The Washington-British Columbia Transboundary Climate-Connectivity Project:

Climate impacts and adaptation actions for wildlife habitat connectivity in the transboundary region of Washington and British Columbia

Prepared by the

Climate Impacts Group
University of Washington

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The work described in this report was completed by science-practice partnerships involving participants from:

- BC Ministry of Forests, Lands, and Natural Resource Operations
- BC Parks
- Colville Confederated Tribes
- Okanagan Nation Alliance
- Pacific Climate Impacts Consortium
- Transboundary Connectivity Group
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Document and Data Layers Availability

This document and companion files, including reports and data layers, are available online at: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915

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Executive Summary

Plant and animal species have historically used movement to adapt to changes in the Earth's climate, shifting their ranges across landscapes to stay within climatically suitable habitat. Species are using this strategy to adapt to present day climate change, but the current rate of change is so rapid that many species will have difficulty keeping pace. In addition, human land use (e.g., highways, cities, farms) presents significant barriers to wildlife movement across today's landscapes. For this reason, enhancing habitat connectivity – the ability of species to move across the landscape – is a leading strategy for helping wildlife respond to climate change. And yet, significant challenges remain in translating this high-level strategy into specific, on-the-ground actions.

The Washington-British Columbia Transboundary Climate-Connectivity Project was initiated to help address these challenges. The region spanning the border of Washington state, USA, and British Columbia, Canada, faces increasing development pressure and limited transboundary coordination of land and wildlife management, both of which may threaten habitat connectivity and limit the potential for wildlife movement in response to change. In addition, the effects of climate change may further reduce habitat connectivity, and species may need novel types of habitat connectivity to complete adaptive range shifts. This project paired scientists and practitioners from both sides of the border to collaboratively identify potential climate impacts and adaptation actions for transboundary habitat connectivity, using a diverse suite of case study species, a vegetation system, and a region.

Case study assessments revealed that climate change is likely to have significant implications for transboundary habitat connectivity. The adaptation actions identified to address potential impacts varied by case study, but fell into two general categories: those addressing potential climate impacts on existing habitat connectivity and those addressing novel habitat connectivity needs for climate-induced shifts in species ranges. In addition, project partners identified priority spatial locations for implementing these actions, as well as additional research needed to improve assessment of climate impacts and adaptation actions for habitat connectivity.

The project resulted in a suite of products designed in collaboration with project partners to ensure their relevance and ease of application to decision-making. These products include this project overview report, which describes the project's rationale, partnerships, approach, key findings, lessons learned, and remaining needs; detailed, stand-alone appendices for each case study, which describe the assessment process and key findings for each, and include all materials used in the assessment; and an interactive project gallery on the online mapping platform, Data Basin, which includes project reports and associated assessment materials, including interactive and downloadable connectivity and climate datasets.

In addition, project participants emerged with enhanced capacity and a transboundary community of practice for addressing climate change and habitat connectivity in their decision-making. However, ongoing support for transboundary capacity building, collaboration, and research will be needed to promote the future resilience of our shared species and ecosystems.

1. Introduction

As the Earth's climate changes, species are responding by adjusting their geographic distributions,[1] moving out of areas that become climatically inhospitable, and into areas that become newly hospitable. However, the ability of species to respond in this way is likely to be limited by both the rapid pace of change and widespread barriers to movement presented by human land use. For this reason, increasing ecological connectivity – the degree to which a landscape facilitates the movement of species and ecological processes – is the most frequently proposed climate adaptation strategy for biodiversity conservation.[2] Increasing connectivity is expected to enhance resilience to climate change by helping species undergo adaptive range shifts, while also reducing existing stresses associated with habitat fragmentation.[3]

Despite recognition of connectivity enhancement's value as an adaptation strategy, little work has been done to translate this broad recommendation into specific, on-the-ground actions for connectivity conservation in a changing climate. Effectively managing habitat connectivity to promote biological resilience requires knowledge about how climate change may impact connectivity, what additional connectivity needs species may have as they undergo range shifts, and what actions can be taken to address these impacts and needs.

The Washington-British Columbia Transboundary Climate-Connectivity Project was initiated to promote effective habitat connectivity management under climate change by addressing two primary challenges: the significant gap between climate and connectivity science and practice; and the analytical, political, and physical barriers to connectivity presented by political borders. The transboundary region of Washington, USA, and British Columbia, Canada (Fig. 1), is an oft-neglected geography among the priority regions of conservation groups and government agencies, yet maintaining its permeability to wildlife movement will be vital to maintaining regional resilience to climate change. Previous work by the Washington Wildlife Habitat Connectivity Working Group (WHCWG) engaged transboundary stakeholders in identifying information needs for managing habitat connectivity in a changing climate.[4] The primary finding of this effort was that no single existing climate or connectivity model output or synthesis of existing model outputs could best inform connectivity conservation under climate change, as any model's usefulness would depend upon the connectivity management goals and activities of the user. But more strikingly, transboundary stakeholders – including land and wildlife managers from government agencies, tribes, and NGOs – made it clear that they did not have the capacity to apply climate-related models to their decision-making. This suggested that the most urgent need was not the creation of new models to guide connectivity management in a changing climate, but rather a concerted effort to translate existing model outputs to meet the information needs of practitioners, and to build practitioners' own capacity to access, interpret, and apply climate-related model outputs to their connectivity management efforts.

Building this capacity by assisting practitioners in identifying climate impacts and adaptation actions for transboundary habitat connectivity would promote many regional and national conservation priorities. Regionally, priorities of the Great Northern and North Pacific Landscape Conservation Cooperatives (GNLCC and NPLCC, respectively) include assessing the implications of climate change for the maintenance of large, intact, permeable landscapes; and facilitating collaboration and adaptation capacity building to inform stakeholder decisions. Habitat connectivity is a priority issue of the GNLCC's Cascadia Partner Forum, whose mission is to build

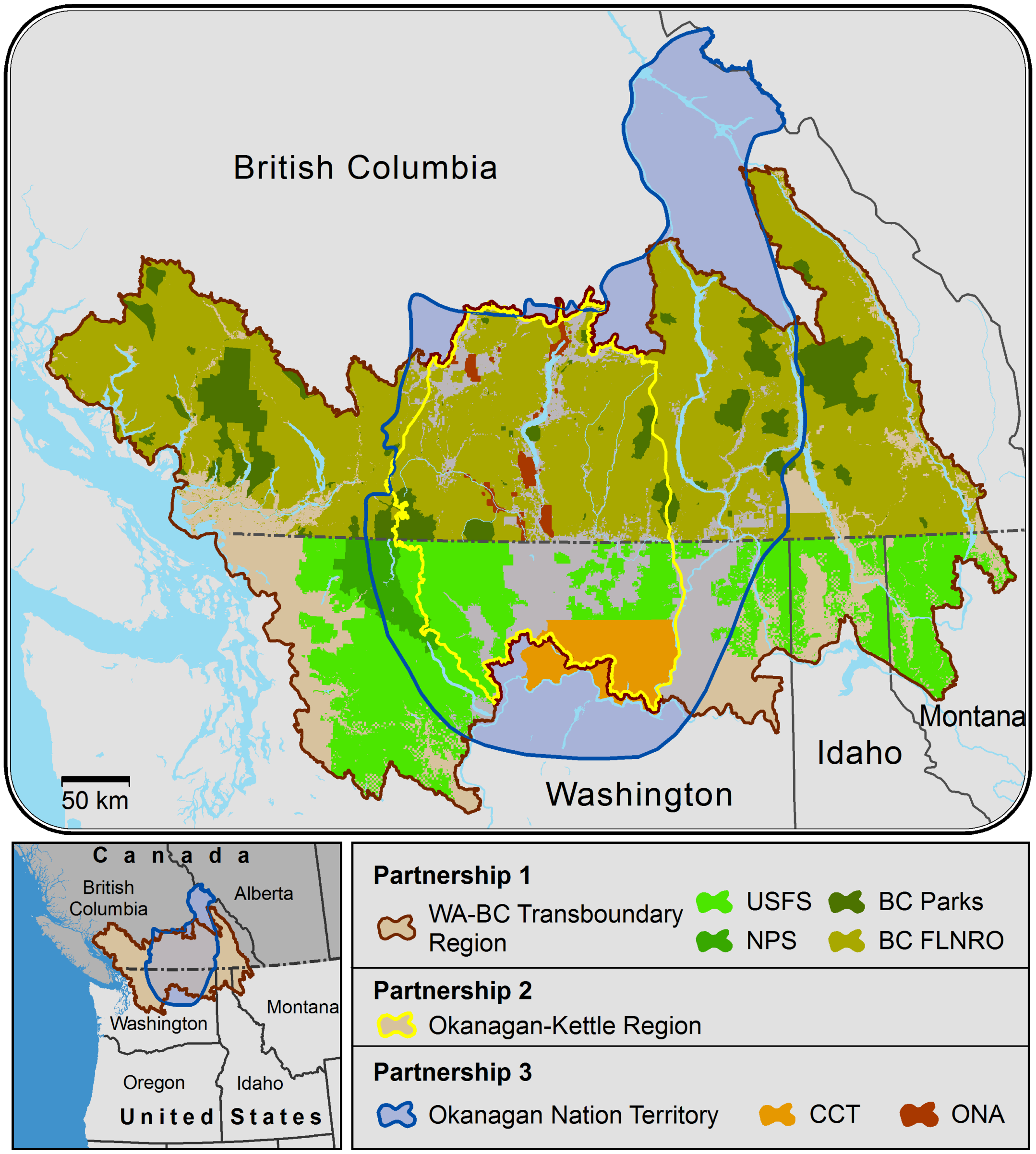

Figure 1. Project area and partnerships: 1) At the scale of the Washington-British Columbia transboundary region: US Forest Service (USFS); US National Park Service (NPS); BC Parks; and BC Ministry of Forests, Lands, and Natural Resource Operations (BC FLNRO); 2) At the scale of the Okanagan-Kettle Region: the Transboundary Connectivity Working Group; 3) At the scale of the Okanagan Nation Territory: Okanagan Nation Alliance (ONA) and Colville Confederated Tribes (CCT).

the adaptive capacity of Cascadia landscapes. At a broader scale, identifying and protecting wildlife corridors are primary goals of the Western Governors' Association's Wildlife Corridor Initiative, and connectivity enhancement is a priority climate change adaptation strategy for the US National Park Service, US Forest Service, and US Fish & Wildlife Service. It is similarly recognized as a priority strategy by provincial and federal ministries in British Columbia and Canada, respectively.

The Washington-British Columbia Transboundary Climate-Connectivity Project thus convened science-practice partnerships aimed at promoting capacity and community of practice building among transboundary land and wildlife managers tasked with maintaining connected, resilient landscapes in a changing climate. **The objective of these partnerships was to produce partnership-specific plans for managing habitat connectivity under climate change,** by:

1) Identifying partner-specific goals and objectives for habitat connectivity management
2) Determining how climate change is likely to impact these goals and objectives, and
3) Developing strategies and tactics for addressing these impacts.

2. Project Partners

We convened three science-practice partnerships reflecting a range of management goals, activities, and scales related to habitat connectivity. The project area spanned the transboundary region of Washington State, USA, and British Columbia, Canada, with partnerships established at three spatial scales (Fig. 1):

- **The Washington-British Columbia Transboundary Region**. Partners included the US Forest Service; US National Park Service; BC Parks; and BC Ministry of Forests, Lands, and Natural Resource Operations
- **The Okanagan-Kettle Region**: Partners included the Transboundary Connectivity Group (i.e., WHCWG and its BC partners).
- **Okanagan Nation Territory**: Partners included the Okanagan Nation Alliance and its member bands and tribes, including the Colville Confederated Tribes.

For all partnerships, science partners included the Climate Impacts Group at the University of Washington and the Pacific Climate Impacts Consortium at the University of Victoria. Together, the science-practice partnerships engaged in a collaborative, iterative assessment of climate impacts and adaptation actions for transboundary habitat connectivity. This co-productive assessment process was designed to promote capacity and community of practice building among practitioner partners while ensuring that project products were directly relevant and immediately applicable to practitioners' decision-making.

3. Assessment Approach

The assessment approach outlined in our original project design consisted of identifying partner-specific goals and objectives for habitat connectivity management, determining how climate change is likely to impact these goals and objectives, and developing adaptation actions for addressing these impacts. However, as described below, project partners ultimately modified this plan in response to the opportunities and constraints presented by a large, transboundary, inter-institutional project. The final assessment approach entailed: 1) focusing the assessment on a suite of case studies, including numerous species, a vegetation system, and a region; 2) identifying potential climate impacts on habitat connectivity for each case study; and 3) developing partner-specific actions for addressing these impacts.

3.1. Identifying case study species, vegetation system, and region

Project partners engaged in a series of initial workshops and phone calls to introduce practitioner partners to the project, develop and build buy-in around the assessment approach, and gain a shared understanding of practitioner partners' goals and objectives for connectivity management. While the original project design called for a single initial workshop, difficulty arranging international travel for practitioner partners (particularly US federal employees) made it impossible to convene all partners simultaneously at the start of the project. We therefore held a series of smaller workshops and phone calls arranged at practitioner partners' convenience, to encourage participation by those unable to travel across the border.

The information gathered at these initial workshops and phone calls provided science partners with an understanding of the connectivity- and climate-related management goals, activities, and capacities of practitioner partners. It also revealed a strong need to focus the work of the partnerships around a limited number of specific connectivity conservation targets. Addressing the extensive and diverse connectivity and climate-related information needs of each individual partner was well beyond the project's capacity, and would not have contributed to the project's goal of promoting a transboundary community of practice via partner collaboration.

Project partners thus collectively agreed to focus their assessment on a suite of transboundary case studies spanning a range of organizational scales, including numerous individual species, a vegetation system, and a region (Table 1). The case study species, system, and region were not intended to act as connectivity conservation umbrellas for the transboundary region's broader biota, as the individualistic nature of species' responses to climate change precludes traditional umbrella approaches to conservation planning. Rather, they were selected based on their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. These selection criteria were chosen to promote transboundary and inter-institutional collaboration around shared conservation priorities, while giving partners the opportunity to explore a range of climate and movement sensitivities, relevant datasets, and adaptation actions.

Table 1. Case study species, vegetation system, and region selected for assessment by project partners.

Species	
Common Name	**Scientific Name**
Wolverine	*Gulo gulo*
Mountain goat	*Oreamnos americanus*
White-tailed ptarmigan	*Lagopus leucura*
Whitebark pine	*Pinus albicaulis*
Canada lynx	*Lynx canadensis*
American marten	*Martes caurina*
Black bear	*Ursus americanus*
Mule deer	*Odocoileus hemionus*
Lewis's woodpecker	*Melanerpes lewis*
Tiger salamander	*Ambystoma tigrinum*
Bull trout	*Salvelinus confluentus*
Vegetation System	
Shrub-Steppe	
Region	
Okanagan-Kettle Region	

3.2 Identifying potential climate impacts on habitat connectivity for case studies

To identify potential climate impacts on transboundary habitat connectivity, project partners created conceptual models that identified the key landscape features and processes expected to influence habitat connectivity for each case study species and system, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[5] Conceptual models prepared by project partners (Fig. 2) were based on participant expertise; peer-reviewed articles and reports; and, when possible, review by species, vegetation system, and regional experts. That said, these models were intentionally simplified and not intended to represent comprehensive assessments of the full suite of landscape features and processes contributing to habitat connectivity.

Project participants used conceptual models together with models of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on habitat connectivity for each case study. Partners did this by evaluating projected future changes for each climate variable included in the model, and how these changes were likely to affect the landscape features and processes important to habitat connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity model outputs to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources included habitat connectivity models produced by the Washington Connected Landscapes Project,[6,7,8] future climate projections produced by the Integrated Scenarios of the Future

Northwest[9] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] and models of projected range shifts and vegetation change produced by the Pacific Northwest Climate Change Vulnerability Assessment.[11]

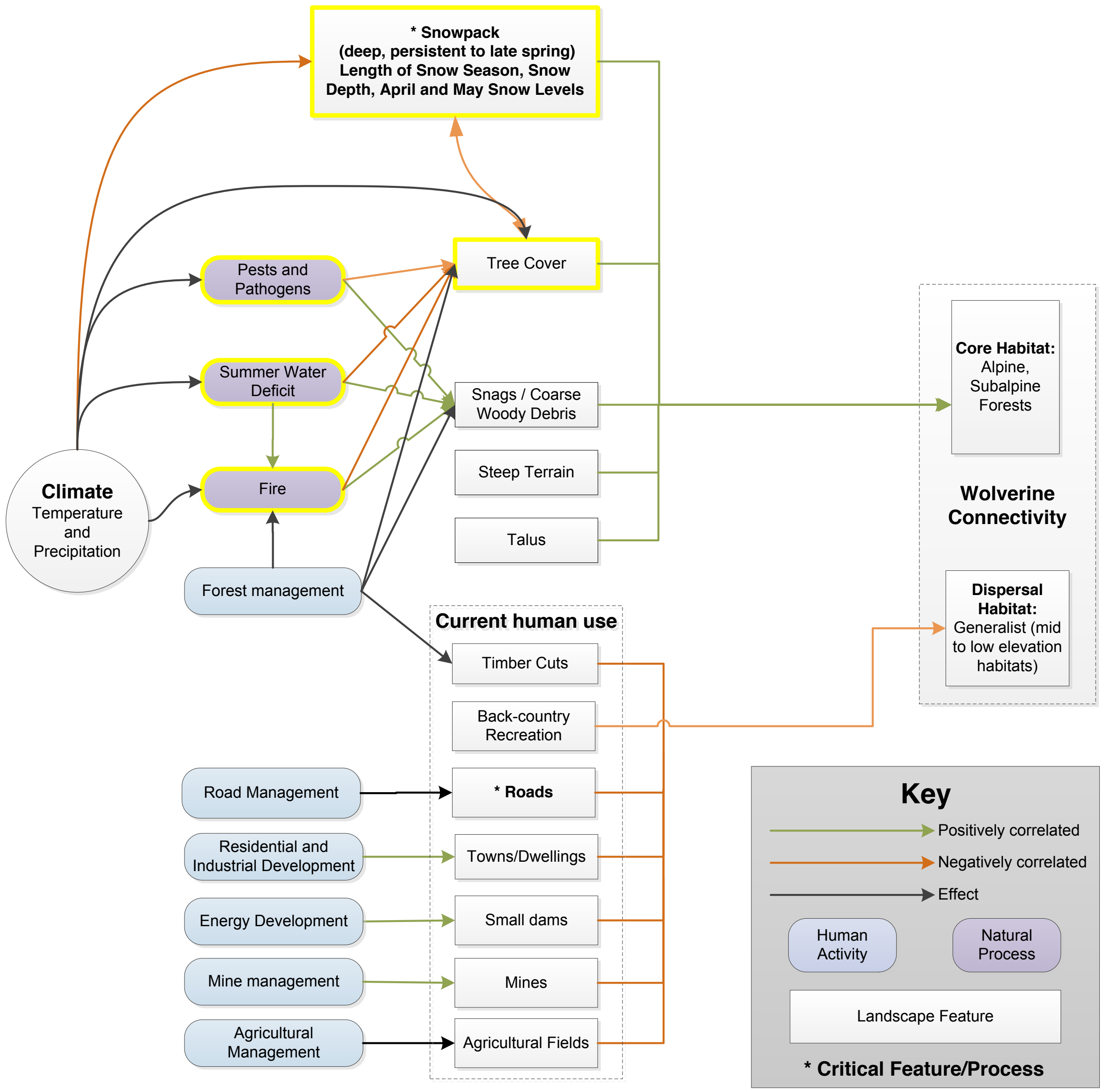

Figure 2. Example conceptual model of habitat connectivity: Wolverine. Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (purple boxes), and human activities (blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are outlined in yellow. Green lines and arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases), but note that a positive correlation is not necessarily beneficial to the species. Orange lines and arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); negative correlations are not necessarily harmful to the species.

3.3 Identifying actions for addressing potential climate impacts on habitat connectivity for case studies

After identifying potential climate impacts on habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts for each species (Fig. 3). Partners did this by considering the management activities identified in the conceptual models, and how specific activities could address potential climate impacts on landscape features or processes important to habitat connectivity. Adaptation actions identified by this approach addressed several distinct categories of impacts and responses, including potential climate impacts on habitat connectivity, novel habitat connectivity needs for promoting climate-induced shifts in species distributions, and spatial priorities for implementation.

It should be noted that one partnership did not use a conceptual model approach, because their connectivity goals and objectives were specific and simple enough that it was not required. The Transboundary Connectivity Group's goal was to identify potential climate impacts and adaptation actions for heavily fragmented valley floors within the Okanagan-Kettle region (Fig. 1), with an emphasis on connectivity priority areas identified in a recent assessment.[12] Participants in this partnership reviewed projected changes in vegetation and relevant climatic variables to identify potential impacts on these valley floors and priority connectivity areas, and then developed actions for addressing these impacts and facilitating species range shifts.

Figure 3. Science-practice partners at a project workshop. Here, partners use conceptual models of habitat connectivity together with models of projected changes in climate to identify potential impacts on habitat connectivity, and actions for addressing these impacts.

4. Project Results

4.1 Key findings of case study assessments

Project partners identified a wide range of potential climate impacts on habitat connectivity in the transboundary region, and a similarly diverse set of adaptation responses. Detailed descriptions of impacts and actions for each case study can be found in Appendices A-M, a summary list of key climate impacts and adaptation actions can be found in Appendix N, and a list of the datasets used to identify potential climate impacts for each case study can be found in Appendix O (see Section 8, below).

The climate impacts identified in the case studies were in many ways similar what would be found in a general climate change vulnerability assessment for Northwest species and ecosystems (e.g., declining snowpack, increasing risk of wildlife, warming stream temperatures). What distinguished this assessment was its focus on how these impacts would affect habitat connectivity: would projected changes in climatic variables make existing core habitat areas and dispersal corridors more or less permeable to wildlife movement? Would projected changes in areas of climatic suitability result in core habitat areas becoming more or less fragmented or isolated? Would a species need to significantly modify its range to reach projected future areas of climatic suitability? Similarly, many response actions resembled what would be found in a regional adaptation plan for species and ecosystems (e.g., employ prescribed burning to reduce risk of severe wildfires), but were focused specifically on reducing risks to habitat connectivity (e.g., implement prescribed burns to maintain the quality and permeability of core habitat areas and dispersal corridors) and providing the additional types of habitat connectivity that may be required to accommodate species range shifts (e.g., identify and protect corridors that fall along climatic gradients, or that connect core habitat areas of declining climatic suitability to areas of projected stable or increasing suitability).

For most case study assessments, climate change was found to have significant implications for habitat connectivity. Anticipated declines in habitat connectivity were due to both potential climate impacts on existing core habitat areas and corridors (e.g., declining black bear habitat connectivity due to projected increases in wildfire risk and drying of moist corridors spanning low elevation valleys) and/or changes in areas of climatic suitability (e.g., declining wolverine habitat connectivity due to shrinking core habitat areas which become increasingly fragmented and isolated). For some case study targets, projected changes in areas of climatic suitability suggested no loss or even increases in climatically suitable habitat within the transboundary region (e.g., tiger salamander and mule deer). However, for such species potential climate impacts on fine-scaled habitat features could have negative impacts on habitat connectivity within areas of future climatic suitability (e.g., impacts on individual tiger salamander breeding ponds due to rising temperatures and changes in hydrology; loss of water resources for mule deer in warm, dry, low elevation corridors).

The adaptation actions identified to address potential impacts varied by case study, but fell into two general categories: those addressing potential climate impacts on existing habitat connectivity and those addressing novel habitat connectivity needs for climate-induced shifts in species ranges. Actions to address potential climate impacts on habitat connectivity included a range of adaptation responses to maintain the quality and permeability of core habitat areas and dispersal corridors, from prescribed burning to invasive species control to riparian restoration. Actions aimed at promoting climate-induced range shifts included: maintaining and restoring corridors between areas of declining climatic suitability and areas of stability or increasing suitability; maintaining and restoring corridors that span elevation gradients (e.g., climate gradient corridors[7]), to ensure that species have the ability to disperse into cooler habitats as the climate warms; and maintaining and restoring riparian areas, which span climatic gradients and are used as movement corridors by many species.

Project partners also identified priority spatial locations for implementing these actions. Spatial priority areas for implementation of adaptation actions included low elevation valleys (e.g., the Okanagan Valley and Fraser River Valley), which currently present major barriers to wildlife movement and could constrain climate-induced range shifts, particularly for high-elevation species; major highways, particularly those that run along low elevation valleys (e.g., BC Highway 97 through the Okanagan Valley) and traverse the Cascades (e.g., BC Highway 3 through E.C. Manning Provincial Park); areas of current and projected future climatic suitability for case study species; and corridors that fall along climatic gradients (e.g., climate gradient corridors[7]). Policy-related actions were also identified that spanned each of the above categories; many of these focused on the need to consider habitat connectivity and climate change across a range of management contexts (particularly land and water management and transportation planning), and to coordinate across institutions and jurisdictions (including governments, tribes and First Nations, NGOs, and particularly private land owners).

Finally, the case study assessments identified additional research that could help to improve identification and response to potential climate impacts on habitat connectivity. Several primary research needs were evident across case studies, including research aimed at improving understanding of species' movement and habitat connectivity (e.g., additional empirical studies of species movement and dispersal, and additional habitat connectivity models for species that lack them); transboundary models of projected changes in relevant climatic variables and impacts (e.g., risk of wildfire and insect outbreaks); and models that could improve the spatial specificity of priority areas for implementation of adaptation actions and connectivity conservation efforts (e.g., models that identify corridors between projected areas of declining climatic suitability and areas of stable or increasing suitability).

4.2 Project products

Project products were designed in collaboration with practitioner partners to ensure their relevance and ease of application to decision-making. These products include:

- **This overview report**, which describes the project's rationale, partnerships, approach, and key findings.

- **Additional reports describing key findings for each case study species, vegetation system, and region**. These reports are provided as appendices to this overview report, and are intended to act as stand-alone resources; they include summary descriptions of the project and assessment process, key findings, and all materials used to identify potential climate impacts and adaptation actions for each case study (e.g., conceptual models, habitat connectivity models, and models of projected future changes in species distributions, vegetation communities, and climate variables). For more information on these reports, see Section 8: Appendices.
- **An interactive project gallery on the online mapping platform Data Basin**. This project gallery includes all project reports and associated assessment materials, including interactive and downloadable connectivity and climate datasets. This gallery can be found at:

  https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

4.3 Outcomes regarding capacity and community of practice building

One of the most important outcomes of this project was the enhanced capacity and community of practice it fostered in both its practitioner and science partners. Practitioner partners gained significant hands-on experience accessing, interpreting, and applying climate and connectivity models to their decision-making (Figs. 3-4). In addition, the project offered practitioners a transferable process for how to evaluate and address climate impacts on habitat connectivity. Finally, practitioner partners universally expressed their appreciation for the opportunity to collaborate with their counterparts across the border. For science partners, the project offered valuable lessons in how to navigate the many barriers posed by political borders, from the analytical (e.g., how to apply disparate datasets that often did not cross the border) to the logistical (e.g., how to effectively engage in knowledge co-production with a diverse, transboundary group of practitioners). It also promoted their own community of practice; the Climate Impacts Group and Pacific Climate Impacts Consortium had had relatively little interaction before this project, despite doing very similar work. Ultimately, the project's intangible products – from capacity building to the emergence of a transboundary community of practice around connectivity management in a changing climate – were at least as valuable as its more concrete deliverables.

5. Lessons Learned

Working across borders with diverse partners to incorporate climate change into the management of habitat connectivity yielded several valuable lessons. In particular, the success of the project had much to do with project partners' adoption of a case study and conceptual model approach, and the ability to respond creatively and flexibly as transboundary and institutional barriers were encountered.

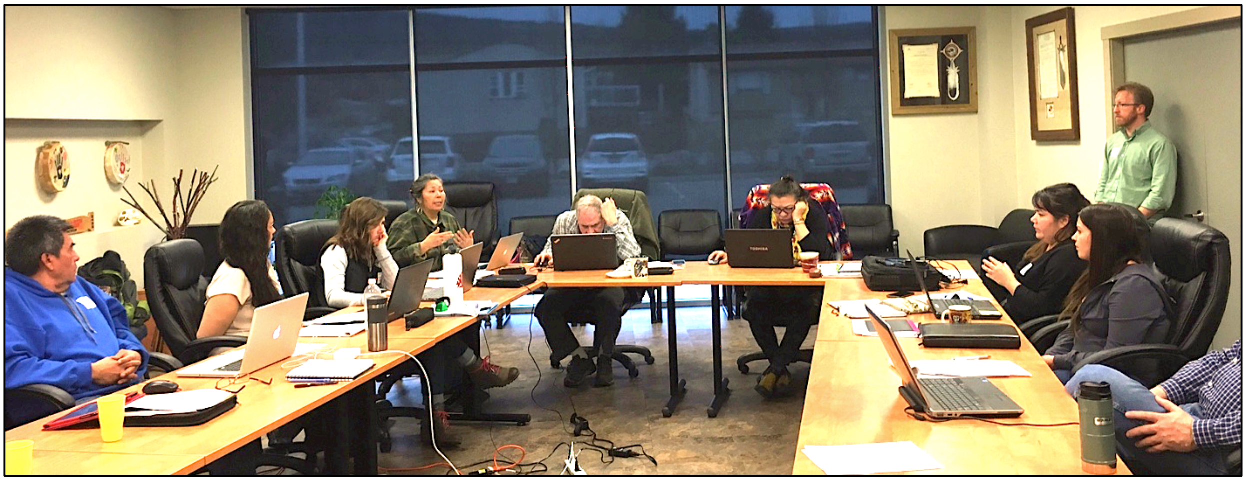

Figure 4. Science-practice partners at a project workshop. Here, partners are engaged in a hands-on training in the use of the online mapping platform, Data Basin, to access and interact with project products and explore applications to decision-making.

5.1 Use of case study species, vegetation system, and region

Employing a case study approach was not in the original project design, yet doing so proved critical to the project's success for several reasons. First, focusing assessments on shared conservation priorities was key to meeting the project goal of promoting collaboration and creating a community of practice among disparate transboundary, inter-institutional partners. A case study approach was also more logistically and analytically efficient than focusing on each individual partner's information needs, making the most of the project's limited capacity. Focusing on specific case studies also helped facilitate the translation of a high-level adaptation strategy (habitat connectivity enhancement) into specific, concrete actions. Finally, our assessment of case studies across a range of organizational scales – from individual species, to a vegetation system, to a geographic region – demonstrated the applicability of this approach to diverse management targets.

5.2 Taking a conceptual model approach

Much like the use of case studies, the use of conceptual models was not in our original project design, but proved key to the project's success. In particular, conceptual models were vital to overcoming the challenge of translating a high-level adaptation strategy into specific, on-the-ground actions. By simplifying the abstract concept of habitat connectivity into its key physical components for each case study, both science and practitioner partners were better able to consider which landscape features and processes contributing to habitat connectivity were likely to be influenced by climate, how specific climate datasets could be used to identify potential climate impacts, and how habitat connectivity model outputs and other datasets could help practitioners identify where and how they could intervene to address those impacts. In short, the conceptual model approach made an initially vague task (i.e., adapt habitat connectivity management to climate change) concrete and tractable, and yielded specific, useful results.

5.3 Employing creativity and flexibility in addressing project barriers

We found that creativity and flexibility were key to overcoming the significant barriers presented by a large, transboundary project with diverse partners. For example, travel to workshops turned out to be a significant barrier to practitioner partner involvement, particularly for US federal employees needing to cross the border into Canada. We responded by supplementing the initial workshop with numerous phone calls and meetings held at practitioners' offices, and by ultimately convening an additional workshop at Peace Arch Park at the Interstate 5 border crossing between Washington and British Columbia; entrance to international peace parks does not require a passport, circumventing institutional restrictions around international travel. Creativity and flexibility were also vital to accommodating the varying levels of engagement possible among practitioner partners. While some practitioner partners were able to participate steadily throughout the project, many individuals flowed in and out over the course of the project, or were only able to participate to lesser degrees (e.g., attending webinars but not workshops). Providing frequent and diverse opportunities for engagement and encouraging individuals to participate when available contributed to a higher level of practitioner participation than if we had adhered to the original project design. That said, this approach required significantly more time and resources – particularly for science partners – than the original project design of two workshops and two webinars.

6. Remaining Needs and Next Steps

6.1 Future research needs

Case study assessments revealed several areas where future research could help improve practitioners' ability to identify and address climate impacts on habitat connectivity. Most importantly, assessments revealed a significant need for the development of transboundary models of both habitat connectivity (which were unavailable for many species) and projected changes in climate variables (e.g., snow pack, risk of wildfire and insect outbreaks). Assessments also indicated a need for additional empirical research on wildlife movement and range shifts, both to validate existing habitat connectivity and range shift models and to inform the development of new models. Finally, assessments showed that additional research is needed to improve the spatial specificity of climate impacts on habitat connectivity and priority areas for adaptation actions, from simple GIS overlays of climate impacts and existing connectivity models, to sophisticated modeling identifying potential corridors between current and future areas of climatic suitability.

6.2 Need for ongoing capacity building

Feedback from project partners suggests that there is significant need for and interest in ongoing efforts to build practitioners' capacity to access, interpret, and apply climate and connectivity datasets to their decision-making. Hands-on, experiential learning involving both scientists and practitioners is particularly effective at building such capacity; however, such efforts are time- and resource-intensive for participants. Future innovation and investment in scaling-up such capacity building (e.g., ongoing workshops, webinars, and trainings or large-scale co-production efforts) are greatly needed.

6.3 Need for continued transboundary engagement

Effectively managing habitat connectivity in a changing climate will require ongoing transboundary engagement of scientists and practitioners to ensure that land and wildlife management is coordinated across the border and informed by the best available science. While numerous mechanisms are in place to ensure coordinated management of transboundary aquatic species and resources, few frameworks exist for promoting such engagement around terrestrial species and ecosystems. There is also need for additional funding streams specifically directed toward collaborative research among transboundary scientists, in order to meet the need for climate and connectivity models that seamlessly span the border, and to promote scientific engagement in transboundary adaptation processes. Funding and institutions that support transboundary engagement among scientists and practitioners will be key to maintaining a connected, resilient transboundary region as the climate changes.

7. References

1. Chen, I.C., Hill, J.K., Ohlemuller, R., Roy, D.B., and C.D. Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. *Science* 333:1024-1026
2. 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.
3. Krosby, M., Tewksbury, J., Haddad, N., and J. Hoekstra. 2010. Ecological connectivity for a changing climate. *Conservation Biology* 24:1686-1689.
4. WHCWG (Washington Wildlife Habitat Connectivity Working Group). 2013. Washington Connected Landscapes Project: British Columbia–Washington Transboundary Habitat Connectivity Scoping Report. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.
5. Cross, M.S., et al. 2012. The Adaptation for Conservation Targets (ACT) framework: a tool for incorporating climate change into natural resource management. *Environmental Management* 50:341–351.
6. Washington Wildlife Habitat Connectivity Working Group. 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. www.waconnected.org.
7. Washington Wildlife Habitat Connectivity Working Group. 2011. Washington Connected Landscapes Project: Climate gradient corridors report. Washington Departments of Fish and Wildlife, and Transportation. Olympia, WA. www.waconnected.org.
8. Washington Wildlife Habitat Connectivity Working Group. 2012. Washington Connected Landscapes Project: Analysis of the Columbia Plateau Ecoregion. Washington's Department of Fish and Wildlife, and Department of Transportation, Olympia, WA.

9. Integrated Scenarios of the Future Northwest Environment. http://climate.nkn.uidaho.edu/IntegratedScenarios
10. Pacific Climate Impacts Consortium (PCIC), Regional Analysis Tool. 2014. https://www.pacificclimate.org/analysis-tools/regional-analysis-tool
11. Pacific Northwest Climate Change Vulnerability Assessment (PNWCCVA). http://www.climatevulnerability.org/
12. Transboundary Connectivity Group. 2016. Providing a Regional Connectivity Perspective to Local Connectivity Conservation Decisions in the British Columbia–Washington Transboundary Region: Okanagan-Kettle Subregion Connectivity Assessment. Available at: http://waconnected.org.

8. Appendices

Appendices to this report describe the key climate impacts and adaptation actions identified for each case study species, vegetation system, and region assessed by project partners. A first set of appendices describes individual case study assessments, including the approach taken, key findings, and all materials and datasets used in the assessment. These appendices include:

Appendix A: Wolverine

Appendix B: Mountain Goat

Appendix C: White-Tailed Ptarmigan

Appendix D: Whitebark Pine

Appendix E: Canada Lynx

Appendix F: American Marten

Appendix G: Black Bear

Appendix H: Mule Deer

Appendix I: Lewis's Woodpecker

Appendix J: Tiger Salamander

Appendix K: Bull Trout

Appendix L: Shrub-Steppe

Appendix M: Okanagan-Kettle Region

These appendices have been prepared as stand-alone documents; they and their associated datasets and metadata can be accessed on the online mapping platform, Data Basin, freely available at:

https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

Two additional appendices summarize findings across case studies, and are available within this overview report. These appendices include:

Appendix N. Summary of key climate impacts and adaptation actions for each case study species, vegetation system, and region.

Appendix O. Datasets used to identify potential climate impacts on each case study species, vegetation system, and region.

Appendix N. Summary of key climate impacts and adaptation actions for each case study species, vegetation system, and region.

I. Addressing Climate Impacts on Habitat Connectivity		Case Study												
Climate impact(s) addressed	**ADAPTATION ACTION**	Wolverine	Mountain Goat	White-tailed Ptarmigan	Whitebark Pine	Canada Lynx	American Marten	Black Bear	Mule Deer	Lewis's Woodpecker	Tiger Salamander	Bull Trout	Shrub-Steppe	Okanagan-Kettle
Increasing risk of wildfire	Using prescribed burns, thinning, and targeted fuel reduction to reduce the risk of catastrophic wildfires.	x			x	x	x	x	x	x		x	x	x
	Incorporating projections and observations of climatic changes (e.g., earlier onset of fire season) to inform the timing of fire prevention techniques as conditions change, in order to maximize safety and effectiveness					x	x	x	x	x			x	x
	Using some degree of fire suppression in cool, moist forests with long fire return intervals.					x	x							
	Referencing the forest and grazing practices of tribes and First Nations to identify traditional strategies for managing fire risk.					x		x	x				x	x
Decreasing snowpack depth and duration	Increasing snow depth locally (e.g., via snow fences), recognizing that local-scale snow management is unlikely to have a significant impact on habitat connectivity. Therefore, prioritize such efforts within important core habitat areas and corridors.	x				x	x							
	Ensuring that snowpack retention practices are compatible with other forest management practices that balance the need for fire and natural resource management with the need for sufficient horizontal cover.					x	x							
	Identifying and prioritizing areas where deep spring snowpack is most likely to persist in the future (e.g., north-facing slops and canyons).	x				x	x							
Changes in vegetation	Monitoring and responding to changes in vegetation (e.g., shifts in tree line, transition of shrub-steppe to other vegetation types, loss of forested corridors in low elevation valleys) that may affect habitat connectivity. Consider use of LIDAR remote sensing and other technologies yielding high resolution data.	x	x	x	x	x		x			x		x	x
	Minimizing forest (or non-target tree) encroachment in key core habitat areas and corridors by mechanically removing invading trees or using prescribed burns to reduce tree recruitment.			x	x								x	
	Developing planting plans that evaluate and potentially include genotypes adapted to projected future climatic conditions				x								x	
Changes in invasive species	Incorporate invasive species management into all activities related to habitat connectivity conservation.												x	x
	In areas heavily invaded by cheatgrass, considering prescribed burning in combination with herbicide and native plant reseeding.												x	x
Changes in seed dispersal	Identifying and protecting stands that are large enough to attract seed dispersers and serve as a seed source				x									
	Identifying and protecting stands that could serve as links or stepping stones for seed dispersers moving among larger stands				x									
Increasing stream temperatures	Restoring riparian vegetation, which will help shade streams and reduce stream temperatures.											x		x
	Excluding cattle from riparian areas to prevent loss of vegetative cover.										x	x		
	Investigate the feasibility and benefit of manually transporting fish around thermal barriers in streams.											x		
Decreasing summer streamflows	Managing forests to maximize groundwater infiltration.											x		
	Using dam release events to maintain water levels and stream temperatures adequate for fish passage.											x		
	Identifying and mitigating barriers such as dams or poorly designed road crossings or culverts to promote fish passage.											x		
Declining water availability and quality for ponds/wetlands	Restoring and/or protecting riparian vegetation to shade ponds, which would reduce water temperatures and evaporation rates.										x			x
	Excluding cattle from ponds and surrounding vegetation (e.g., by installing fencing), and using techniques (e.g., fabric and gravel installation) to prevent cattle from leaving pockmarks, which reduce pond quality.										x			x
	Protecting and/or reintroducing beavers into watersheds, which may improve wetland quality and connectivity.								x		x			x
	Widening ponds to increase access for salamanders and/or deepening ponds to increase pond persistence into summer.										x			x
	Adding water and removing predatory fish from key ponds (highly resource intensive; an emergency measure).										x			x
	If frost seal does not occur often enough to maintain spring wetlands, considering artificially irrigating key wetlands.								x		x			
	Establishing retention ponds in urban areas, and treating them as managed wetlands.										x			x
	Diverting rainwater into existing ponds (while addressing potential for chemical run-off and turbidity issues).										x			x
Changes in the timing, location, and intensity of human activities	Managing access in core habitat areas and corridors (especially those projected to maintain climatic suitability) to reduce impacts from recreation, grazing, and other uses.		x	x		x	x	x					x	
	Monitoring changes in the timing and intensity of recreation and other activities, particularly within core habitat areas and movement corridors.	x					x	x						

II. Enhancing Connectivity to Facilitate Range Shifts		Case Study												
Climate impact(s) addressed	**ADAPTATION ACTION**	Wolverine	Mountain Goat	White-tailed Ptarmigan	Whitebark Pine	Canada Lynx	American Marten	Black Bear	Mule Deer	Lewis's Woodpecker	Tiger Salamander	Bull Trout	Shrub-Steppe	Okanagan-Kettle
Geographic shifts in species ranges	Maintaining and restoring corridors between areas of declining climatic suitability and areas of stability or increasing suitability.	x	x			x	x	x		x	x	x	x	
	Evaluating the risks and benefits of manually transporting species to areas of projected stable or increasing climatic suitability.			x	x							x		
	Maintaining and restoring corridors that span elevation gradients (e.g., climate gradient corridors), to ensure that species have the ability to disperse into cooler habitats as the climate warms.	x	x	x	x	x	x	x	x	x	x		x	x
	Maintaining and restoring riparian areas, which span climatic gradients and are used as movement corridors by many species.					x	x	x	x	x				x
	Planning the placement, orientation, and shape of reserve patches to maximize connectivity, span climatic gradients, and cross low-elevation valleys.					x	x	x						

III. Spatial Priorities for Implementation		Case Study												
TOPIC ADDRESSED	**SPATIAL PRIORITY**	Wolverine	Mountain Goat	White-tailed Ptarmigan	Whitebark Pine	Canada Lynx	American Marten	Black Bear	Mule Deer	Lewis's Woodpecker	Tiger Salamander	Bull Trout	Shrub-Steppe	Okanagan-Kettle
Spatial Priorities for Implementation	Existing core habitat areas and corridors, which will be important for maintaining populations under current climate, and facilitating species response to future change. Pinch-points, barriers and restoration opportunities, and areas of high network centrality all offer potential priority areas for implementation.						x	x			x	x	x	
	Climate-gradient corridors, which may facilitate species dispersal into cooler habitats as climate warms.	x		x	x	x	x	x		x			x	x
	Climate-resilient core habit areas and corridors (i.e., those that are projected to remain climatically suitable).			x	x	x	x	x		x	x	x		x
	Riparian areas, which currently act as species movement corridors, and also span climatic gradients, facilitating dispersal into cooler habitats.					x	x	x		x				
	Cold-water refuges – areas within streams that have persistently lower temperatures than other stream areas											x		
	Ponds that are deep, free of predatory fish, and located in cooler and/or wetter micro-climates.										x			x
	Highways, especially those that run along low-elevation valleys (e.g., Highway 97 and 3A) and those that cross the Cascade Range (e.g., Highway 3 and Interstate 90), which may present barriers to climate-driven range shifts.	x	x			x	x	x	x					
	Low elevation valleys, particularly the Fraser River Valley and the Okanagan Valley. Connectivity Focus Areas offer key areas for implementation in the Okanagan Valley.	x	x			x		x	x	x	x		x	x

III. Policy Considerations		Case Study												
TOPIC ADDRESSED	**ADAPTATION ACTION**	Wolverine	Mountain Goat	White-tailed Ptarmigan	Whitebark Pine	Canada Lynx	American Marten	Black Bear	Mule Deer	Lewis's Woodpecker	Tiger Salamander	Bull Trout	Shrub-Steppe	Okanagan-Kettle
First Nations and tribal referrals response processes	Encouraging the use of highways design techniques that preserve connectivity (e.g., overpasses, open span bridges, culverts).					x		x	x					
	Encouraging the incorporation of wildlife-friendly fencing into permitting and planning processes.					x		x	x					
	Considering impacts and opportunities for habitat connectivity during the referrals process.												x	
	Evaluating opportunities to reduce grazing pressure in key corridors.												x	
Laws and regulations	Monitoring core habitats and movement corridors for suitability and being prepared to address and/or modify the legal context for management (e.g., Endangered Species Act).				x	x						x		
	Considering timing tribal/First Nation hunting seasons around key dispersal periods and/or lowering take limits to reduce pressure on populations.							x	x					
Land and water use planning and management	Limiting the development of forestry activities at high elevations (particularly those likely to remain climatically suitable).				x									
	Managing forestry activities to ensure that forest canopy cover remains continuous throughout corridors for montane forest species, and that large trees, old snags, and tree cavities remain present.					x	x							
	Reviewing and implementing existing guidance and plans relating to species habitat management, modifying to address climate.	x			x	x	x	x		x	x		x	
	Investigating whether having multiple priority species affected in the same area could lead to greater pressure to change management practices if cumulative impacts can be demonstrated.	x	x			x	x	x						
	Coordinating stewardship and management activities with governments, NGOs, tribes and First Nations, and private landowners.	x			x		x	x	x	x	x		x	
	Placing limitations on proposals so that they enhance conservation measures (e.g., require buffers).													
	Striving for community design that limit fragmentation of habitat and include habitat corridors.					x		x						
	Identifying and protecting wetlands and other water sources in valleys. These may help to promote movement of montane forest species through dry, low-elevation valleys, while also promoting core habitat area and corridor quality for low-elevation species.							x	x	x				x
	Securing water rights to maintain moisture in riparian areas and wetlands that provide core habitat and movement corridors.						x	x	x	x	x	x		x
	Carefully reviewing water permit requests for new irrigation withdrawals to ensure that key ponds, wetlands, and water resources remain available within core habitat areas and dispersal corridors.										x		x	
	Monitoring trends and reviewing policies relating to vineyard establishment. Strive to avoid establishing vineyards in shrub-steppe core habitat areas or corridors.												x	
	Considering establishment of additional conservation areas at elevations above current species ranges to protect future habitats.												x	
	Using large parcel zoning to maintain contiguity of natural areas within First Nation and tribal lands. Outside of these lands, work with private landowners and environmental policy to maintain contiguous swaths of suitable land that will facilitate movement. Consider full range of approaches, from land purchases and easements to stewardship activities.					x		x	x				x	
Transportation Planning	Coordinating with transportation agencies to evaluate appropriate management responses to potential changes in seasonal road openings and closings as snow conditions change and higher elevation habitats potentially become more accessible to people.	x	x				x	x						
	Coordinating with transportation agencies to ensure that new roads do not negatively impact priority areas for habitat connectivity under climate change (e.g., climate-gradient corridors, or climate-resilient core habitat areas and corridors).	x	x			x	x	x	x		x	x		x
	Coordinating with transportation agencies to mitigate barrier effects of roads crossing priority areas for habitat connectivity under climate change (e.g., by incorporating crossing structures into road design, or retro-fitting roads with crossing structures).							x			x			

IV. Research Needs		Case Study												
TOPIC ADDRESSED	**ADAPTATION ACTION**	Wolverine	Mountain Goat	White-tailed Ptarmigan	Whitebark Pine	Canada Lynx	American Marten	Black Bear	Mule Deer	Lewis's Woodpecker	Tiger Salamander	Bull Trout	Shrub-Steppe	Okanagan-Kettle
Research needs	Developing transboundary habitat connectivity models.			x							x			
	Gathering additional empirical information on species movement to validate and improve corridor models, and understand what landscape features facilitate or hinder movement.			x	x	x	x	x		x		x		
	Mapping current population locations (as opposed to general range boundaries).			x	x	x								
	Incorporating projected changes in human land use into habitat connectivity models.												x	
	Developing fine-scale, transboundary models of riparian location and condition.					x	x	x	x	x				
	Developing transboundary models of wildfire risk and probability of pest outbreaks.		x	x		x	x	x	x	x		x	x	
	Developing climatic niche models.		x	x									x	
	Evaluating the extent to which areas projected to become climatically suitable for species include suitable non-climatic conditions (e.g., soils, vegetation, aquatic habitat).										x		x	
	Identifying climate-resilient core habitat areas and corridors (i.e., those likely to maintain climatic suitability, and experience relatively modest changes in relevant climatic variables).	x	x	x	x	x	x	x		x	x		x	
	Identifying potential climate impacts on specific existing core habitat areas and corridors.	x	x			x	x	x		x				
	Identifying corridors between locations with projected declines in climatic suitability and areas with projected stable or increasing climatic suitability.	x	x			x	x	x		x	x			
	Developing transboundary models of cold-water refuges and projected future bull trout distributions.											x		
	Developing transboundary aquatic habitat connectivity models (including identification of significant barriers to movement).											x		

Appendix O. Datasets used to identify potential climate impacts on each case study species, vegetation system, and region.

DATASETS USED IN ASSESSMENT	Case Study												
	Wolverine	Mountain Goat	White-tailed Ptarmigan	Whitebark Pine	Canada Lynx	American Marten	Black Bear	Mule Deer	Lewis's Woodpecker	Tiger Salamander	Bull Trout	Shrub-Steppe	Okanagan-Kettle
I. Habitat connectivity models													
Species Corridor Network	x	x			x	x	x	x		x			
Landscape Integrity Corridor Network			x	x					x		x	x	
Climate-Gradient Corridor Network	x	x	x	x	x	x	x	x	x	x	x	x	x
Connectivity Focus Areas													x
II. Projected changes in species distributions													
Climatic Niche Model	x			x	x	x	x	x	x	x		x	x
Cold Water Climate Shield											x		
III. Projected changes in vegetation communities													
Climatic Niche Vegetation Model	x	x	x		x	x	x						x
Mechanistic Vegetation Model	x	x	x		x	x	x						x
IV.Projected changes in insect survival													
Mountain Pine Beetle Survival	x			x	x	x	x	x	x				
V. Projected changes in climatic variables													
Spring (April 1) Snowpack	x	x	x	x	x	x	x		x	x	x	x	
Late Spring (May 1) Snowpack						x							
Length of Snow Season	x	x	x	x	x	x	x						
Percentage of Winter Precipitation Captured in April 1st Snowpack					x			x					
Number of Frost Days												x	x
Growing Season Length							x						
Increase in Average Annual Daytime Temperature			x							x			
Total Spring Precipitation			x						x	x		x	x
Total Summer Precipitation								x		x			x
Annual Maximum 24-hour Precipitation											x		
Number of Heavy Precipitation Days						x							x
Average Precipitation Intensity						x							x
Total Spring Runoff										x	x		x
Total Summer Runoff										x	x		x
Evapotranspiration, July-September							x			x			x
Evapotranspiration, March-May										x			x
Potential Evapotranspiration, July-September									x				
Dry Spell Duration					x		x	x	x		x	x	
Water Deficit, July-September	x	x		x			x	x			x		x
Soil Moisture, July-September		x		x		x	x	x	x	x		x	x
Days with High Fire Risk	x	x	x	x	x	x	x	x	x		x	x	x
Stream Temperature											x		