Appendix E. Decision Support System for Landscape Connectivity Planning

William L. Gaines, James S. Begley, and Andrea L. Lyons

Washington Conservation Science Institute

1.0 Introduction

Landscape connectivity, or "the degree to which the landscape facilitates or impedes movement among resource patches" (Taylor et al. 1993), is important for many ecological and evolutionary processes (McRae et al. 2012, Singleton and McRae 2013). For example, the ability of animals to move at a variety of spatial and temporal scales is important for population persistence, genetic exchange, dispersal, and movement in response to climate change (Crooks and Sanjayan 2006, Heller and Zavaleta 2009, Nunez et al. 2013). Consequently, the maintenance or restoration of habitat connectivity has become a central issue addressed in conservation assessments and planning (Crooks and Sanjayan 2006, Hilty et al. 2006, WHCWG 2010). This has led to a variety of methods and tools that have been developed to assist researchers and managers in their planning efforts (see Singleton and McRae 2013 for a recent overview).

Generally, conservation assessments are conducted at relatively broad spatial scales with the objectives of identifying a regional network of core areas (areas of relative high quality habitat to be connected) and linkages (the best areas currently available to provide connectivity between core areas). Within the northwestern US, broad-scale connectivity assessments provide information about habitat networks for specific focal species (Singleton et al. 2002, WHCWG 2010) or identify areas of relatively little human impacts (landscape integrity, WHCWG 2010, Krosby et al. 2015). While these assessments are informative in terms of identifying regional connectivity patterns, they are generally too coarse in scale to provide planners with linkage-specific details needed to identify and prioritize conservation actions (WHCWG 2013).

One of the linkages identified in multiple broad-scale assessments occurs in north-central Washington, potentially connecting the North Cascades Mountains to the Kettle Range (Gaines et al. 2001, Singleton et al. 2002, WHCWG 2010). This linkage represents one of the only remaining options in Washington to provide for habitat connectivity between the North Cascades and Kettle Range for a variety of wildlife species (Singleton et al. 2002, WHCWG 2010). The linkage extends across the Okanogan Valley, which is largely comprised of private lands, and lies between core areas that occur on publicly owned lands to the west and east of the valley. US Highway 97 is a major north–south transportation route in eastern Washington and bisects the linkage immediately north of the town of Riverside for about 11.7 miles. An average of 350 mule deer are killed annually by vehicles on this section of highway within the linkage, making it one of the highest wildlife-vehicle collision hotspots in the State of Washington (WSDOT 2014).

An impressive coalition of state, federal, tribal, and nongovernmental interests have joined together, enabled and facilitated by the National Fish and Wildlife Foundation through their Great Migrations and Corridors program, to collaborate towards the protection of wildlife habitat, rural livelihoods, and heritage in this landscape in the *Working for Wildlife Initiative*. This multi-year public-private effort will build on existing partnerships and facilitate new ones to take advantage of timely opportunities to maintain and restore habitat connectivity in the Riverside linkage for Canada lynx, Columbian sharp-tailed grouse, and mule deer. Conservation strategies include restoration of forest health and wildlife habitat, creating safer passage for wildlife and motorists on Highway 97, conservation of working lands, and reduction of wildlife conflicts with livestock and communities. In setting conservation goals for the initiative, a need was identified to quantify measurable contribution of efforts to the maintenance and restoration of habitat connectivity in this linkage that could be monitored annually and cumulatively over time. Additionally, initiative partners identified a desire to use connectivity science to inform their decision-making and priority setting.

A Decision Support System (DSS) is a computer-based information system that supports organizational decision-making activities. The DSS described in this paper was developed to assist partners in the *Working for Wildlife Initiative* in establishment of a baseline and quantifiable connectivity conservation goals, evaluation of conservation options, determination of conservation priorities, and measuring progress towards achieving landscape connectivity goals. The DSS was designed to help inform initiative partners as to where strategic investments could be focused on conservation actions that provide the greatest conservation gains. Our objective for this paper is to provide an overview of our DSS approach, both the collaboration and technical aspects. We hope that by providing an example application of how a DSS can be used in connectivity planning, it will inspire others to create even better and more robust tools.

2.0 Methods

Our DSS is a set of resistance surface based geographical information system (GIS) models developed using ArcGIS 10.3 (ESRI 2015). As previously stated, our DSS is designed to inform connectivity planning and monitor progress towards meeting connectivity goals of the *Working for Wildlife Initiative* in an area known as the Riverside Linkage (Fig. 1)(Singleton et al. 2002, WHCWG 2010).

We used the steps outlined in Singleton and McRae (2013) and WHCWG (2013), with some modifications, to describe our collaborative process and technical methods. These steps include: 1) Convene a collaboration team, 2) Identify the goals of the assessment and objectives of the analysis, 3) Select focal species or habitats, 4) Define the analysis area and scale, 5) Compile spatial data, 6) Run connectivity analysis and evaluate conservation actions, 7) Identify priority conservation actions and 8) Run connectivity analysis to measure progress towards connectivity goals.

2.1 Convene a Collaboration Team

In February 2013 National Fish and Wildlife Foundation staff invited representatives from state, federal, tribal and non-governmental agencies working on natural resource and wildlife issues in this landscape to convene for a conservation planning discussion. Attendees at this meeting and additional individuals that collaborated on the development of the business plan, formed the foundation of the *Working for Wildlife Initiative*. This foundation and partners that have joined the initiative since its inception act as the collaboration team (Table 1). At our initial meeting, the group brainstormed a conceptual model of the primary factors that influence terrestrial habitat connectivity within the linkage area (Fig. 2). This conceptual model informed the development of strategies and goals in a business plan for the initiative (NFWF 2014). The idea of a DSS was discussed to support the initiative's planning, implementation, and monitoring.

2.2 Identify Goals and Objectives

Previous connectivity planning efforts have stressed the importance of collaboration teams developing clear goals and measurable objectives (Rudnick et al. 2012, Singleton and McRae 2013). The 2014 Working for Wildlife Initiative business plan that is annually revised as needed clearly establishes the collaborative conservation goals. Specific objectives were also established for the DSS : 1). Map current conditions to provide a visual representation of the analysis area. 2). Evaluate potential conservation actions to determine which actions contribute the most to the conservation or restoration of landscape connectivity. The list of potential conservation actions was identified by the collaboration team and included in the conceptual model (Fig. 2). We created spatial representations of these conservation actions in order to evaluate their influence on habitat connectivity. 3). Establish quantifiable goals for conserving and restoring habitat connectivity within the linkage to measure progress by over the life of the initiative. 4). Identify what conservations actions most influence connectivity to determine priorities for where and what actions provide the greatest benefits. 5). Use the DSS to monitor changes in landscape connectivity and progress towards connectivity goals as conservation actions are implemented.

2.3 Focal Species and Habitats

The *Working for Wildlife Initiative* initially identified three focal species to guide the development of their business plan: Canada lynx, Columbian sharp-tailed grouse, and mule deer. However, in subsequent discussions, the collaboration team asked for a more holistic list of focal species and habitat to be integrated into the DSS. Thus, for the DSS tool development, we relied on previous assessments to identify focal species and habitats that were appropriate for the location and spatial extent of our analyses as well as the conservation goals of the initiative. These analyses included peer-reviewed processes for selection of focal species and habitats. In the state-wide connectivity assessment conducted by the Washington Wildlife Habitat Connectivity Working Group (WHCWG 2010) several focal species were used and we included those species for which our study area was identified as an important landscape linkage. Gaines et al. (2015) also went through an extensive focal species selection process and we selected a subset of species from this assessment that were relevant to our study area. Finally, the WHCWG (2012) completed the Columbia Plateau connectivity assessment using some of the same focal species from the state-wide assessment and adding several others based on an extensive focal species selection process. Based on this body of previous connectivity studies, we selected the following focal species and ecological guilds/groups: Canada lynx (*Lynx canadensis*), a general carnivore group representing species such as American blackbear (*Ursus americanus*) and bobcat (*Lynx rufus*), an ungulate group representing mule deer (*Odocoileus hemionus*) and bighorn sheep (*Ovis canadensis*), and a shrub-steppe group representing sharp-tailed grouse (*Tympanuchus phasianellus*) and American badger (*Taxidea taxus*).

2.4 Analysis Area and Scale

We compiled both GIS data and maps from previous assessments (Singleton et al. 2002, WHCWG 2010) that identified the importance of this linkage to a connected network of habitats to help delineate our analysis area extent (Fig. 1). Our analysis area includes the multi-species corridor identified in Singleton et al. (2002) located between Riverside and Tonasket. We also incorporated the areas proposed by the Washington State Department of Transportation for wildlife crossing structures in the Highway 97 transportation corridor. This provided a relatively broad linkage that we used as our analysis area (Fig. 1).

We divided the analysis area into six subareas using breaks of high, moderate, and low elevations for areas both west and east of Highway 97. These breaks are based on obvious/natural features that are present within the existing landscape encompassed within our delineated analysis area (Fig. 3). The two “low” elevation areas include areas on either side of Highway 97 to facilitate a “highway effect” that can be modeled and monitored over time, and will potentially include wildlife mitigation measures such as crossing structures and fencing. These subareas also provide convenient landscapes to quantify and monitor changes, both positive and negative, to landscape connectivity over time.

2.5 Spatial Data

We compiled GIS data that allowed us to best represent the spatial condition of each of the factors that were determined to influence landscape connectivity within this linkage using a 30 meter resolution (Fig. 2). The GIS data represents the ecological (vegetation composition and structure), topographical (slope, elevation), and human use (housing density, roads) variables that have been used to model landscape connectivity for our focal species (Singleton et al. 2002, WHCWG 2010, Gaines et al. 2015). In addition, our collaboration team was particularly interested in understanding the potential impact of future human development projections on habitat connectivity. Therefore, we incorporated current and projected housing densities by using GIS data provided for years 2000, 2020, and 2030 with the year 2000 acting as our baseline condition.

2.6 Connectivity Analysis and Conservation Actions

The connectivity analysis begins with the development of resistance surfaces for each focal species group under current conditions and future conditions based on projected housing development patterns. We used published resistance values from previous efforts to help attribute each of the mapped variables for each focal species group to develop resistance surfaces (Singleton et al. 2002; WHCWG 2010, 2012; Gaines et al. 2015). Resistance surfaces were further used to create layers of cost-weighted distance and subsequent least-cost corridors for each of the focal species groups. The corridors for each focal species were overlaid to show the location of multiple species corridors and the number of focal species/habitat identified for each corridor. This provided additional information that the collaboration team can use to determine priority areas.

Based on GIS layers available for analysis, the collaboration team identified the following conservation strategies of the *Working for Wildlife Initiative* to analyze the contribution of specific potential conservation actions to maintaining or restoring habitat through the DSS process: 1). Installation of wildlife crossing structures in Highway 97, 2). Road management approaches that would reduce impacts to wildlife habitat and restore habitat connectivity (i.e. road closures, road to trail conversions, and road decommissioning), and 3). Land conservation for parcels with willing landowners.

We first assessed baseline conditions by isolating the effects of three types of human influences: 1) Highway 97, 2) secondary/local roads, and 3) human development (measured as housing density). To assess the influence of Highway 97, we ran connectivity analyses and summarized metrics with and without the influence of the highway in order to show how the presence of the highway corridor influenced connectivity. To assess the influence of secondary/local roads, we ran connectivity analyses and summarized metrics with all roads compared to a scenario without secondary roads (we retained all primary roads considering these part of the baseline conditions as they were needed for access). For an assessment of the impacts of human development we used a habitat connectivity metric of the percent change of zonal means of resistance for current conditions (using 2000 data) and 2030 housing density projections for the six subareas.

For our DSS, we developed and applied a set of GIS tools to produce a priority ranking system to help identify areas for potential conservation actions within the analysis area. We used existing spatial data of habitat concentration areas (HCA) from the WHCWG (2010) for our focal species groups to generate cost-weighted distances (CWD) from resistance surfaces of current conditions (CWD_Current) and the year 2030 (CWD_2030). These two CWD layers were then subtracted from each other to display the change of CWD (ΔCWD) from current conditions to projected future conditions (CWD_2030 – CWD_Current = ΔCWD). This was further reclassified into four quantiles using the following values: 1 = most change, 2, 3, and 0 = no change. A least-cost corridor (LCC) was developed using the same HCAs and CWD_Current and reclassified into four quantiles using the following values: 100 = best linkage, 200, 300, and 400 = weakest linkage. Numerical values of priority ranks were generated by adding the reclassified ΔCWD and LCC layers (ΔCWD + LCC = Priorty Rank Values). This output results in a combination of 16 numerical values (see table below). These numerical priority rank values were further reclassified into subjective ranking categories for easier interpretation (see table below). These ranking categories are based on interpretation are subject to change.

100 = High	200 = High	300 = Low	400 = Very Low
101 = Very High	201 = Very High	301 = Moderate	401 = Very Low
102 = High	202 = High	302 = Moderate	402 = Very Low
103 = High	203 = High	303 = Low	403 = Very Low

We also developed a GIS tool with the ability to run different scenarios to evaluate potential effects to habitat connectivity if housing density was increased on a particular land parcel (or parcels). The tool enables users to manually adjust the housing density of any number and configuration of land parcels. This then results in a corresponding modification of the resistance surfaces. Along with the modified resistant surfaces, CWDs and LCCs can be developed and can be compared with baseline conditions to help the collaboration team with their decision making and planning process. Similar to the priority ranking system mentioned above, this tool is useful for identifying and prioritizing areas for potential land acquisitions and conservation easements.

We used multiple metrics (resistance surfaces, cost-weighted distances, least-cost corridors) to summarize the potential changes to landscape connectivity that could result from implementation of conservation actions and projected human development. We summarized changes to resistance to movement for each focal species group using resistance values assigned to each pixel within each subarea. We then used the percent change in mean (zonal) resistance within each subarea by comparing the baseline (current) conditions to proposed or projected conditions.

2.7 Conservation Priorities and Targets

The connectivity analyses allowed visual representation and quantification of the potential benefits of each proposed conservation action and their cumulative effects. We presented the results of this analysis to the collaboration team and they used this information to establish priorities, refine their conservation action proposals, and to establish conservation goals or targets. The connectivity metrics that we used to express the potential contribution of conservation actions were used to quantify and develop measurable connectivity conservation targets included in the initiative's business plan. Translating a desire to maintain and restore habitat connectivity for multiple species in a specific geography has been instrumental in the initiative's partners success in competing for funds to implement conservation actions to date.

2.8 Monitoring Progress

As conservation actions are implemented, they are reported at annual meetings. These actions are spatially represented so that an updated resistance surface can be generated and connectivity metrics summarized. In this manner the DSS can be used to track changes to baseline conditions and measure progress towards connectivity conservation targets.

2.9 Continued DSS development

An important consideration in the development of the DSS is the ability to adapt the system to new information and to the evolving needs of the collaboration team. Choosing a modeling system that is easily adaptable is important, as it is not always possible to anticipate the needs of the collaboration team during the initial DSS development. In addition the quality and availability of data layers influence the DSS tool and its use. The datalayers used in the initial development of the tool varied in quality. As the collaboration team works to identify connectivity restoration strategies, we are refining spatial datalayers to better reflect the level of precision needed to inform local-scale conservation decisions. Furthermore, some data layers are not available to allow analysis of specific conservation strategies. For example, detailed vegetation structure information to analyze the impacts of habitat restoration strategies is not consistently available across the initiative landscape. Therefore, the tool can spatially display where investments in habitat restoration are made and alternative approaches to monitor effectiveness are necessary.

3.0 Results

3.1 The Decision Support System

The DSS was developed as a result of extensive discussions among the technical specialists and conservation practitioners that comprised the collaboration team of the *Working for Wildlife Initiative*. Key components of the DSS that were important to the collaboration team included: multiple focal species and habitats, the ability to quantify the contribution of various conservation actions to the connectivity of focal species habitats, anticipation of future development patterns, a repeatable and transparent connectivity analysis process, and the development of metrics that can be tracked overtime to measure progress towards meeting conservation targets.

3.2 Baseline Conditions

Our connectivity analysis of the baseline conditions within the linkage showed that Highway 97, secondary roads, and housing development patterns all had considerable influence on the current and projected future (e.g., 2030) condition of the linkage (Table 2). The influence of these human activities varied by subarea. Within the east and west low subareas, the cumulative influence of Highway 97 and projected housing density had the greatest impact on the connectivity metrics. In the east and west moderate and high subareas secondary roads had the greatest influence followed by the projected housing density.

3.3 Conservation Actions

The DSS provided two sources of information that were important for the discussions about conservation actions within the Riverside Linkage. First, information was provided to show priority areas within the linkage that would be most beneficial to the maintenance or restoration of habitat connectivity for the focal species (Figs. 4, 5). Second, the DSS provided a means of quantifying the relative contribution of each proposed conservation action to the maintenance or restoration of habitat connectivity for focal species.

3.4 Monitoring Progress

To date, conservation actions that have been implemented include conservation easements and restoration of habitats by reducing the network of forest roads. These actions were mapped and the DSS showed a corresponding 9.8 to 38.7% improvement (e.g., reduced resistance), varying by focal species/habitat, in the connectivity metrics in the east-mid subarea. In this way, progress towards restoring or maintaining habitat connectivity for focal wildlife species was quantified and monitored.

4.0 Discussion

Multiple broad-scale scientific assessments (Singleton et al. 2002, WHCWG 2010, Gaines et al. 2015) identified the importance of maintaining a connected network of habitats between the Cascade Mountains and Kettle Range for a variety of focal species. Scientists in British Columbia and Washington, including authors of this paper, used this to justify conducting finer-scale analyses of this larger landscape to inform local conservation actions in specific linkages (WHCWG 2013). This landscape formed the geographical extent of the *Working for Wildlife Initiative*, where National Fish and Wildlife Foundation and initiative partners aimed to translate science integrated with local knowledge into conservation action. In doing so a need for additional analysis and development of a DSS tool was identified to set quantifiable conservation goals, analyze the individual and cumulative impact of conservation actions, and monitor progress towards connectivity goals.

Our progression, from broad-scale assessment to finer-scale analysis to conservation actions, provides an example of how to use connectivity science to inform on-the-ground action, an important series of steps identified by the WHCWG (2013). A vital component of this progression was the collaboration between conservation scientists and local stakeholders.

Creating an inclusive collaboration team is necessary to develop a broad understanding of connectivity science and a sense of investment in the successful application of the assessment information (WHCWG 2013, Singleton and McRae 2013). Inclusion in the development of landscape modeling is perhaps the best way to educate potential users about the process and to develop ownership in the application of the results (Beier et al. 2008). The development and application of the DSS provided a structured approach to collaboration and a way for collaborators to visualize (e.g., maps) the landscape conditions and relative contribution of various conservation actions. An important lesson learned is that the complex language associated with connectivity science is often extremely confusing. Terms such as resistance surface, cost-weighted distance, least-cost corridor, circuit theory, etc., while important and meaningful to conservation scientists illicit blank stares and looks of confusion from most collaborators. We found that using the term "habitat connectivity" as a general means of expressing very complex analyses worked best.

The development and use of a DSS is an important step for a collaboration team and should not be taken lightly. The decision to develop and the design of the DSS needs to be focused on meeting the needs of the collaboration team, and to answer the questions that they have posed. In our particular situation, the *Working for Wildlife Initiative* collaboration was interested in identifying priority areas within their landscape for conservation actions, assessment of the relative contribution of the conservation actions towards maintaining or restoring habitat connectivity, and as a means of setting goals and monitoring progress. We found it was vital to keep the DSS as simple as possible, and for the system to be adaptable. Ultimately, the goal is for members of the collaborative to use the DSS on their own.

A foundational component of conducting connectivity assessments is the development of resistance surfaces, and these were certainly integral to the development of our DSS. Resistance surfaces represent hypothesized relationships between landscape features and gene flow, and are based on underlying biological functions such as relative abundance or movement probabilities in different land cover types (Spear et al. 2010). The development of resistance surfaces has received much discussion in the literature and varies from use of expert opinion (e.g., Singleton et al. 2002, WHCWG 2010, Krosby et al. 2015), to the use of resource selection functions (e.g., Squires et al. 2013), to using landscape genetic methods (e.g., Shirk et al. 2010). Because of the importance of resistance surfaces to the results of connectivity assessments, it is imperative that conservation scientists continue to focus research on the validation and improvement of these hypothesized relationships (Spear et al. 2010, Singleton and McRae 2013).

5.0 Conclusions

We developed and used a DSS to inform conservation actions for the *Working for Wildlife Initiative* collaboration team. Our DSS provided a structured approach to progress from broad-scale connectivity assessments to finer-scale assessments within a specified linkage to on-the-ground conservation actions. The collaboration team identified key goals of the DSS to be: Identify priority areas within the the initiative landscape for the maintenance or restoration of habitat connectivity; Evaluate the relative contribution of conservation actions proposed by the collaborative to the maintenance or restoration of habitat connectivity; Inform setting conservation goals using connectivity metrics; and Monitor progress towards meeting conservation goals. The collaboration provided an opportunity for the application of connectivity science to inform conservation actions. Conservation actions are currently being implemented by a diverse array of organizations and agencies that participate in the *Working for Wildlife* collaboration team.

Acknowledgements

We are very grateful to all of the members of the *Working for Wildlife Initiative* collaboration team for their patience and input in the development of the DSS. In addition, their dedication and passion for the landscape is apparent in the actions they are taking. We thank Dr. Peter Singleton and Andrew Shirk for their advice on what connectivity analyses and metrics to use and how best to summarize them in a DSS. We thank Carly Vynne for her willingness to "try something different" and support for the development of the DSS. Finally, we thank Jen Watkins for her incredible energy and willingness to keep us organized and focused, not an easy task.

Literature Cited

Beier, P., D. R. Majka, and W. D. Spencer. 2008. Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology 22:836–851.

Crooks, K. R., and M. Sanjayan. 2006. Connectivity conservation. New York - Cambridge.

Gaines, W. L., P. H. Singleton, and A. L. Gold. 2001. Conservation of rare carnivores in the North Cascades Ecosystem, western North America. Natural Areas Journal 20:366–375.

Gaines, W. L., B. C. Wales, L. H. Suring, J. S. Begley, K. Mellen-McLean, and S. Mohoric. 2015. Terrestrial species viability assessments for the national forests in northeastern Washington (General Technical Report PNW-907). Portland, OR – U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Heller, N. E., and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142:14–32.

Hilty, J. A., W. Z. Lidicker, and A. M. Merenlender. 2006. Corridor ecology: the science and practice of linking landscapes for biodiversity conservation. Washington, DC – Island Press.

Krosby, M., I. Breckheimer, D. J. Pierce, P. H. Singleton, S. A. Hall, K. C. Halupka, W. L. Gaines, R. A. Long, B. H. McRae, B. L. Cosentino, and J. P. Schuett-Hames. 2015. Focal species and landscape "naturalness" corridor models offer complementary approaches for connectivity and conservation planning. Landscape Ecology doi:10.1007/s10980-015-0235-z.

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.

National Fish and Wildlife Foundation (NFWF). 2014. Working for Wildlife: Maintaining Okanogan's working lands and wildlife heritage. A National Fish and Wildlife Foundation plan to conserve a crucial linkage for lynx and other wide-ranging species. Available from www.nfnw.org.

Nunez, T. A., J. J. Lawler, B. H. McRae, D. J. Pierce, M. B. Krosby, D. M. Kavanagh, P. H. Singleton, and J. J. Tewksbury. 2013. Connectivity planning to address climate change. Conservation Biology 27:407–416.

Rudnick, D. A., S. J. Ryan, P. Beier, S. A. Cushman, F. Dieffenbach, C. W. Epps, L. R. Gerber, J. Hartter, J. S. Jenness, J. Knitsch, A. M. Merenlender, R. M. Perkl, D. V. Preziosi, and S. C. Trombulak. 2012. The role of landscape connectivity in planning and implementing conservation and restoration priorities. Issues in Ecology 16:1–20.

Shirk, A. J., D. O. Wallin, S. A. Cushman, C. G. Rice, and K. I. Warheit. 2010. Inferring landscape effects on gene flow: a new model selection framework. Molecular Ecology 19:3603–3619.

Singleton, P. H., W. L. Gaines, and J. F. Lehmkuhl. 2002. Landscape permeability for large carnivores in Washington: a geographic information system weighted-distance and least-cost corridor assessment (Research Paper PNW-549). Portland, OR - U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Singleton, P. H., and B. H. McRae. 2013. Assessing habitat connectivity. Pages 245–270 in F. L. Craighead and C. L. Convis (Eds.), Conservation Planning: Shaping the Future. California - Earth Science Resource Institute.

Spear, S. F., N. Balkenhol, M-J. Fortin, B. H. McRae, and K. Scribner. 2010. Use of resistance surfaces for landscape genetic studies: considerations for parameterization and analysis. Molecular Ecology 19:3576–3591.

Squires, J. R., N. J. DeCesare, L. E. Olson, J. A. Kolbe, M. Hebblewhite, and S. A. Parks. 2013. Combining resource selection and movement behavior to predict corridors for Canada lynx at the southern range periphery. Biological Conservation 157:187–195.

Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity if a vital element of landscape structure. Oikos 68:571–573.

Washington Department of Transportation (WSDOT). 2014. Wildlife Carcass Collection Database. Olympia, WA.

WHCWG (Washington Habitat Connectivity Working Group). 2010. Washington Connected Landscapes Project: statewide analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. Available from http://www.waconnected.org.

WHCWG (Washington Habitat Connectivity Working Group). 2012. Washington Connected Landscape Project: Analysis of the Columbia Plateau Ecoregion. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. Available from http://www.waconnected.org.

WHCWG (Washington Habitat Connectivity Working Group). 2013. Washington Connected Landscape Project: British Columbia–Washington Transboundary Habitat Connectivity Scoping Report. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. Available from http://www.waconnected.org.

Figures and Tables

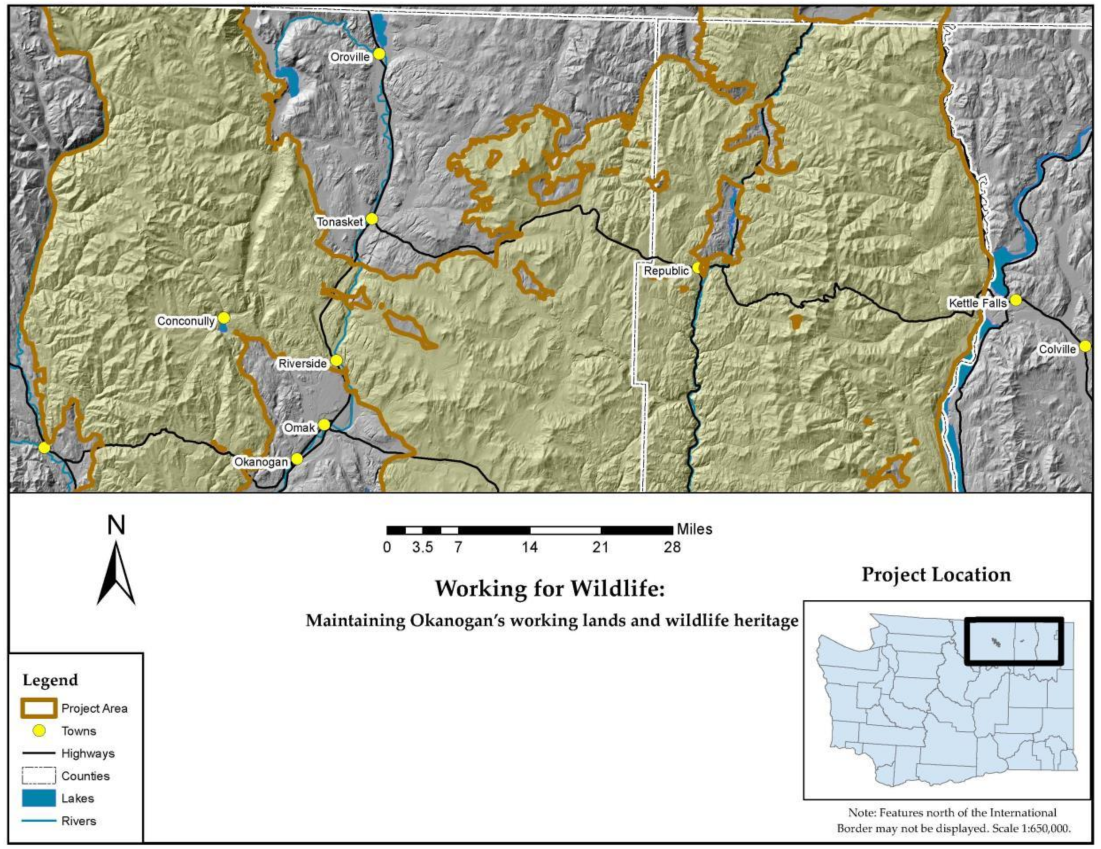

Figure 1. Map showing the Riverside Linkage and the focus area for the Working for Wildlife Initiative.

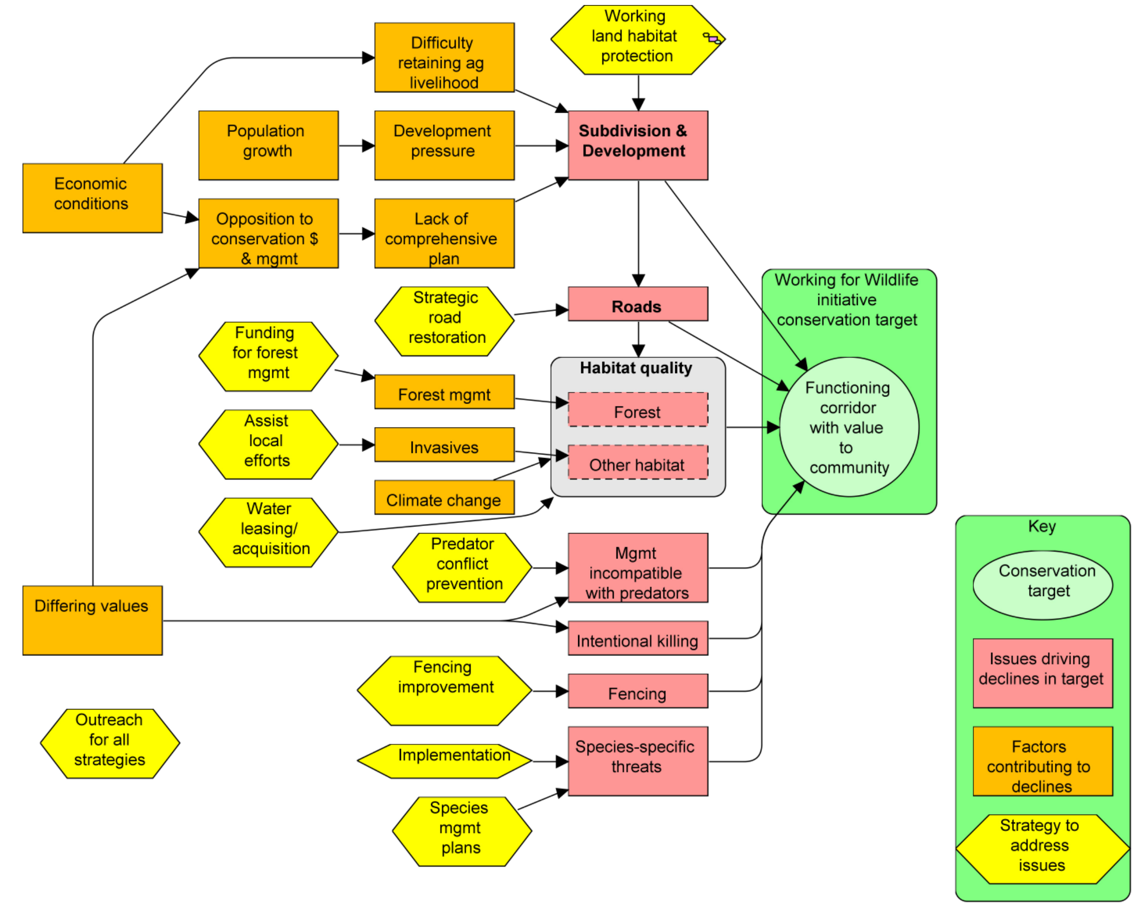

Figure 2. A conceptual model of the key issues that influence habitat connectivity within the Riverside Linkage and strategies to address the issues.

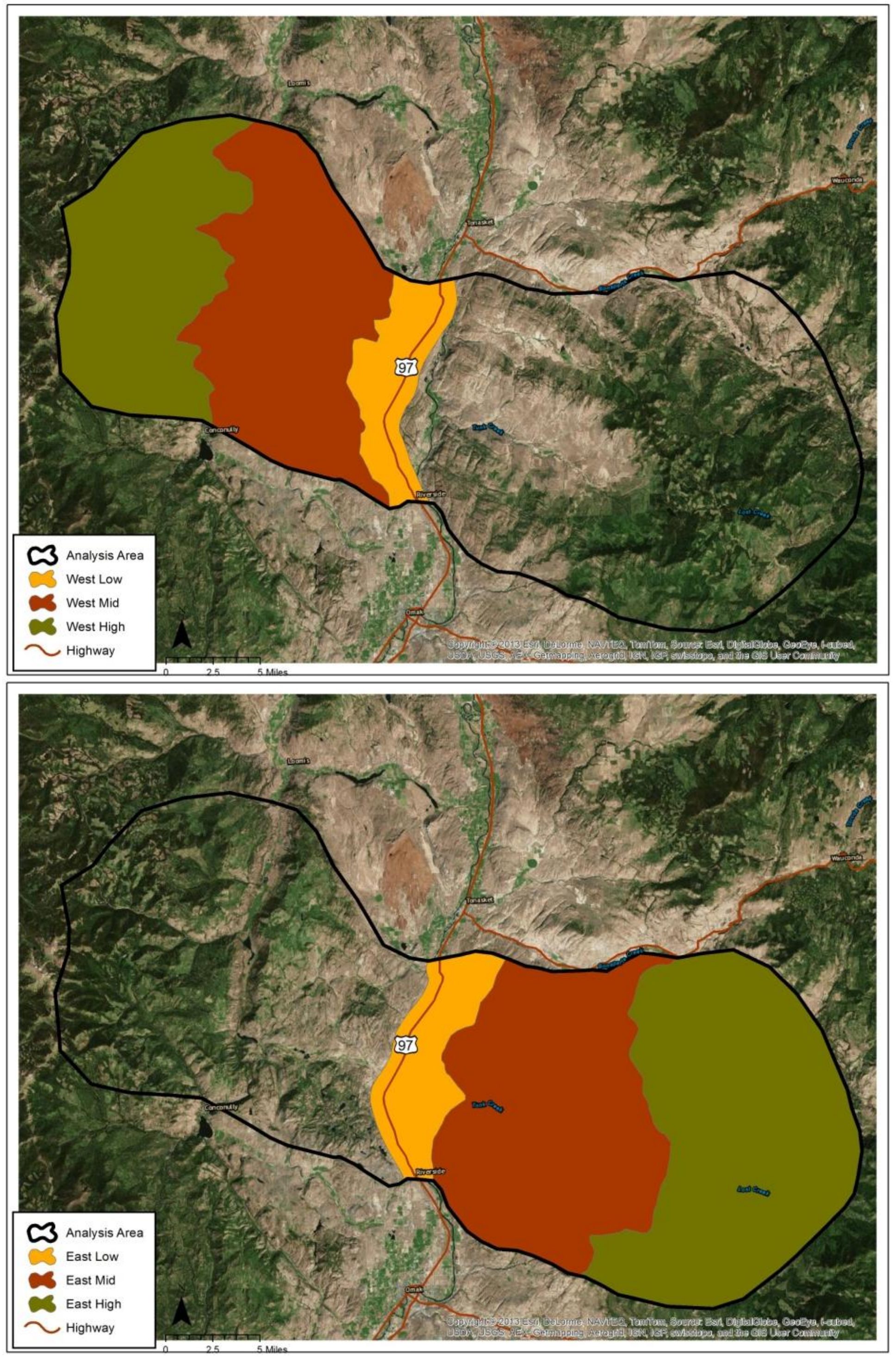

Figure 3. Subareas within the Riverside Linkage used to quantify habitat connectivity metrics.

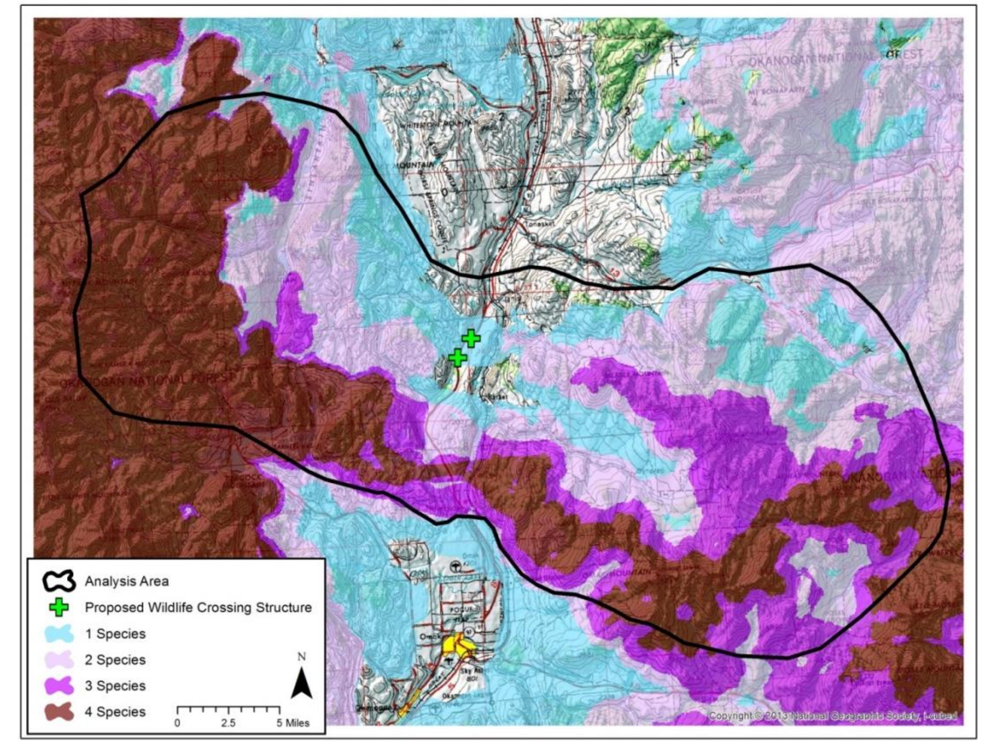

Figure 4. Combined results of cost-weighted distance and least-cost corridor models showing the portions of the Riverside Linkage that are currently the most permeable for the greatest number of focal species/habitats.

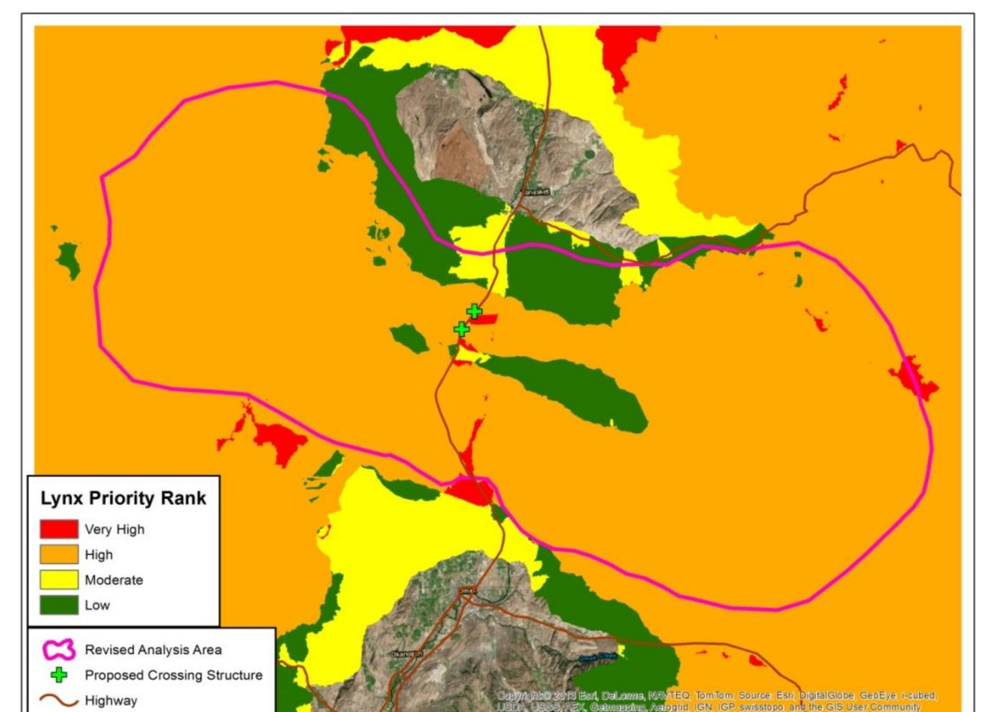

Figure 5. Combined results of the priority-ranking model for Canada lynx showing the portions of the Riverside Linkage based on projected housing densities where conservation actions would have the most beneficial impacts.

Table 1. The agencies and organizations on the Working for Wildlife Initiative Collaboration Team.

The Collaboration Team	
National Fish and Wildlife Foundation	Trust for Public Lands
Conservation Northwest	Okanogan Land Trust
Washington Department of Fish and Wildlife	Colville Confederate Tribes
Okanogan County Conservation District	Colville National Forest
Washington Department of Natural Resources	Okanogan-Wenatchee National Forest
Washington Department of Transportation	Wenatchee Forestry Sciences Lab
Washington Conservation Science Institute	

Table 2. Percent change in resistance values (zonal mean) from baseline conditions for focal species groups by conservation actions and subareas within the Riverside Linkage. Acres are the total of each subarea.

Focal Species/Group	Western Portion of Linkage			Eastern Portion of Linkage		
	High 73,653 acres	Mid 86,552 acres	Low 23,041 acres	High 115,931 acres	Mid 98,945 acres	Low 25,764 acres
Highway 97(Influence to Resistance)						
Canada lynx	NA	NA	1.2%	NA	NA	1.1%
General carnivore	NA	NA	3.4%	NA	NA	3.2%
General ungulate	NA	NA	4.6%	NA	NA	4.4%
General shrub steppe	NA	NA	0.2%	NA	NA	0.3%
Secondary/Local Roads (Influence to Resistance)						
Canada lynx	3.7%	1.9%	0.9%	0.8%	1.7%	3.4%
General carnivore	0.9%	0.9%	1.0%	1.0%	0.9%	0.9%
General ungulate	14.5%	21.9%	18.1%	17.0%	30.4%	33.1%
General shrub steppe	0.3%	0.7%	0.9%	0.3%	0.5%	0.8%
Future Housing Development (Influence to Resistance)						
Canada lynx	0.5%	0.6%	8.9%	2.6%	1.1%	9.2%
General carnivore	1.4%	1.8%	21.0%	7.0%	5.0%	22.7%
General ungulate	0.3%	0.9%	15.8%	2.9%	2.5%	16.9%
General shrub steppe	0.1%	0.7%	20.3%	1.0%	1.5%	23.4%