as needed.

Based in part on feedback from the ALI, we developed new methods for synthesizing analyses across focal species, and incorporated these into our Columbia Plateau Phase II analysis.

-*Online report, maps, and decision support for statewide climate linkage analysis*
Status: Online report, maps, and FAQ for statewide and Columbia Plateau analyses are available at: http://waconnected.org/climate-change-analysis/, including a synthesis of climate and focal species products.

-*Enhanced linkage products (choke points, restoration opportunities, centrality) online*
Status: Our analysis products (Phase II Addendum: Habitat Connectivity Centrality, Pinch-Points, and Barriers/Restoration Analyses) are now online: http://waconnected.org/columbia-plateau-ecoregion/

Based in part on feedback from the ALI, we developed new methods for synthesizing analyses across focal species. These methods and results for the Columbia Plateau are presented in Chapter 13 of the Phase II Addendum. Spatial data from these analyses can be viewed and downloaded at www.databasin.org.

Objective 3: Public release of GIS tools with user guides and ongoing support
-*Release integrated tools to identify choke points and restoration opportunities*
Status: *Pinchpoint Mapper* and *Barrier Mapper* have been released with user guides as part of the *Linkage Mapper* toolkit and can be found at https://code.google.com/p/linkage-mapper/

-*Release Network version of Circuitscape to prioritize linkages and core areas*
Status: a new version of *Circuitscape* can be found at www.circuitscape.org. *Centrality Mapper* integrates this into *Linkage Mapper*. User guide and module can be found at https://code.google.com/p/linkage-mapper/

-*Release Climate Linkage Mapper*
Status: *Climate Linkage Mapper* has been released as part of the *Linkage Mapper* toolkit and can be found at https://code.google.com/p/linkage-mapper/

As mentioned above, each of these tools is exceeding 100 downloads per month.

Additionally, we released a set of utilities based on code we developed for LCC projects to facilitate creating inputs for connectivity modeling:
http://www.circuitscape.org/gnarly-landscape-utilities

Other stated goals
-*Submit manuscripts on climate adaptation corridors and choke point/restoration analyses to international journals*
Our climate corridor manuscript has been published in *Conservation Biology* (Nunez et al. 2013) and is available at: http://onlinelibrary.wiley.com/doi/10.1111/cobi.12014/abstract. We've also published a restoration analysis manuscript in *PLoS ONE* (McRae et al. 2012), available at:

http://www.plosone.org/article/info:doi/10.1371/journal.pone.0052604. A third manuscript using the new version of *Circuitscape* was recently published in *Ecology Letters* (Lawler et al. 2013). An fourth manuscript combining the restoration tool with return-on-investment analyses has just been accepted at *Frontiers in Ecology and the Environment* (Torrubia et al., accepted). A fifth manuscript combining centrality, choke-point, and restoration analyses for multiple species is in preparation as well (target journal TBD). Lastly, Jenny McGuire, a post-doc with Josh Lawler at the University of Washington, is using Climate Linkage Mapper to identify important climate corridors across the entire lower 48 United States. They will be writing this up for publication soon.

-*Present to a minimum of 4 diverse stakeholder groups by APR 2013*
Status: complete. We have presented our work in local forums (e.g., WHCWG and Arid Lands Initiative meetings, the annual WildLinks conference), webinars (e.g., the May 20, 2013 installment of the WHCWG's "Applying the Science" series) and different national and international venues (e.g., The Wildlife Society and Ecological Society of America). We have presented our analyses in Conservation Biology and Landscape Ecology classes as well, and the enhanced connectivity tools have been incorporated into graduate and undergraduate landscape ecology labs (an example can be found here).

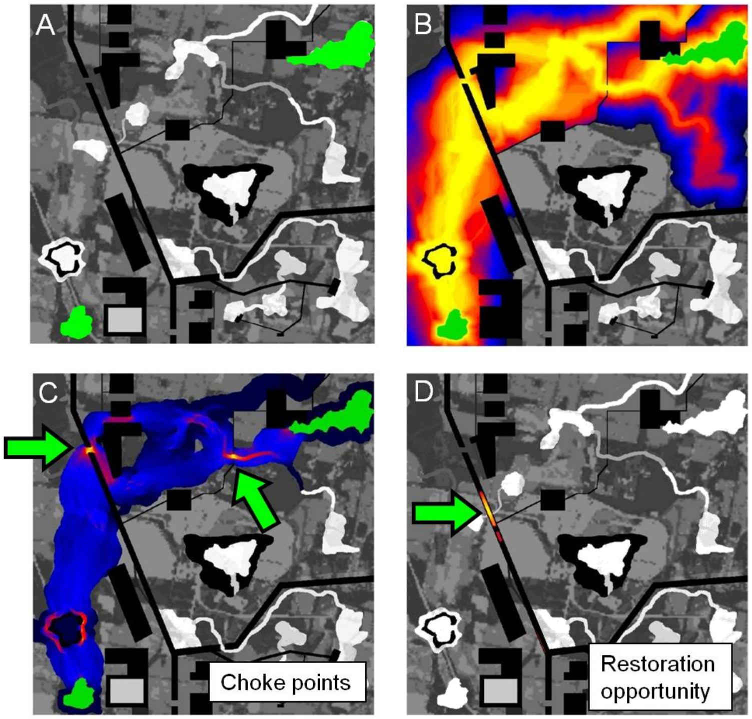

Figure 1. Example of choke points and restoration opportunities identified by least-cost and circuit theory algorithms. (A) Simple landscape, with two patches to be connected (green) separated by lands with varying resistance to dispersal (low resistance in white, higher resistance in darker shades). (B) Least-cost corridor between the patches (lowest resistance routes in yellow, highest in blue). (C) Choke points identified by *Circuitscape* within least-cost corridor. Areas where connectivity could be compromised by the loss of a small amount of habitat glow yellow. These could be prioritized over areas that contribute little to connectivity, such as the dark blue "corridor to nowhere" at the top of the panel. (D) Restoration opportunity detected by new algorithms described in McRae et al. (2012). If restored (e.g., with a highway crossing structure), this would re-route the corridor through a much more efficient path and reduce choke-point effects.

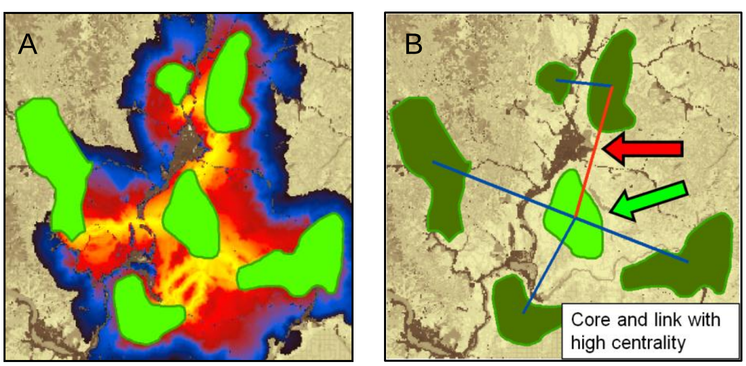

Figure 2. Example of how network centrality tools can be used to inform prioritization among core areas and linkages. (A) Least-cost corridors identified by *Linkage Mapper* among core areas. (B) Network of core areas produced by *Linkage Mapper*. Arrows indicate a core area and a linkage that have high centrality. These are "gatekeepers" of connectivity because losing either would disproportionately affect connectivity across the network (Estrada and Bodin 2008; Carroll et al. 2012). A network version of *Circuitscape* now automatically analyzes *Linkage Mapper* outputs to identify core areas and linkages that are most critical for maintaining connected networks.

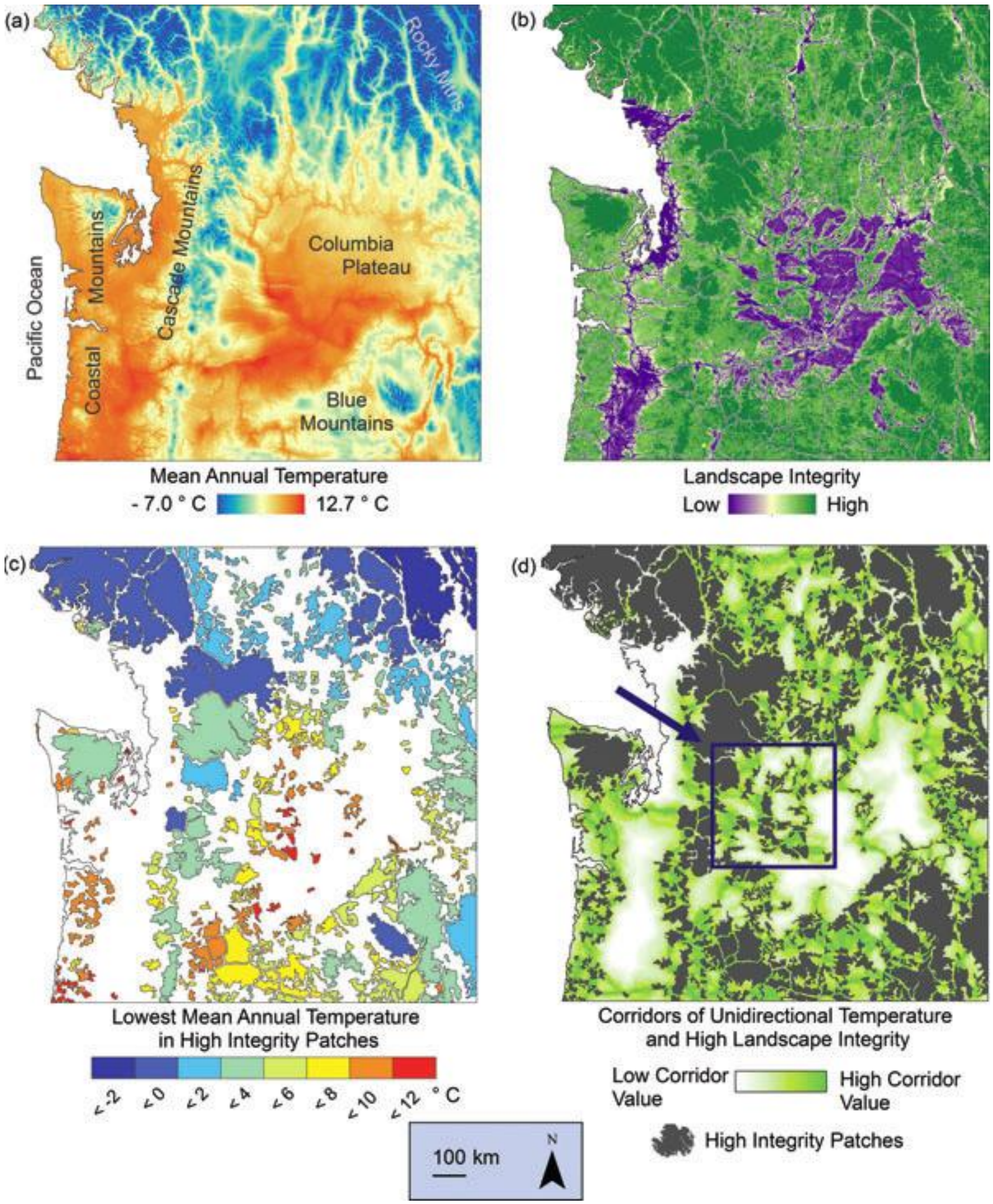

Figure 3. Climate gradient linkage products from Nunez et al. (2013). Data used in our climate corridor model included (a) a mean of mean annual temperatures from 1971 to 2000 and (b) a landscape-integrity index (a metric of naturalness that incorporate data on urban areas, distance to roads, agriculture, and other land uses). High-integrity patches (c) are linked on the basis of differences in temperature within the patches, creating (d) a network of corridors modeled between the patches using *Climate Linkage Mapper.* The new tool identified corridors containing unidirectional changes in temperature and high landscape integrity.

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