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RESEARCH



## Planning for ecological connectivity across scales of governance in a multifunctional regional landscape

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### ABSTRACT

Although a landscape is a single environmental system, human systems of governance at the landscape scale are often fragmented across jurisdictions and diverse stakeholders, impeding coordinated planning to maintain ecological connectivity. We sought solutions to overcome this challenge for wildlife corridor conservation in a rapidly developing, multifunctional landscape in one of North America's most endangered ecoregions. Circuitscape modelling was used to identify key wildlife movement corridors through our study area. We then describe how the results of this modelling have informed a collaborative multi-stakeholder process leading to shared conservation objectives across scales of governance and illustrate its success with our case study. We conclude that achieving landscape-scale conservation objectives requires ongoing and coordinated collaboration facilitated by a dedicated group of individuals and informed by science.

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ecology; British Columbia

### Introduction

Multi-functional landscapes are composed of a mosaic of land cover types that collectively provide a range of ecosystem services to human communities (Fischer et al. 2006; Parrott and Meyer 2012). A key challenge for conservation and environmental planning in such landscapes is maintaining sufficient heterogeneity and contiguity of land cover types so as to conserve natural habitats and associated ecosystem services while accommodating the development of the built environment and other anthropogenic land uses (Cumming et al. 2014; Kirchner et al. 2015). In addition, while the landscape is a single environmental system, often governance is distributed across multiple jurisdictions and scales (federal, provincial, regional & municipal), hindering coordination of environmental conservation efforts. In multifunctional landscapes where land use and land cover change are occurring rapidly, regional-scale planning initiatives are essential to ensure that this change does not result in excessive fragmentation of existing natural areas. This challenge is most pressing in regions of Western North America that are outside of large metropolitan areas and/or that still retain large natural or semi-natural areas yet are experiencing rapid land cover change due to development pressures as a result of human population growth (Lawler et al. 2014). Often this growth is driven by migration of people desiring to access the ecosystem services provided by the natural landscape, yet these same

services are endangered by the resulting land use and land cover change.

Given the relatively low amount of development that has already occurred in such landscapes compared to large metropolitan or agricultural regions, there is an opportunity to identify a future network of functionally connected habitats within a larger, less-developed setting. With foresight, it may be possible to avoid expensive land restoration and recovery initiatives and retain the multifunctional quality of the landscape. While it is well known to conservation scientists that a connected network of natural habitats is an important prerequisite to conserving species on a landscape, facilitating wildlife movement, and retaining water quality and related ecosystem services that contribute to human well-being (Taylor et al. 1993; Haddad et al. 2015; Mitchell et al. 2015; Lamy et al. 2016), these concepts are often overlooked when construction and development projects are having immediate economic benefits for human communities. There is thus clearly a need for landscape connectivity modelling and corridor identification work to be better translated into outcomes that can be used and incorporated by decision-makers into the planning process.

Here, we describe how wildlife habitat connectivity modelling was used to identify opportunities for maintaining ecological connectivity in a landscape faced with high rates of land use and land cover change and how the outcomes of this modelling have served to inform policy decisions across multiple levels of government. The

project is a collaboration between scientists, environmental planners, local governments, and conservation groups and is a successful example of how translational ecology (*sensu* (Enquist et al. 2017)) can inform a shared vision for sustainable land development that promotes ecological connectivity and associated ecosystem services provisioning at the regional landscape scale.

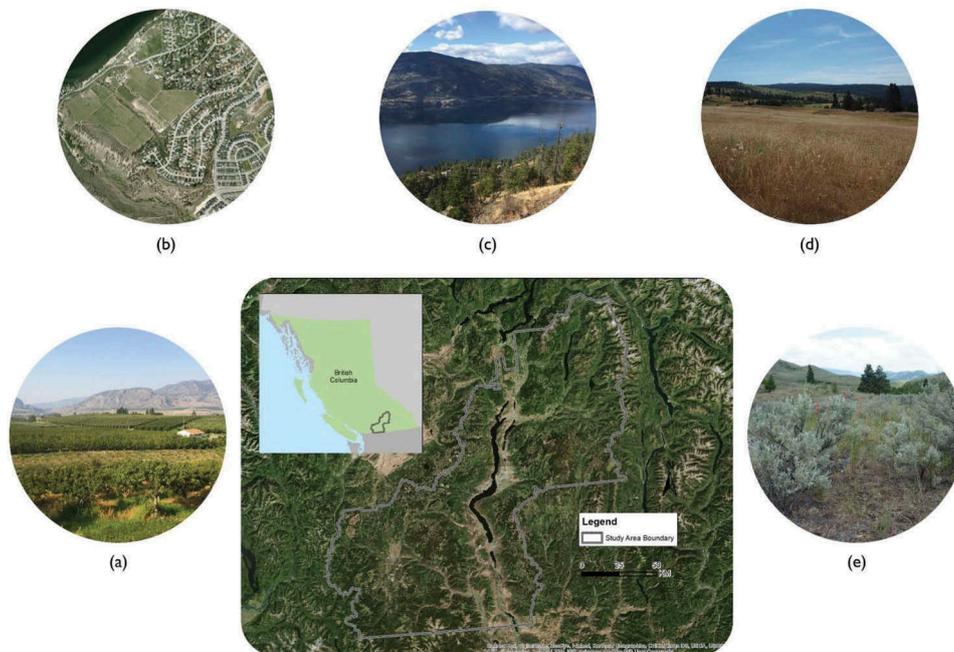
## Methods

### Study area

Our study area is the 8000 km<sup>2</sup> Okanagan Valley in British Columbia, Canada (Figure 1), which is located in one of North America's most endangered ecoregions and has been identified as a Canadian biodiversity hotspot (Warman et al. 2004; Kerr and Cihlar 2004). The Okanagan is a multi-functional landscape typical of many developed nations, with urban, forested and agricultural land use (Figure 1). The variegated terrain gives rise to mild microclimates that support orchards and wineries. The region has a human population of about 365,000 (BC Stats 2017). Tourism, driven by outdoor recreation and other opportunities linked to the agricultural and natural land cover, attracts over 3.7 million visitors a year (TOTA 2017). The Okanagan is home to considerable native biodiversity, including remnant grassland, shrub-steppe ecosystems, and fire-prone open fir and pine forests (Lea 2008). The valley is the northernmost

tip of the semi-arid North American Great Basin ecoregion, which extends southward from the Okanagan into the United States. It represents a northern refuge for many endemic species and has been identified as a critical pinch point for north-south migration of species due to topographical and environmental constraints as a result of the mountains to the east and west (Transboundary Connectivity Group 2016).

The Okanagan is home to almost 30% of British Columbia's species at risk, as well as many rare and endangered species (Warman et al. 2004; Freemark and Meyers 2006). Habitat loss and fragmentation are the leading causes of species loss and endangerment in the Okanagan (South Okanagan Similkameen Conservation Program 2014). Rare and sensitive ecosystems are located in the lower-elevation valley bottom, which is also where anthropogenic land cover is concentrated. While the cause of species decline is relatively easy to identify, the solutions are not obvious. The region is subject to intense development pressure, with the largest city of Kelowna experiencing an 8.4% population increase over the most recent five-year census period (Statistics Canada 2016). The current landscape contains a significant percentage of natural habitat (over 50% of the total land area), but most of this habitat is unprotected and faces multiple pressures from human use and land development. Most of the land in the valley bottom is privately owned and much has been transformed into low-density housing, urban or agricultural use. Land



**Figure 1.** The Okanagan valley in British Columbia, Canada. Centre: Satellite imagery of the study area. The dry valley bottoms (light brown) are the northern limit of the shrub-steppe ecosystems extending south to the American Great Basin desert. Light green areas in the valley bottom are irrigated agriculture. Higher elevation areas (darker green) are dominated by lodgepole pine forest. (a) irrigated orchards that have replaced desert habitat; (b) typical development patterns interspersing single-family housing, agriculture, and natural habitat; (c) Okanagan Lake, the largest of the valley bottom lakes; (d) grassland used for grazing; (e) native shrub-steppe vegetation.

at higher elevations, while largely publicly owned, has overlapping tenures, including leases for natural resource use and extraction. The entire landscape is the unceded traditional territory of the indigenous S'yilx People of the Okanagan First Nation.

The present land use governance structure for the Okanagan includes First Nations, municipal, regional, provincial and federal governments. This layered governance structure with overlapping jurisdictions is similar to that of most Canadian provinces. All levels of government play different roles in land use management and planning. In British Columbia, like in many parts of the world, there is no level of government that currently has the necessary jurisdiction to implement a landscape-scale wildlife corridor, and no such official designation exists. Instead, different government agencies have at their disposal diverse mechanisms that can be applied to influence or constrain land use planning in ways that might achieve conservation goals.

Land tenure in the Okanagan includes private land, Indian Reserve land, public 'crown' land and other public lands (e.g. parks and public institutions). The entire land base is divided into three regional districts that encompass the boundaries of several municipalities and Indian Reserves. Opportunities for conservation depend on both the type of land tenure and on government jurisdiction. In the Okanagan, most land area falling within municipal boundaries is privately owned and is zoned for use by municipal governments, who also are typically responsible for providing building and construction permits and developing and enforcing environmental protection regulations within their boundaries. First Nations governments generally oversee land use on Indian Reserves and are legally required to be consulted and accommodated on decisions regarding land and resource use that could impact their indigenous interests anywhere in their traditional territory. Regional districts administer services to larger regions and oversee land use planning and development on private land outside of municipal boundaries. Public 'crown' land outside of municipal boundaries is typically managed by different provincial government ministries such as the Ministry for Forests, Lands, Natural Resource Operations and Rural Development, the Ministry of Energy, Mines & Petroleum Resources and the Ministry of Environment and Climate Change Strategy. Each of these ministries regulates the use of different natural resources on crown lands and oversees environmental protection and development related to the use of those resources. The Province is legally obligated to work in consultation and cooperation with First Nations on all such decisions. Public stakeholders are also consulted on, and may influence, land-use decisions on public 'crown' lands. Lastly, except in specific cases, the Canadian federal government has minimal direct influence on land-use decisions in the Okanagan; however, it can indirectly affect land use and management through collaboration with provincial

ministries and through federal policies and legislation that might incentivise certain actions by individuals or corporations. All levels of government, as well as public stakeholders, must thus be included in any landscape-scale ecological connectivity planning process.

In this context, the objective of our study was to identify where wildlife is currently most likely to move through the Okanagan landscape and to use that knowledge to facilitate a concerted dialogue with stakeholders about opportunities for conservation or stewardship actions that promote ecological connectivity in identified corridors. Like many regions in Western North America, the Okanagan is experiencing a growing population and increasing rates of land cover change for development. It is therefore essential to plan proactively and establish a network of corridors and protected areas that can maintain native biodiversity and ecological function on the landscape given projected future development. Achieving this, however, does not fall within the jurisdiction of any single agency as described above, and requires coordination across multiple levels of governments. Our Okanagan case study thus provides an example for other regions in the world facing similar challenges of accommodating human population growth while implementing meaningful and effective environmental protection across scales of governance.

### *Identification of wildlife movement corridors*

Since we were concerned with maintaining overall ecological connectivity at the landscape scale, our approach was coarse-grained and non-species-specific. We built on a multi-year project carried out by regional government and environmental NGOs that led to the publication of a Biodiversity Conservation Strategy (BCS) for the Okanagan (South Okanagan Similkameen Conservation Program, Okanagan Collaborative Conservation Program, and Caslys Consulting 2014). One of the products of the BCS was a generic species resistance to movement map for the study area that was built based on provincial government land use and land cover datasets. The resulting raster map covered the full study area at a 25 m resolution. In this map, a resistance value is assigned to each parcel of land based on its land cover type and topographical features. Specifically, resistance is calculated as a weighted function of elevation, slope, terrain ruggedness, accessibility to water and land cover (Caslys Consulting 2013). Weighting was based on estimates about the relative ability of an average terrestrial animal species to traverse different land cover types and topographical features (for example, traversal is assumed to be easier in close proximity to water and on gentle slopes; high elevation, rugged, or steep slopes present higher resistance; intact native vegetation has low resistance and densely built urban areas and roads are movement barriers). This resistance map thus depicts the relative ease with which species

can move through different parts of the landscape, without identifying habitat corridors *per se*. The map was developed and validated as part of an extensive consultation process with expert biologists from relevant government departments, environmental consultants, and local stakeholders and is widely used as a planning tool within the three regional districts of the Okanagan. Our work used this map, in recognition of its importance for local decision-making and planning, and to ensure uptake of our research results by end-users. The complete BCS maps and detailed methods are publicly available on the British Columbia Provincial Government Ecological Reports Catalogue web repository (<http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=42389>).

Identification of movement corridors can be done using a range of methods that typically relate habitat quality and other landscape characteristics to ease of movement by wildlife, based on either expert or empirically derived resistance surfaces (Beier et al. 2011; Zeller et al. 2012; Koen et al. 2014; Graves et al. 2014). Empirical approaches to developing resistance surfaces usually require animal movement data for focal species in the landscape of interest. Resource selection functions and other habitat use models are often calculated on these data to infer a resistance model for focal species (e.g. (Graves et al. 2014)). In our case, empirical data for animal movement through the study area were largely non-existent. We, therefore, relied on the expert derived resistance surface created for the BCS and described above. This surface was non-species specific, although oriented to the movement requirements of terrestrial vertebrates, not including birds or amphibians. Our approach is similar to the ‘naturalness-based’ connectivity modelling approach shown by Krosby et al. (2015) to be effective and efficient for corridor planning on large landscapes.

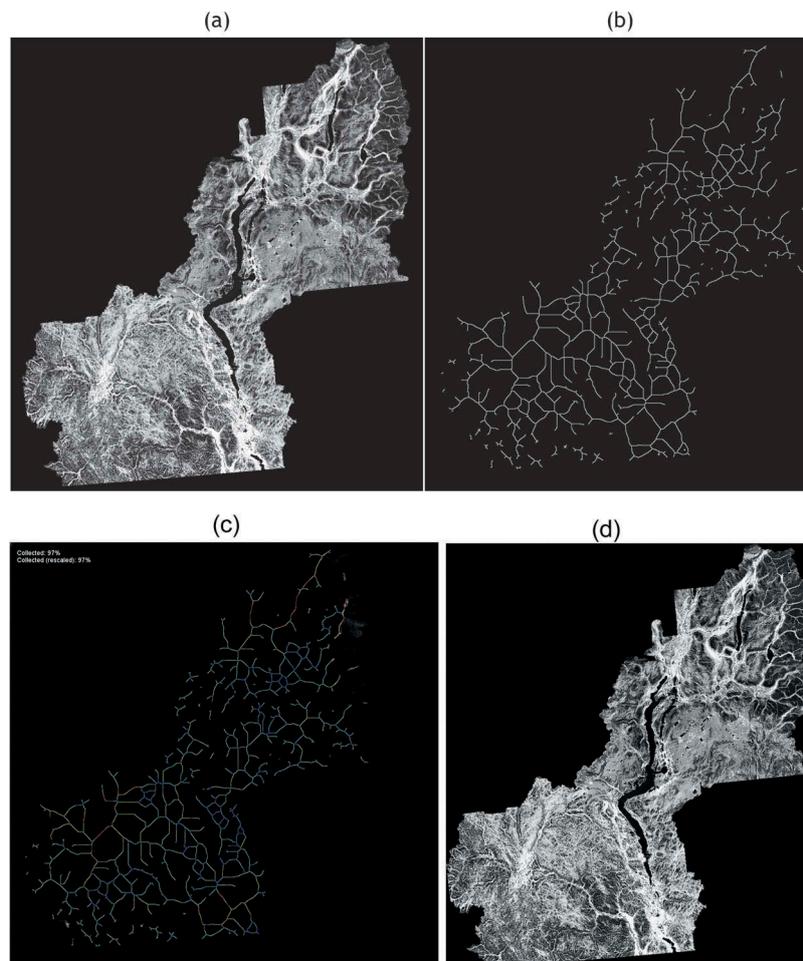
We identified and interpreted corridors using the Circuitscape model (Adriaensen et al. 2003; McRae et al. 2008a). Circuitscape simulates a random walk through a resistance surface to identify key areas on the landscape that facilitate or impede movement given the landscape’s composition and configuration; it has been widely used for wildlife corridor planning (Carroll et al. 2012; Dutta et al. 2016; Dickson et al. 2019). Circuitscape outputs a map of ‘current density’ which is an estimate of the probability, for each grid cell on the map, that a random walker will move through that cell based on a given resistance surface (i.e. it is the net flow of current through that cell) (McRae et al. 2008b). Circuitscape searches for all possible pathways through a landscape and is well suited to cases where the objective is to find parts of a landscape that contribute to connectivity as part of a network, as distinct from seeking a specific route to connect two points (Pelletier et al. 2014). It was thus well adapted to our needs and selected as a tool for this project.

We identified corridors using a three-stage process (Figure 2): first, producing the current density surface using Circuitscape, second, simplifying the Circuitscape output into a network of linear features using techniques borrowed from computer vision, and third, estimating the amount of current associated with each linear segment. We used the habitat resistance map of the BCS classification as per-pixel resistance values in Circuitscape. Using the tiling technique of Pelletier et al. (2014), we computed a seamless mosaic of estimated current density across the study area (Figure 2(a)). The resulting map covers the entire study area with a continuous field of values, which to the eye reveal pinch points and pathways of movement. The surface indicates a relative contribution of each pixel to landscape connectivity, but it does not specifically delineate locations of wildlife movement corridors. It is thus not particularly useful to regional and municipal environmental planners for corridor designation in the land use zoning process, since planners need to be able to identify precise corridors locations and boundaries on a map. While ecologists may understand the landscape as being a matrix with various degrees of permeability to movement for wildlife, such a vision is difficult to reconcile with current land use planning processes that seek one zoning designation per land parcel. To address this shortcoming, we used image processing techniques (Gonzalez and Woods 2008) to reduce the highly complex current density surface to a ‘skeleton’ showing the principal routes throughout the landscape (Figure 2(b)). The technique applied a topology-preserving thinning algorithm (the ‘morphology thinning’ functionality of ImageMagick 6.8.3 available at <https://imagemagick.org/>) to the current density map to identify lines following the centre points of current flow paths. This simplified the current density maps to representative vectors that form corridors through the landscape. To estimate the relative importance of each skeleton segment for wildlife movement, we then modelled the skeleton segments as gravitational attractors of the surrounding current on the density map (Figure 2(c)). This was done with a Python program (available on request) that simulated a gravitational force on the Circuitscape output exerted by each pixel along the skeleton (where the force is higher for pixels of high current density). The ‘amount’ of Circuitscape current was iteratively moved closer to the attracting skeleton until all current in the image had arrived at its corresponding location on the skeleton. The process is illustrated in Figure 2(d).

## Results

### Regional corridor mapping

The output of the Circuitscape modelling (Figure 2), from the three stages of current flow density to weighted skeleton corridors, were used to generate mapping layers



**Figure 2.** Intermediate steps used to identify wildlife movement corridor locations in the study area. (a) raw output from Circuitscape in the form of a current density map (white is high flow, black is low flow); (b) the 'skeleton' extracted from (a) indicating lines of high flow. (c) skeleton showing relative 'weights' of branches (red is high, blue is low); Figure 2(d) animation illustrating the whole process of deriving the weighted skeleton beginning with the current density map. <http://complexity.ok.ubc.ca/planning-for-ecological-connectivity-across-scales-of-governance-in-a-multifunctional-regional-landscape/>

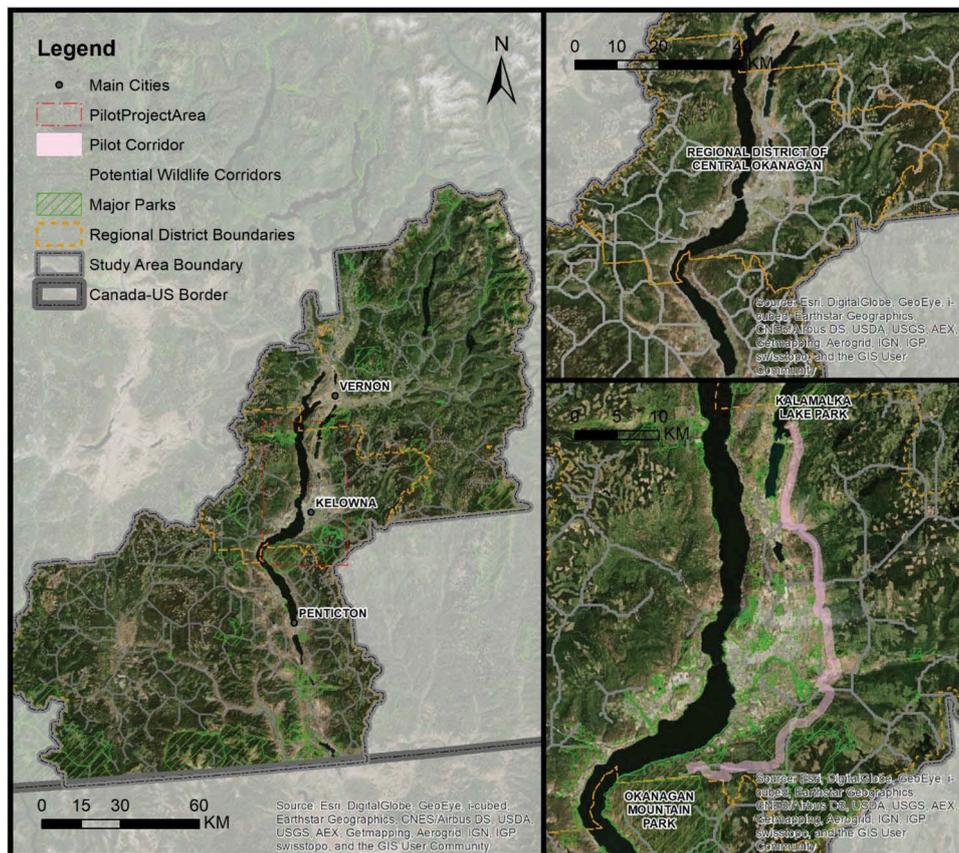
identifying corridors in formats that were useable by regional and municipal planners and other land use decision-makers. The maps were simplified into: (1) a single representation of the network of potential movement corridors through the valley overlaid on imagery for the region (Figure 3(a)), and (2) a map of the key regional corridors running through the Central Okanagan, selected based on the relative weights of their skeleton segments and their importance for facilitating regional-scale wildlife movement (Figure 3(b)). The maps have been widely shared with decision-makers and the general public by our team via presentations, flyers, posters and museum exhibits to communicate the general locations of wildlife corridors in the Okanagan Valley.

### **Corridor implementation: from science to policy**

Maintaining or restoring ecological connectivity at the scale of a regional landscape in British Columbia cannot be achieved using a top-down approach. It requires the establishment of

a common vision amongst all governmental and non-governmental stakeholders and then concerted and coordinated efforts by all stakeholders. Each stakeholder may use different policy, stewardship, or other mechanisms at their disposal to accomplish the shared goal.

Since the identified corridors for our study area cross land which is both privately and publicly owned, falls under different jurisdictions, and which has diverse land use designations, there are a variety of mechanisms that can be used to implement protection of the corridors. For example, municipal and regional governments might designate wildlife corridors within their boundaries in overarching planning documents such as Official Community Plans and Regional Growth Strategies, and then constrain the type of land development that can occur in these areas. On private land, stewardship incentive programs may help to achieve conservation objectives. For example, conservation on farmland might be achieved through the use of beneficial farm management practices by landowners. In some cases, for



**Figure 3.** (a) Map of all wildlife movement corridors through the Okanagan, as identified in Figure 2(b), overlaid on imagery and existing protected areas; (b) Zoom on the central Okanagan region of interest for the pilot project with key regional corridors highlighted; (c) Final path of the pilot project Okanagan mountain to Kalamalka lake ecological Corridor location. The 1 km wide pilot corridor skirts around the eastern side of the city of Kelowna and connects two large provincial parks.

non-agricultural land, acquisition of private land for the creation of protected areas is a possibility. In most cases in the Okanagan, however, due to the high cost, land acquisition for conservation purposes is prohibitively expensive, and for public land, existing land use designations (e.g. range tenure, forestry, energy development) have to be taken into consideration. Any implementation solutions, therefore, need to be respectful of existing land use and land tenure.

To test solutions, a pilot corridor implementation process in the Central Okanagan was undertaken. The implementation process has involved extensive consultation and coordination with diverse groups and has been facilitated by the Okanagan Collaborative Conservation Program (OCCP), a not-for-profit organization, in close collaboration with the University of British Columbia (UBC) research team and environmental planners from supportive regional and municipal governments.

As a first step, a one-day workshop was convened, in which approximately 50 people representing organizations from diverse sectors were invited to attend. Participants included representatives from federal and provincial government ministries, First Nations, regional, and municipal governments, environmental not-for-profit organizations, industry and academia. Participants were presented with a series of maps

showing the locations of key regional corridors identified through the Circuitscape modelling work (Figure 3(b)), overlaid on maps of current land use, land tenure, and land cover data. Participants were asked to provide input about: 1) the locations of the corridors based on their knowledge and understanding of the landscape; 2) prioritization of the different corridors for conservation purposes; 3) any implementation challenges or opportunities they perceived (e.g. land use designations compatible or incompatible with wildlife movement), and 4) lists of policy mechanisms or programs that their organization could apply to help conserve the corridors. The workshop resulted in a series of recommendations for corridor implementation, as well as prioritization of corridor routes for conservation (Gieselman 2015).

Following the workshop, a small steering committee was formed to carry the project forward, in consultation with a larger 'action team' composed of interested workshop participants. The steering committee consists of planners and scientists from a few key organizations leading the project (OCCP, UBC and local government planning departments). Based on the recommendations and outcomes of the workshop, a section of the corridor network in the Central Okanagan was selected by the steering committee as a pilot project for implementation. This corridor traverses around the east side of the

City of Kelowna through native grassland and open woodland habitat and connects two large provincial parks, Okanagan Mountain Park and Kalamalka Lake Park (Figure 3(c)). The chosen pilot corridor is a critical pinch point and is the last remaining low elevation route for north-south movement of species along this section of the east side of Okanagan Lake. It contains large tracts of relatively intact privately owned grassland ecosystems currently used for cattle grazing, public crown land which is mostly open woodland, as well as areas of more intensive agriculture and low-density rural housing. Local knowledge and provincial government occurrence records confirm that the corridor is regularly used by ungulates, cougar, wolves, coyotes and black bear that live in and transit the valley, including a large herd of elk. It also provides habitat for 28 provincially or federally listed plant and animal species of concern (endangered or threatened), including the American badger, Western Screech owl, Spotted bat, Great Basin Spadefoot toad, Western rattlesnake, Gopher snake, Long-billed Curlew and Grasshopper sparrow (Haney et al. 2006; Conservation Data Centre – BC Ministry of Environment 2019).

After identifying which corridor to prioritize, the first task of the steering committee was to refine the corridor route and define its width. Because the derived skeleton represents an area of flow rather than a pinpoint pixel-wide path, it was used as a guide to locating the real-world corridor in light of local knowledge of land tenure and land use. The final route of the pilot corridor is shown in Figure 3(c). The route is the combined outcome of the path identified by the Circuitscape modelling, and expert input. Consultation within the corridor steering committee and the broader stakeholder action team led to a refinement of the route to take advantage of recently created parks and other conservation opportunities planned for the area. In several cases, small deviations were made to simplify implementation by reducing the number of private land parcels traversed by the corridor in cases where there was a single large parcel of comparable ecological value immediately adjacent. Some deviations were also necessary to accommodate land-use change such as recent housing developments that had occurred since the production of the maps used for the creation of the resistance layer. Lastly, the northern leg of the corridor was extended along contour lines and through a regional park to provide connectivity to Kalamalka Lake Provincial Park in the north. While not identified with the Circuitscape modelling, this extension was seen by the steering committee and action team members as being of critical ecological value, as it provides connectivity between two large protected areas, Okanagan Provincial Park in the south, and Kalamalka Provincial Park in the north. With the exception of this northern segment, all other corridor

deviations still retain the main path within the areas of high current flow output by Circuitscape.

The corridor width was defined as 1 km, based on empirical studies showing that the large mammal species likely to use the corridor have flight responses from humans that often fall between 400–600 m (Fauvelle and Ford 2016). This width, therefore, provides these mammals moving through the centre with sufficient buffer from human activities that may occur on the edge of the corridor. While a width of 1 km may not always be achievable given current or projected land use, city officials and planners are asked that if a segment needs to be narrower, that this narrow section be as short as possible, and be compensated by increased width at each end of the narrow section. Within and near the corridor, recommendations to municipalities and landowners include: restricting the development of built structures, retaining and restoring native vegetation, and removal of unnecessary fencing and use of wildlife-friendly fencing where appropriate.

Work on this pilot corridor is leading to the development of a toolkit of approaches applicable to different land use and land tenure types along the corridor route. Approaches used include a range of policy mechanisms (e.g. corridor designation in official community plans, environmental development permit areas, etc.) as well as landowner stewardship programs and incentives. The path of the corridor has been communicated to municipal councils for inclusion in their official community plans as they are revised, and may be designated as a wildlife corridor within the Regional District of Central Okanagan's next regional growth strategy. Development of official community plans and regional growth strategies is a multiyear process that requires public consultation and which is carried out in 5-year cycles. Designation of the corridor within these high-level planning documents, which constitute public policy once approved by elected councils, is the first step towards protection and implementation. Other policy initiatives being implemented include incentive programs for agricultural landowners to undertake management practices that benefit ecosystem services and biodiversity, and crown land forest management practices that are consistent with designation as a wildlife corridor. In tandem with policy work, a public awareness campaign about the importance of ecological connectivity in the region has been launched to gain public support for the initiative. Lastly, the pilot corridor project is serving as a model for the implementation of other corridor segments of the modelled skeleton throughout the Okanagan.

## Discussion

Retaining functional connectivity in this region under development pressure faces a range of implementation

challenges related to the multiplicity of landowners, land tenures and levels of government each covering different jurisdictions (First Nations, municipal, regional, provincial and federal). In addition, the multifunctionality of the landscape, which currently supports livelihoods in a diversity of economic sectors including forestry, ranching, agriculture, industry and services, means that different stakeholders value the landscape in different ways. Coordinated land use planning initiatives amongst all of these sectors and different levels of governance will be required to conserve and restore existing native habitats in the Okanagan, and to maintain their connectivity with the rest of the landscape. Implementing and conserving wildlife corridors in the region is thus a classic ‘wicked problem’ for which there is no single, simple solution (Rittel and Webber 1973).

Our network governance approach to large landscape-scale conservation in the Okanagan is not dissimilar to successful approaches taken elsewhere in North America (Scarlett and McKinney 2016). A steering committee composed of individuals from the key organizations provides leadership in implementation of the project, and a larger ‘action team’ containing a broader representation of stakeholder groups provides expert input and oversight. This distributed leadership model allows for fluidity in leadership roles and facilitates open dialogue and knowledge sharing amongst all participants (Imperial et al. 2016).

While this phase of the project has been focused on maintaining connectivity for wildlife movement, it is part of a larger dialogue with decision-makers about the importance of ecosystem services for the well-being and livelihoods of people living in the landscape. Our communication materials discuss the role of the ecological corridors as being important for species, but also for ecosystem services. This messaging aligns well with current Canadian Federal and provincial government conservation guidelines and initiatives (e.g. biodiversity.ca). It is also particularly important for small urban centres in Western North America and elsewhere whose regional economies and livelihoods depend on ecotourism, agriculture and forestry sectors, all of which are tightly coupled to the environment. Planning for ecological connectivity is thus very much part of a larger discourse around how best to accommodate future development while retaining essential ecosystem services in a multifunctional landscape.

The corridors identified through our modelling work represent places where species would be the most likely to transit in the landscape, based on the assumptions inherent to the resistance layers used as input to the modelling process. These key movement corridors often occur in locations where topography or land cover and land use restrict the number of options that species have for movement. They are thus critical connections between habitats in the

valley. It should be noted that the input resistance layer was not species-specific and therefore the suggested locations for corridors and linkages may not be appropriate for all species. However, recent work comparing coarse-grained versus focal species approaches to connectivity planning has shown that coarse-grained analyses can capture the key opportunities for ecological connectivity on a landscape (Krosby et al. 2015). This is confirmed by the high degree of overlap in the locations of movement corridors identified through our modelling work with those identified for the larger US–Canada transboundary region, using different approaches and datasets (US Fish & Wildlife Service et al. 2016). Ongoing work by our group is exploring the use of the landscape for movement by select focal species (e.g. Bighorn sheep and tiger salamander) to ensure that their requirements will be met by the corridors identified in the present analyses and to recommend adjustments if necessary (Allen et al. 2016, 2019). We note, however, that in a large-scale, multi-stakeholder planning process where social and economic decision criteria drive conservation decisions in tandem with science, a coarse-grained approach is probably sufficient. In our particular case, the coarse-grained approach was one of the key factors for success, because conversations did not get derailed around discussions of any particular species and its particular needs or potential use of the corridor.

Analyses for the Washington, USA – British Columbia, Canada transboundary region (Transboundary Connectivity Group 2016) emphasize the importance of maintaining north-south movement corridors for facilitating species migration and potential habitat range shifts as shrub-steppe species expand habitats northward in response to climate change. Our project has contributed to this larger goal of maintaining ecological connectivity in the Canadian portion of this critical, and highly endangered ecoregion. It has also led to important dialogue around how a landscape can develop differently; and to public discussion on how to achieve sustainable development that maintains ecosystem services and quality of life in the region in a context of rapid land cover change.

This project is a successful example of how science can contribute to positive change through meaningful community engagement. It is an example of the emerging area of translational ecology in which ecologists, stakeholders and decision-makers work together to co-develop research that translates into real-world solutions (Enquist et al. 2017). The production of the original Circuitscape maps, while technically challenging and methodologically innovative, was only a first step in the implementation of the ecological corridors. While many projects result in the creation of

connectivity maps to identify wildlife corridors, implementation and protection of these corridors require bringing people together in the same room. Relationship building, communication, and coordination amongst the various stakeholders and levels of governance in order to achieve the end objective of corridor conservation has been a much more lengthy and sometimes challenging process. The continued input and participation of scientists in this process have been essential to our success.

Lastly, while a landscape is a single system, most landscapes are governed in fragmented ways. This fragmentation in governance is the single biggest challenge in achieving and coordinating planning for ecological connectivity. In our experience, demonstrating what needs to be done to preserve a species, ecosystem, or ecological function is often the easy part of a project; achieving that objective across scales of governance and within a context of complex social and economic constraints and opportunities is altogether different.

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