Appendix B: Climate impacts and adaptation actions for mountain goat

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-practice partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, vegetation systems, and regions chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the mountain goat (*Oreamnos americanus*).

Figure B.1. Mountain goat.

The mountain goat is found in alpine and subalpine areas across northwestern North America. In the Washington-British Columbia transboundary region, the mountain goat exhibits relatively low habitat connectivity across the North Cascades Range.[2] Barriers to mountain goat movement are presented by both natural factors (e.g., very high or low elevations, bodies of water) and human factors (e.g., highways, urban and agricultural areas), with significant barriers present along major highways (Appendix B.1).[2]

Future climate change may present additional challenges and needs for mountain goat habitat connectivity.[3-4] First, climate change may impact mountain goat core habitat and dispersal corridors in ways that may make them more or less permeable to movement. Second, existing mountain goat core habitat and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in mountain goat distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for mountain goat habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on mountain goat habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary mountain goat habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence mountain goat habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix B.2). 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.[6] The mountain goat conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally

[i] This report is Appendix B of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to mountain goat habitat connectivity

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on mountain goat connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, project partners 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 include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

Key impacts on transboundary mountain goat habitat connectivity identified via this approach include changes to the area and distribution of mountain goat climatic suitability, changes in subalpine and alpine habitat, and declines in the amount and duration of snowpack.

Changes in areas of climatic suitability

Climate change may impact mountain goat habitat connectivity by changing the extent and location of areas of climatic suitability for mountain goat; this may render some existing core habitat areas and corridors unsuitable for mountain goat, and/or create new areas of suitability. Climatic niche models for mountain goat were not available as part of this project. However, Johnston et al. (2012)[11] modeled changes in mountain goat climatic niche space within Washington State. The projections were made using two different modeling techniques, two climate models, and two emissions scenarios (for a total of 8 projections). There is strong agreement among the models that mountain goat climatic niche space will contract moderately by mid-century (20-50% reduction) and significantly by the end of the century (~90% reduction). These contractions are likely to result in remaining climatically suitable habitat being more fragmented and isolated.

Changes in subalpine and alpine habitat

Mountain goats occur in both subalpine and alpine areas, but prefer open habitat when deep snow is not prohibitive. Changes in the distribution and quality of subalpine and alpine habitats in the transboundary region could therefore be expected to affect mountain goat habitat connectivity.

Two types of models are available that estimate future changes in vegetation for the transboundary region: climatic niche models and mechanistic models (Appendix B.3).[ii] Both types of models are based

[ii] Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[iii] Both models also use the A2 (high) emissions scenario.[iv] Both mechanistic and climatic niche vegetation models project that cold forest vegetation types will shift higher in elevation and replace open alpine habitat across the transboundary region (Appendix B.3). This would reduce mountain goat habitat connectivity by decreasing the extent of core alpine and subalpine habitat areas, and increasing fragmentation and isolation of remaining core habitat areas. In addition, drier summers (Appendix B.4: Water Deficit, July-September; Soil Moisture, July-September) may negatively impact forage quality in alpine and subalpine habitats. However, drier summers and Increased risk of wildfire (Appendix B.4: Days with High Fire Risk) may help to maintain open habitats at high elevations as the treeline rises.

Declining amount and duration of snowpack

Projected declines in the amount and duration of snowpack (Appendix B.4: Spring (April 1st) Snowpack; Snow Season Length) may affect mountain goat habitat connectivity by improving movement conditions for the species. Deep snow physically impedes mountain goat movement. In winter, mountain goats tend to move into forested areas, where snow is less deep. From this perspective, reduction in snow levels would improve movement conditions. However, there are some areas that are projected to see increased snow, which may be detrimental to mountain goat habitat connectivity. In addition, mountain goats may not move long distances in winter, which could reduce the importance of snow for connectivity. Snow levels also affect summer moisture levels (Appendix B.4: Soil Moisture, July-September), which could have a negative impact on summer forage quality. Finally, declines in the amount and duration of snowpack may result in earlier opening and later closing of roads that have historically been closed by heavy winter snow. Resulting increases in road access could negatively affect mountain goat habitat connectivity.

Adaptation responses

After identifying potential climate impacts on mountain goat 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 (Appendix B.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on mountain goat habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in mountain goat distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on mountain goat habitat connectivity

Actions to address the potential for mountain goat habitat to become increasingly isolated and fragmented include:

[iii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs)[12,13] which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[iv] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.[14]

- Identifying and protecting corridors and resources likely to facilitate mountain goat movement across low elevation valleys, in order to maintain connectivity among high elevation core habitat areas. Habitat connectivity models (Appendix B.1) could be used to evaluate low-elevation corridors for areas where continued permeability will be especially important to maintaining broader connectivity, and which should thus be high priorities for connectivity conservation efforts.
- Anticipating and managing for lengthening of existing corridors in response to increased habitat fragmentation due to future warming. Though mountain goats are capable of long distance movements, if routes become too long, this could reduce or restrict movement between core habitat patches.

Actions to address the potential for climate change to impact connectivity through increased road access in high elevation areas include:

- Managing roads to account for potential for future increases in access within mountain goat core habitat areas and corridors. Monitoring and evaluating the impacts of the timing of road openings and closures on mountain goat habitat and corridors will be important for informing management response. Proposals to develop new roads should be carefully evaluated to determine impacts on mountain goat habitat and connectivity.

Enhancing connectivity to facilitate range shifts

Actions that may help the mountain goat adjust its geographic distribution to track shifts in its areas of climatic suitability include:

- Maintaining and restoring corridors between areas of declining climatic suitability (e.g., low elevation habitat) and areas of stability or increasing suitability. For example, identifying optimal movement routes between lower elevation mountain peaks to mountains with larger areas of high elevation habitat.
- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors, Appendix B.1), to ensure that mountain goats have the ability to disperse into cooler, higher elevation habitats as the climate warms. Many of these elevational movement routes are likely to be important for seasonal migration as well, making their protection a robust management decision (i.e., it will benefit the species regardless of future changes).
- Monitoring and coordinating with transportation planning processes to minimize road impacts on climate-gradient corridors (e.g., by incorporating crossing structures or avoiding building new roads that cross climate-gradient corridors).

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Highways, especially those that run along low-elevation valleys (e.g., Highway 97 and Highway 3A) and those that cross the Cascade Range (e.g., Highway 3 and US Interstate 90). These present dispersal barriers that may limit mountain goat dispersal and range shifts. For example, Highway 3 runs east-west through E.C. Manning Provincial Park and may create a dispersal barrier for south-north movement through the North Cascades; if there is evidence that the road creates a barrier, it could be a candidate for a crossing.

Policy considerations

Transportation planning

Actions for addressing climate impacts on mountain goat connectivity through transportation planning include:

- Coordinating with transportation agencies to evaluate appropriate management responses to potential changes in seasonal road openings and closings.
- Coordinating with transportation agencies to ensure that new roads do not negatively impact mountain goat connectivity as climate changes.
- Investigating whether having multiple priority species affected in the same area can lead to greater pressure to change management practices if cumulative impacts can be demonstrated.

Research Needs

Future research that could help inform mountain goat connectivity conservation under climate change includes:

- Developing transboundary climatic niche models for mountain goat. These models would help identify the potential extent of habitat loss and fragmentation that could occur with climate change, and allow identification of those core habitat areas and corridors are most likely to remain climatically suitable. Potential high priority areas include corridors between climate resilient core areas and between at-risk core areas and resilient core areas.
- Developing fine-scale, transboundary maps of steep, rocky slopes. Steep, rocky slopes are a critical component of mountain goat movement corridors. These map layers would improve mountain goat connectivity modeling.
- Identify potential climate impacts on specific mountain goat core habitat areas and corridors. Overlay projected climate changes with existing mountain goat corridor networks to quantify expected impacts on specific areas within the network. This may help direct the adaptation actions described above to appropriate areas.
- Identifying climate resilient mountain goat core habitat areas and corridors. Overlay corridor networks (Appendix B.1) with projections of vegetation change (Appendix B.3) and snow cover change (Appendix B.4). Core areas and corridors within the current range that are projected by multiple models to retain suitable climatic conditions and vegetation, and to see the least change in relevant climatic variables, may be considered most likely to be resilient. For example, high elevation areas that are likely to maintain alpine and subalpine vegetation, and to not have significant increases in snowpack, may be most likely to retain suitable habitat. Climate-resilient core habitat areas and corridors may be used to identify priority areas for the adaptation actions described above.
- Identifying corridors between locations with projected declines in climatic suitability and areas with projected stable or improving climatic suitability. Use climatic niche models (Appendix B.3) and vegetation projections (Appendix B.4) to identify potentially stable or improving locations. Use corridor models (Appendix B.1) to identify potential corridors for connecting vulnerable mountain goat core habitat areas to areas projected to remain climatically suitable or become newly suitable.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[v]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[vi] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

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[v] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (Accessed January 2016).

[vi] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices B.1-4

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For the mountain goat, these materials include:

Appendix B.1. Habitat connectivity models
Appendix B.2. Conceptual model of habitat connectivity
Appendix B.3. Projected changes in vegetation communities
Appendix B.4. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. B.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

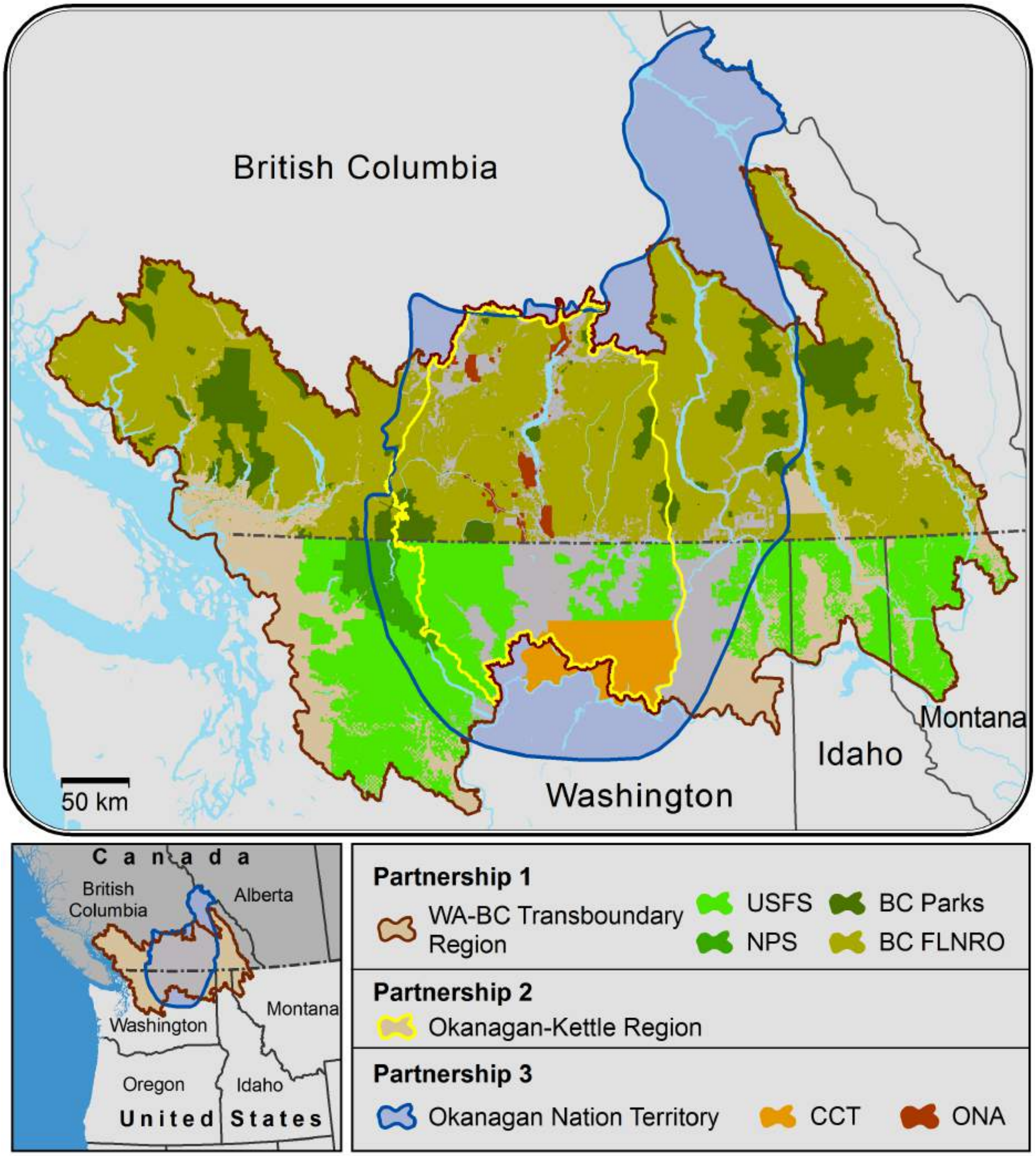


Figure B.2. Project partners and assessment areas.

Appendix B.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vii] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

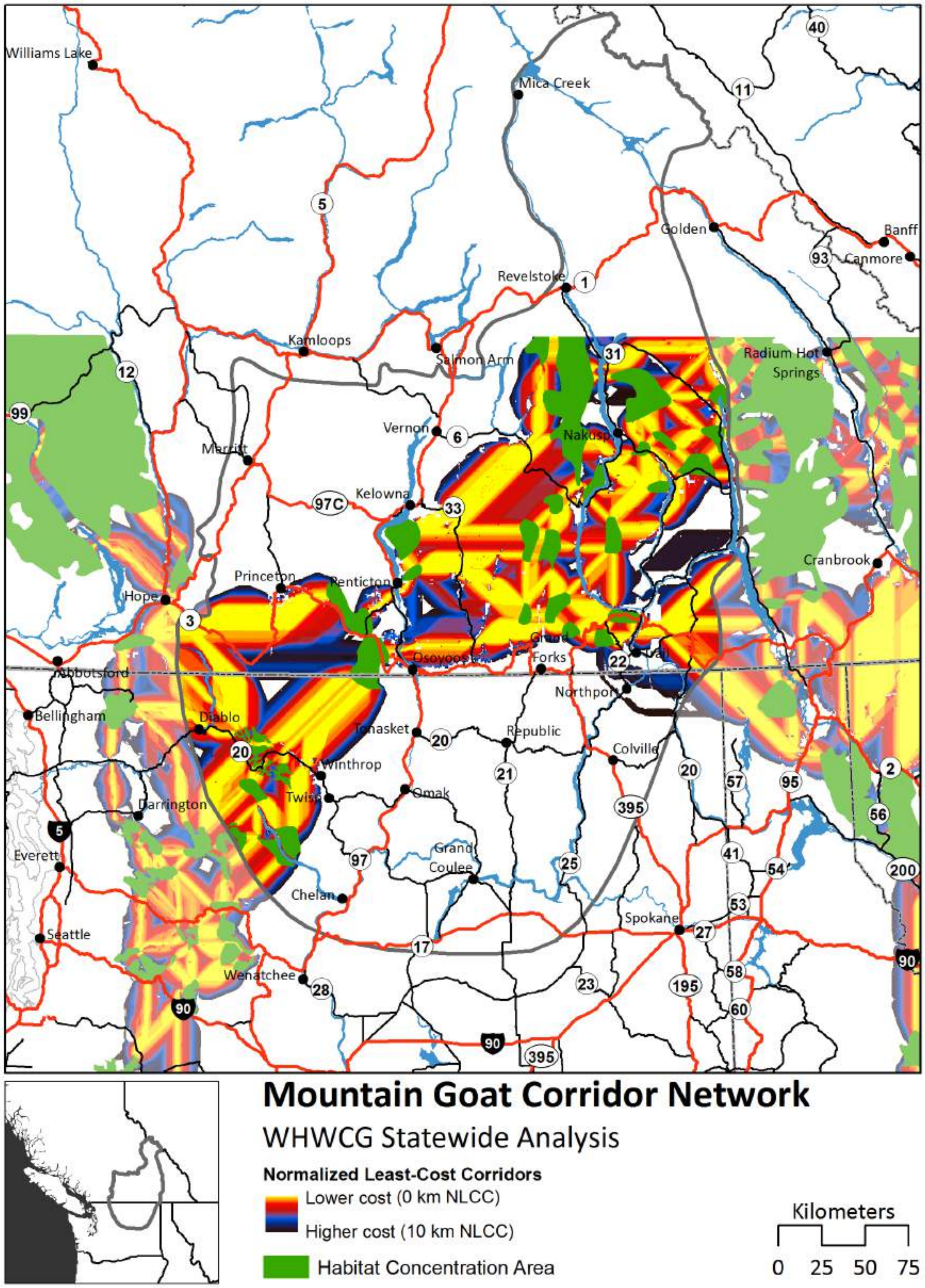
a) **WHCWG Statewide Analysis: Mountain Goat Corridor Network.**[2] This map shows Habitat Concentration Areas (HCAs, green polygons), which are large, contiguous areas featuring little resistance to species movement; and corridors (glowing yellow areas) connecting HCAs, modeled using least cost corridor analysis. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).**[7] This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vii] For detailed methodology and data layers see http://www.waconnected.org.

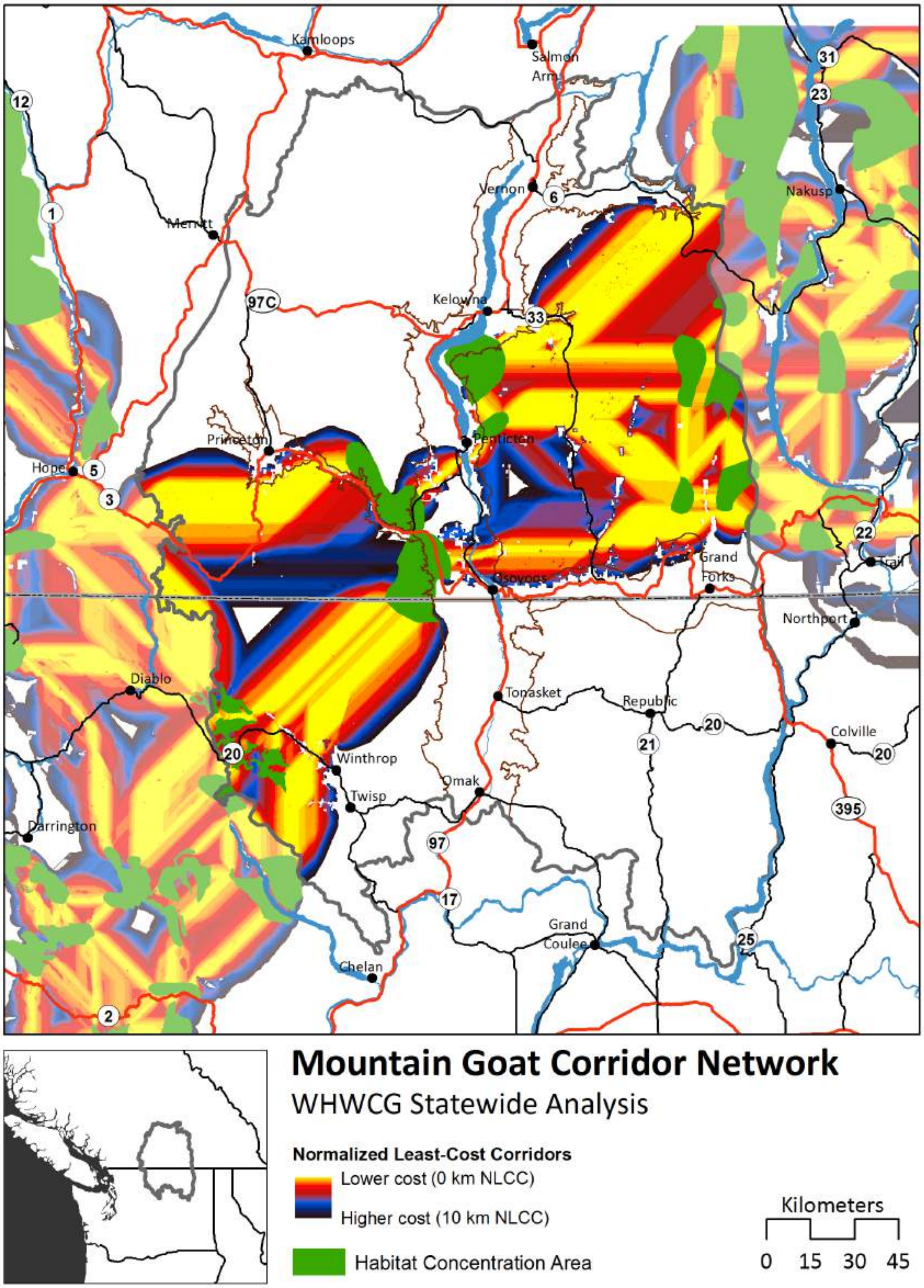
Appendix B.1a. WHCWG Statewide Analysis: Mountain Goat Corridor Network

i) Extent: Okanagan Nation Territory



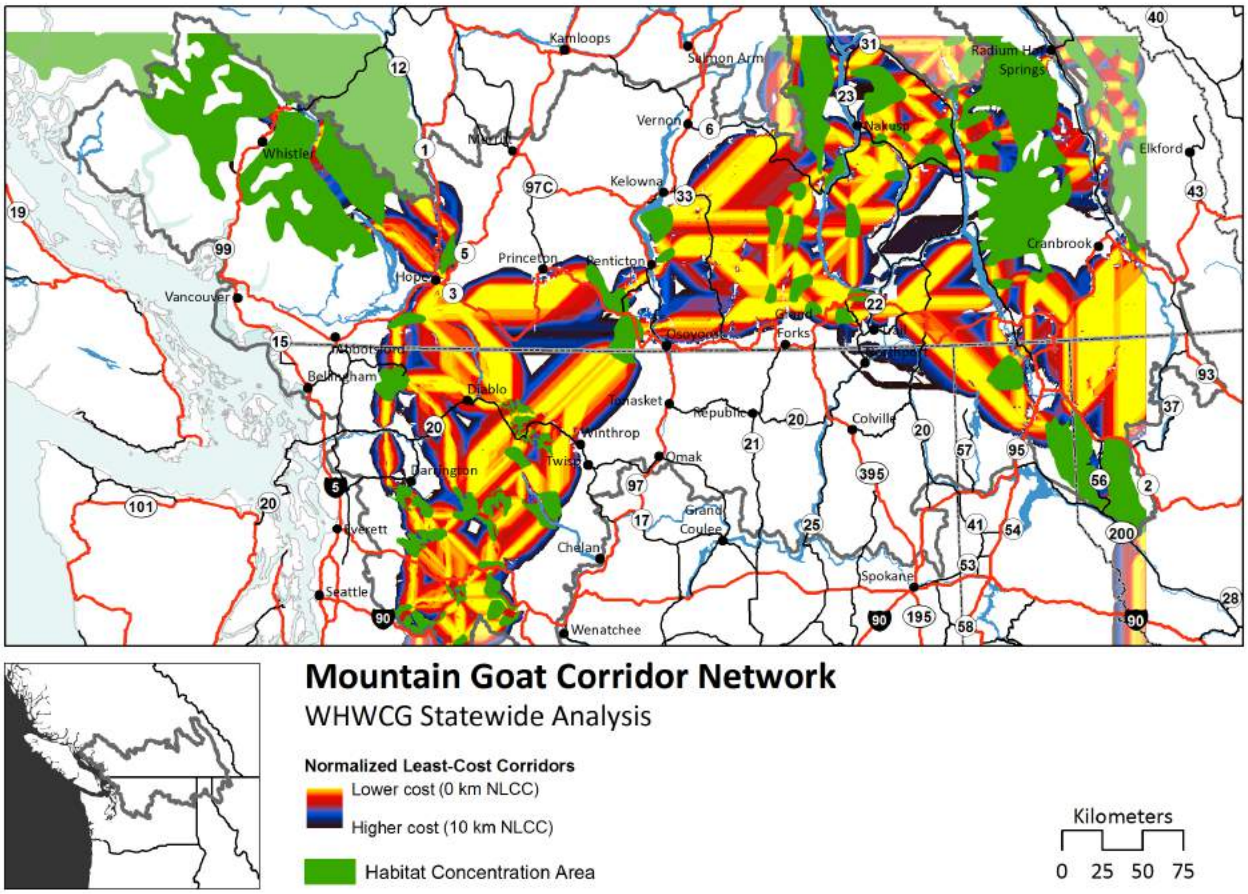
Appendix B.1a. WHCWG Statewide Analysis: Mountain Goat Corridor Model

ii) Extent: Okanagan-Kettle Region



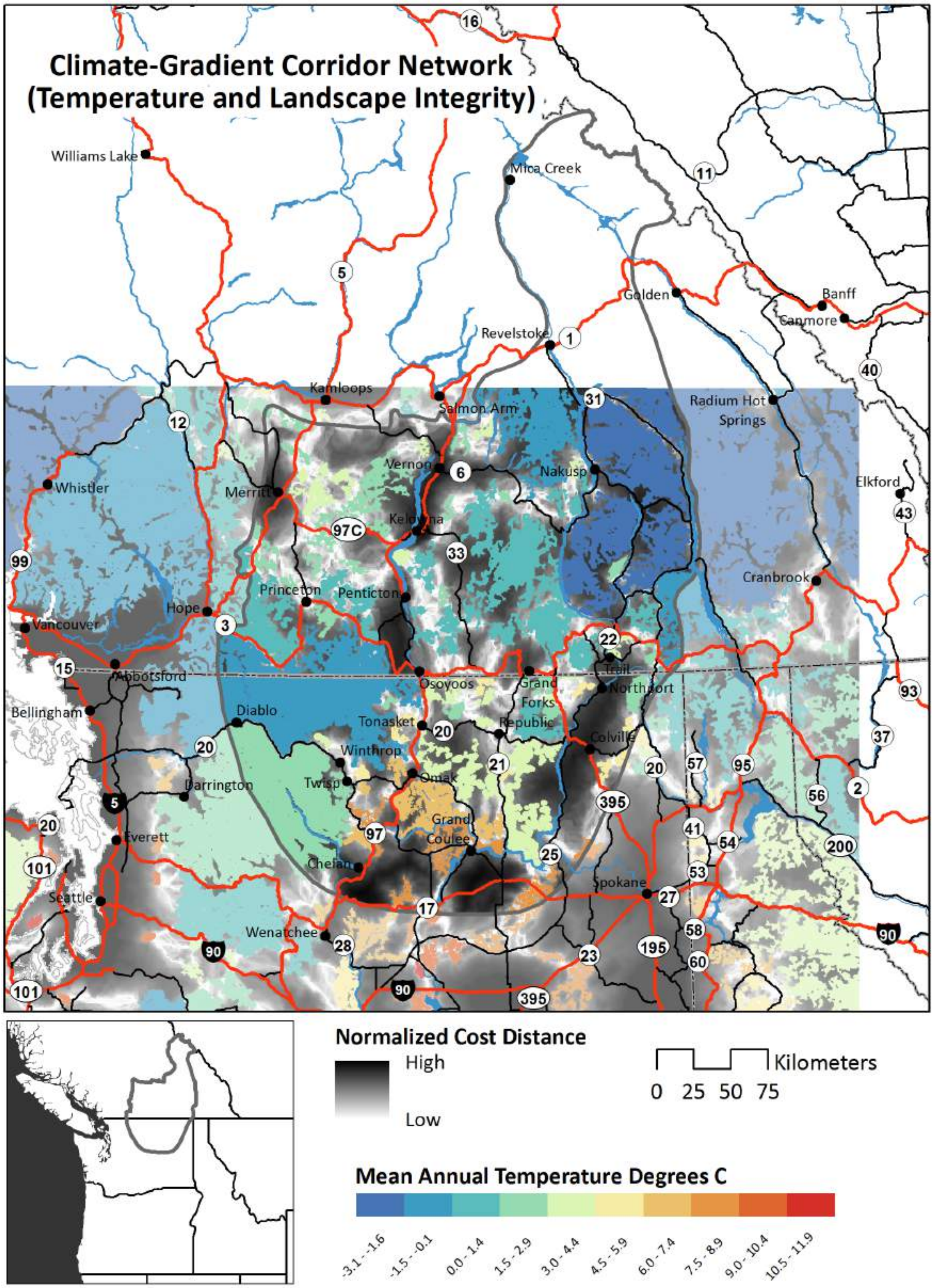
Appendix B.1a. WHCWG Statewide Analysis: Mountain Goat Corridor Model

iii) Extent: Washington-British Columbia Transboundary Region



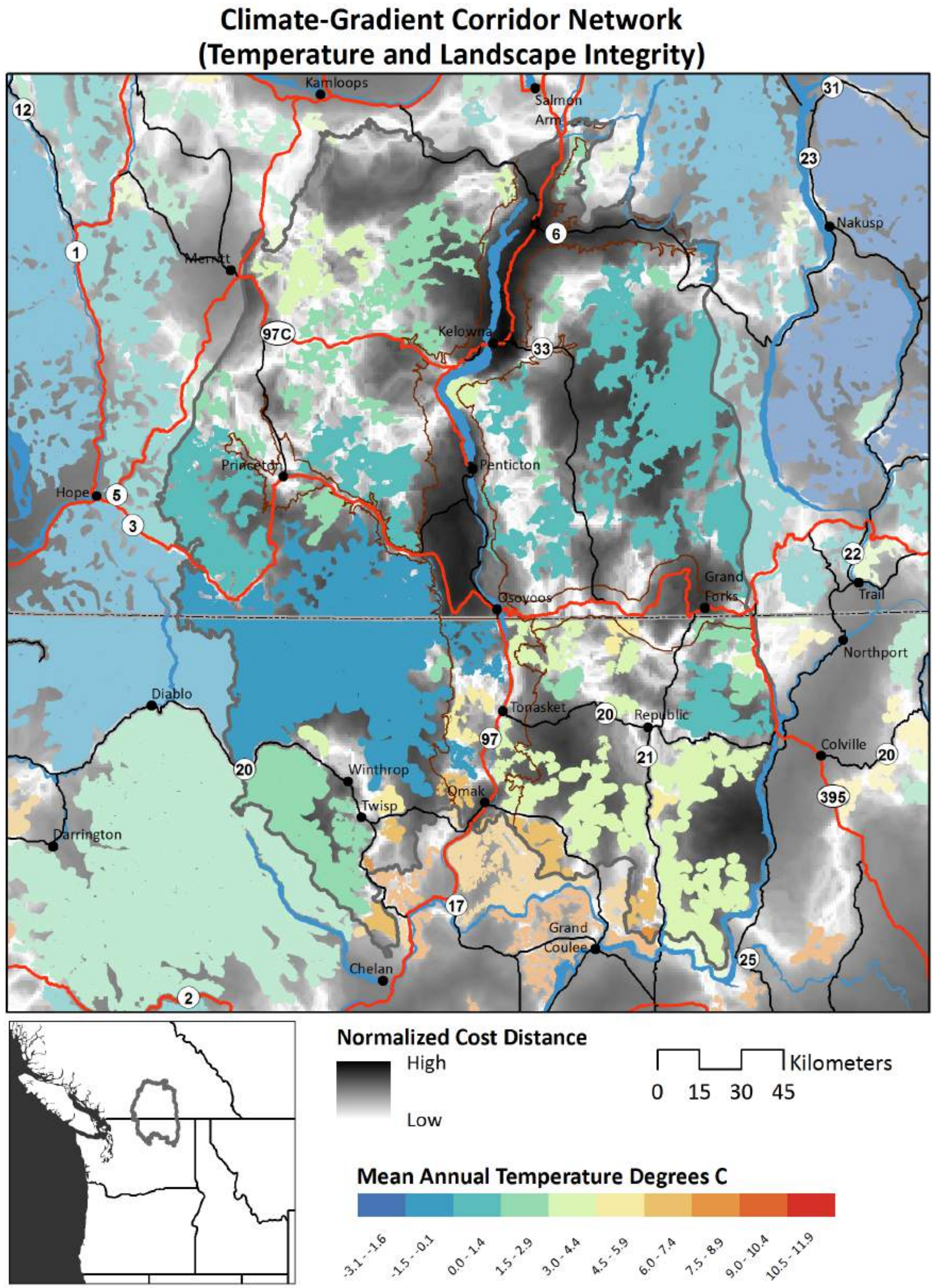
Appendix B.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

i) Extent: Okanagan Nation Territory



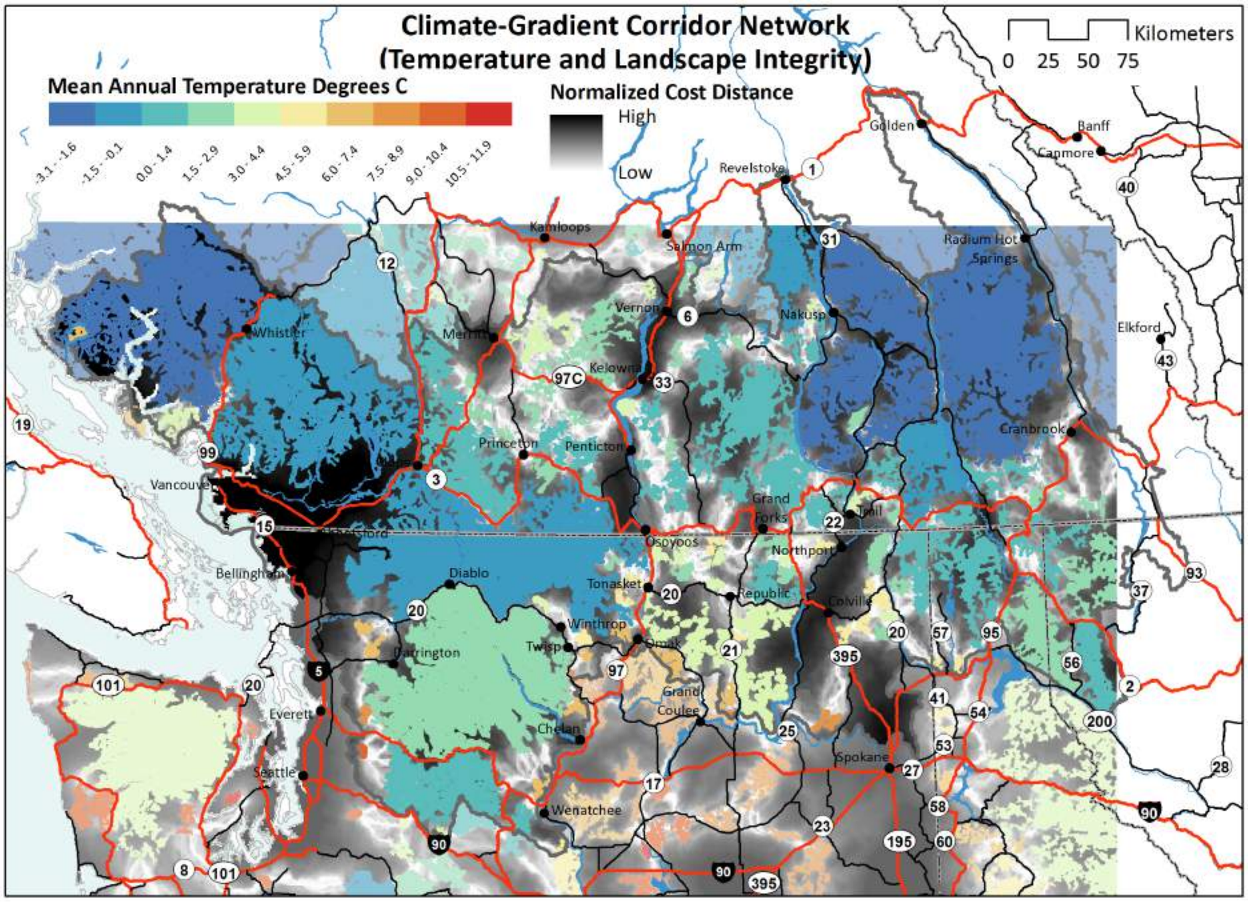
Appendix B.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

ii) Extent: Okanagan-Kettle Region



Appendix B.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix B.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary mountain goat habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence mountain goat habitat connectivity, 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.[6] The mountain goat conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to mountain goat habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner 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 highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the mountain goat conceptual model included:

- Cliff Nietvelt, BC FLNRO
- Andrew Shirk, UW Climate Impacts Group

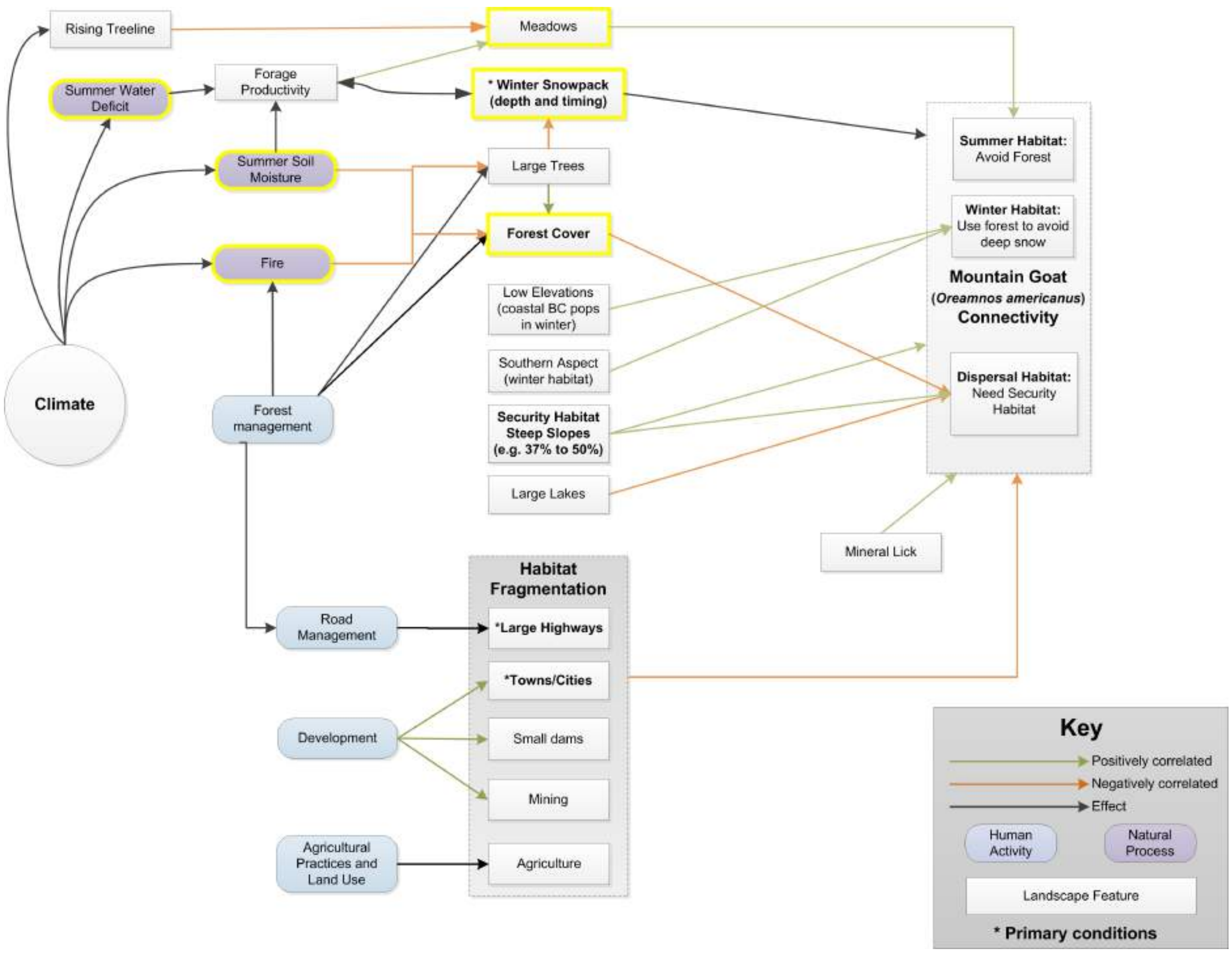
Key references used to create the mountain goat conceptual model included:

Innes, Robin J. 2011. *Oreamnos americanus*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at: http://www.fs.fed.us/database/feis/ [Accessed 5 May 2015].

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

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.

Appendix B.2. Conceptual model of mountain goat habitat connectivity



Appendix B.3. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[viii] Both models also use the A2 (high) emissions scenario.[ix]

a) **Biome Climatic Niche Vegetation Model.**[x] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xi] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

[viii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs)[12,13] which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

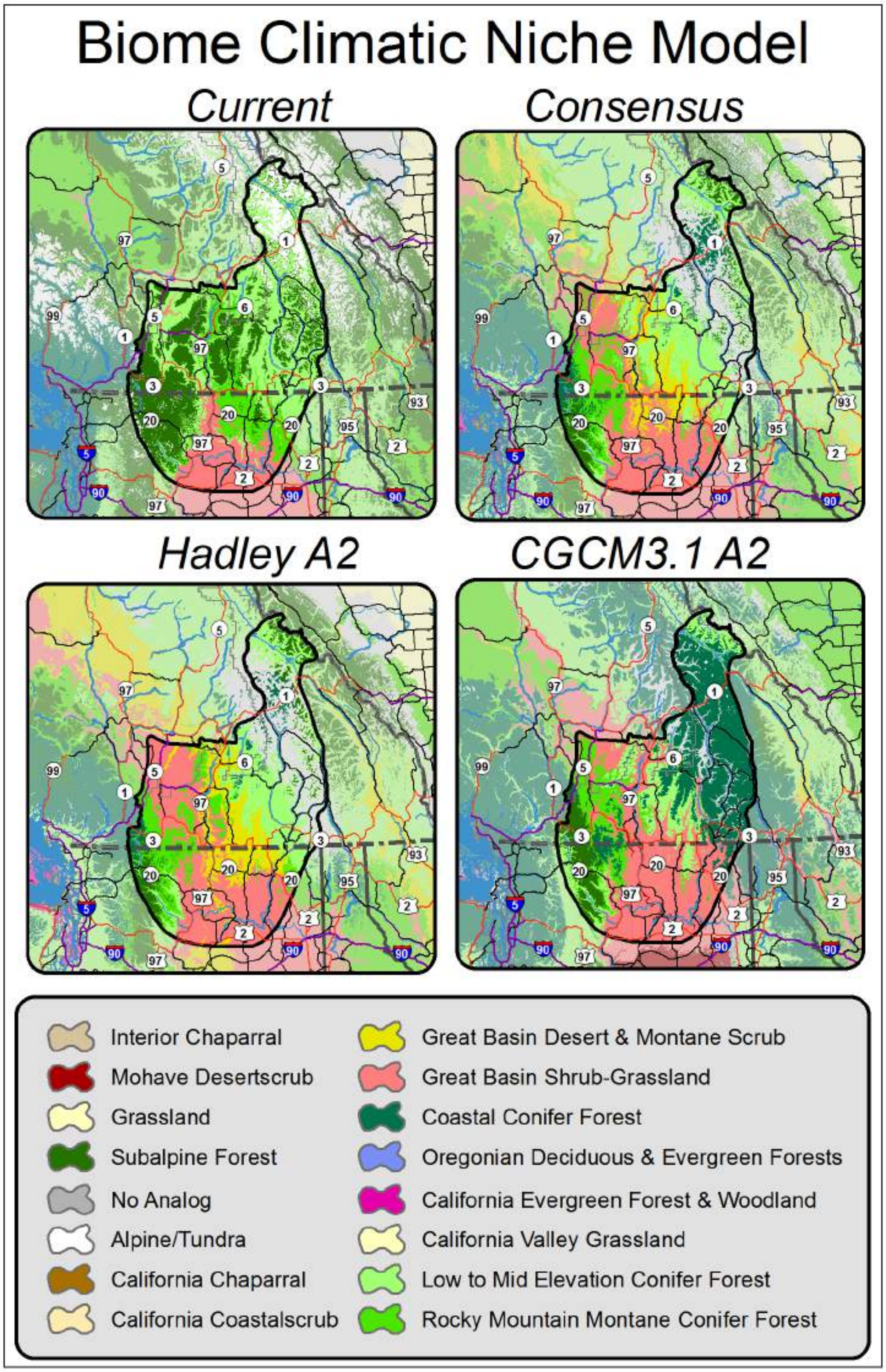
[ix] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.[14]

[x] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xi] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

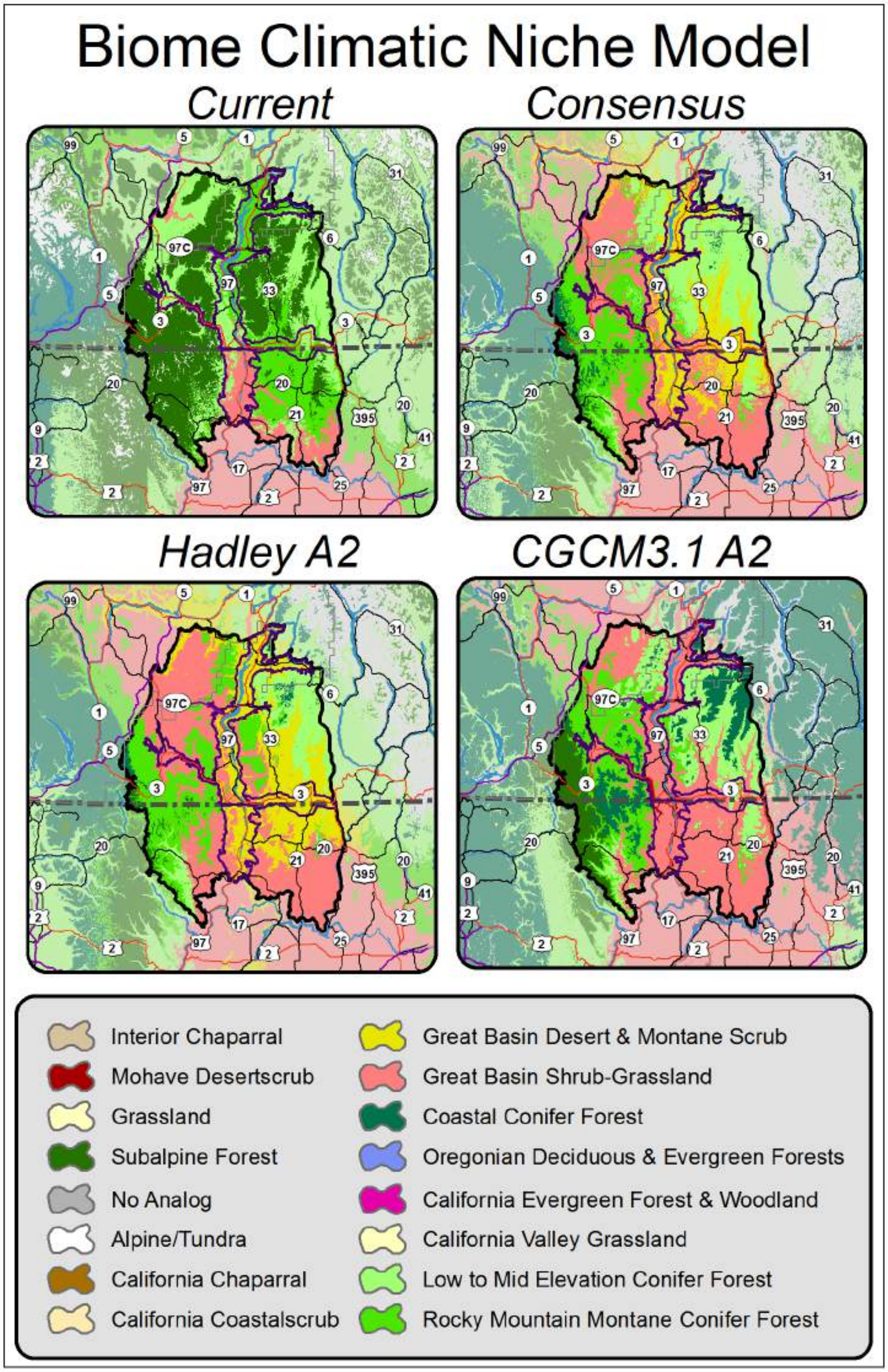
Appendix B.3a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



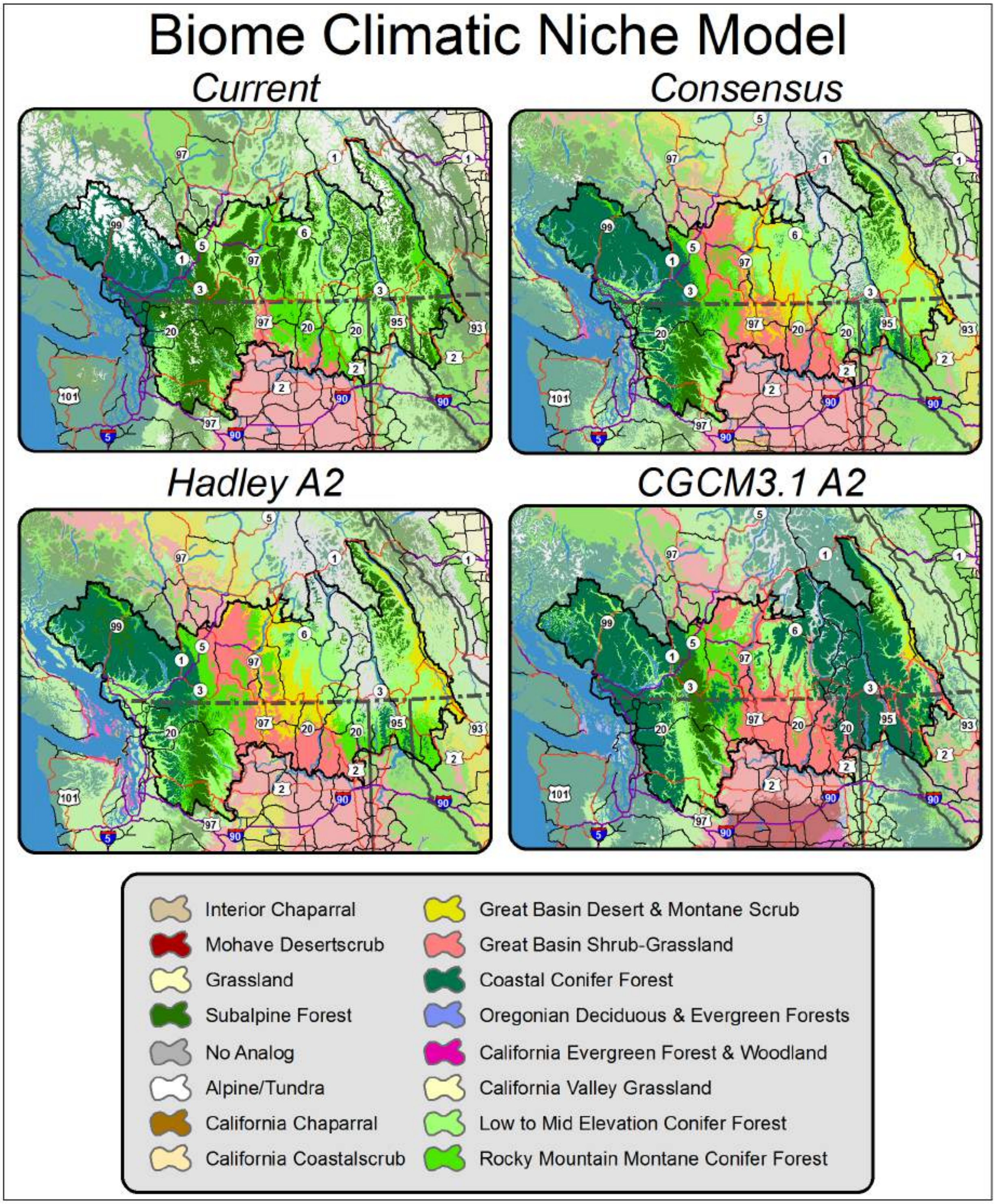
Appendix B.3a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



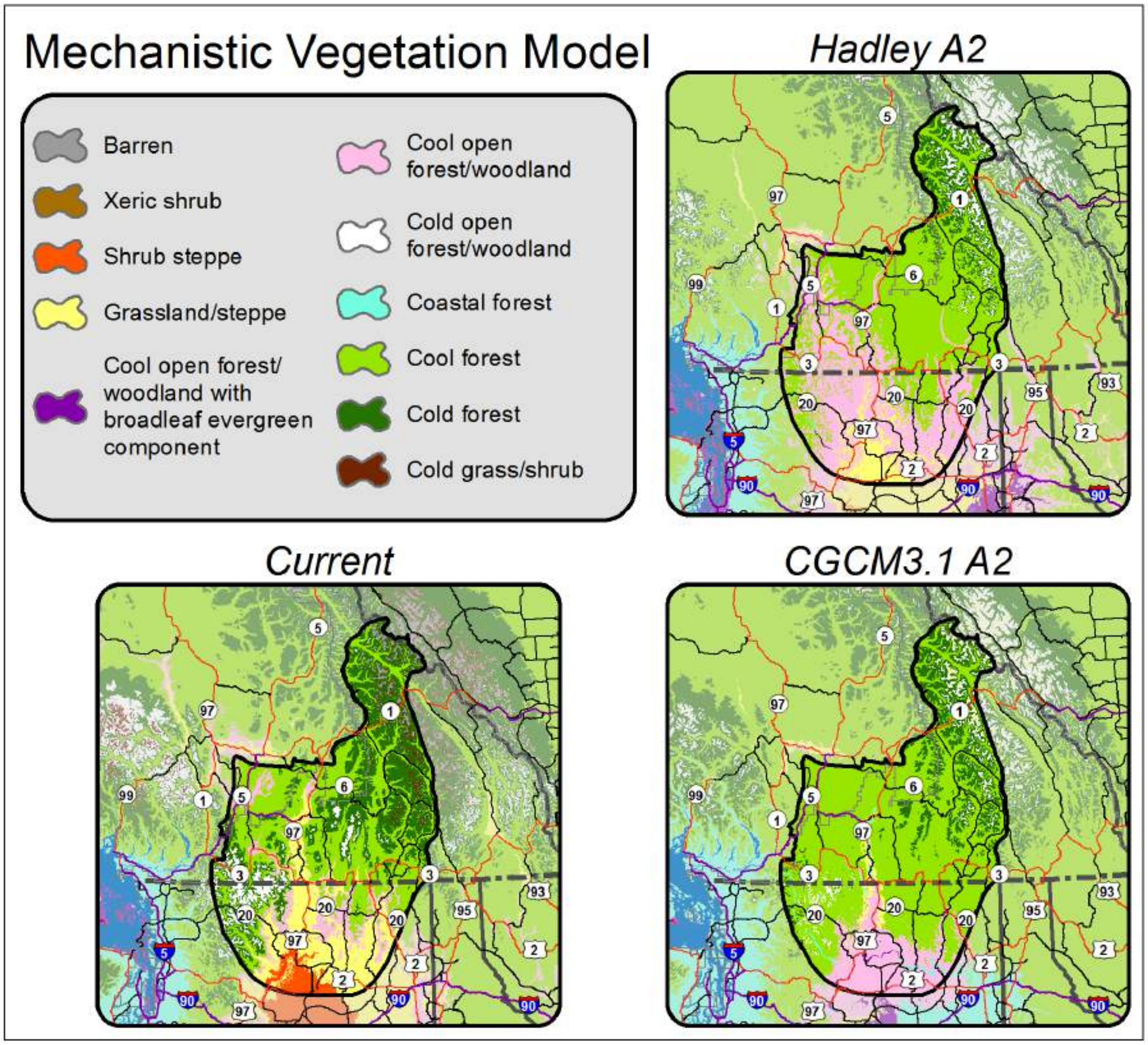
Appendix B.3a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



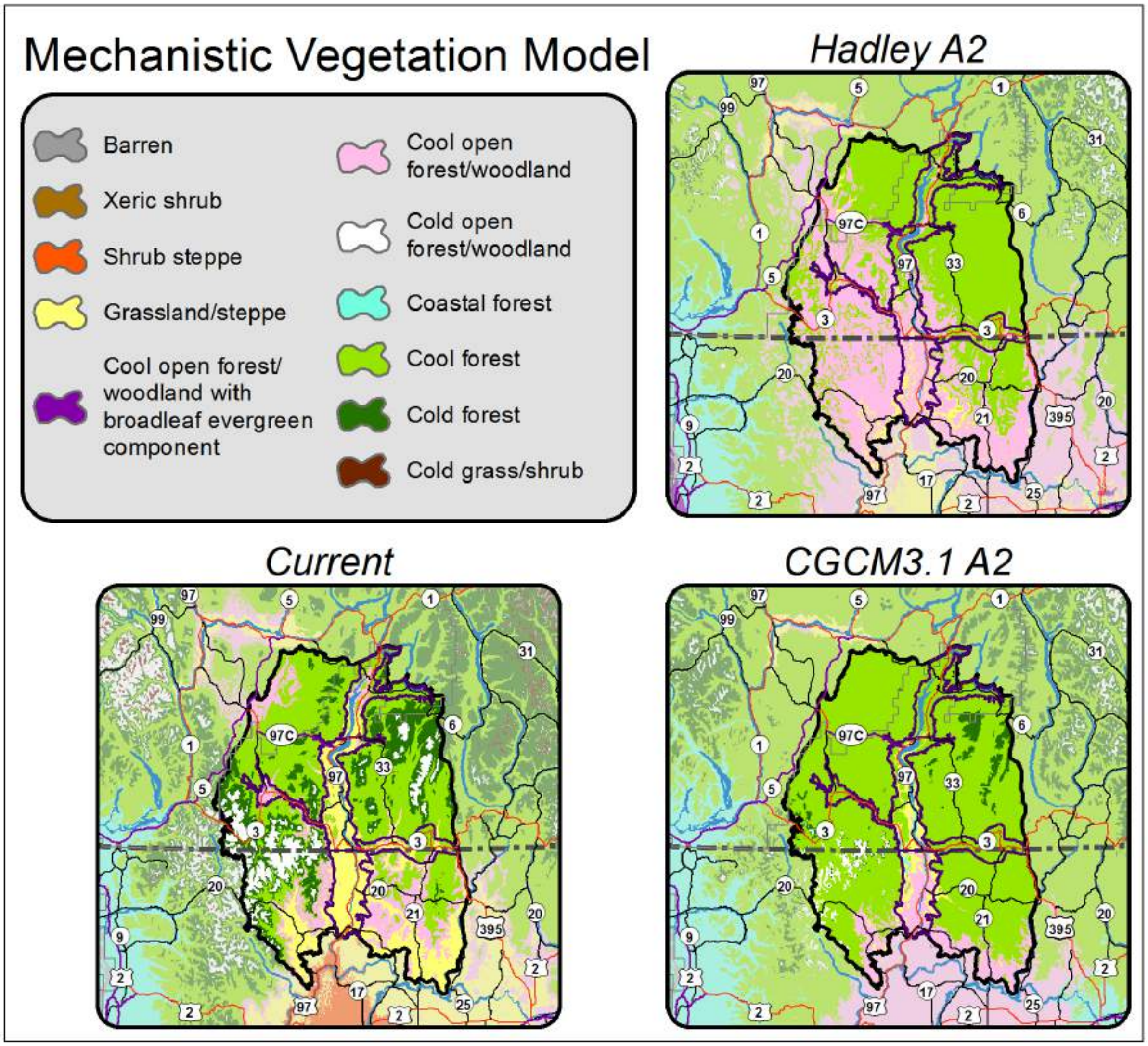
Appendix B.3b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



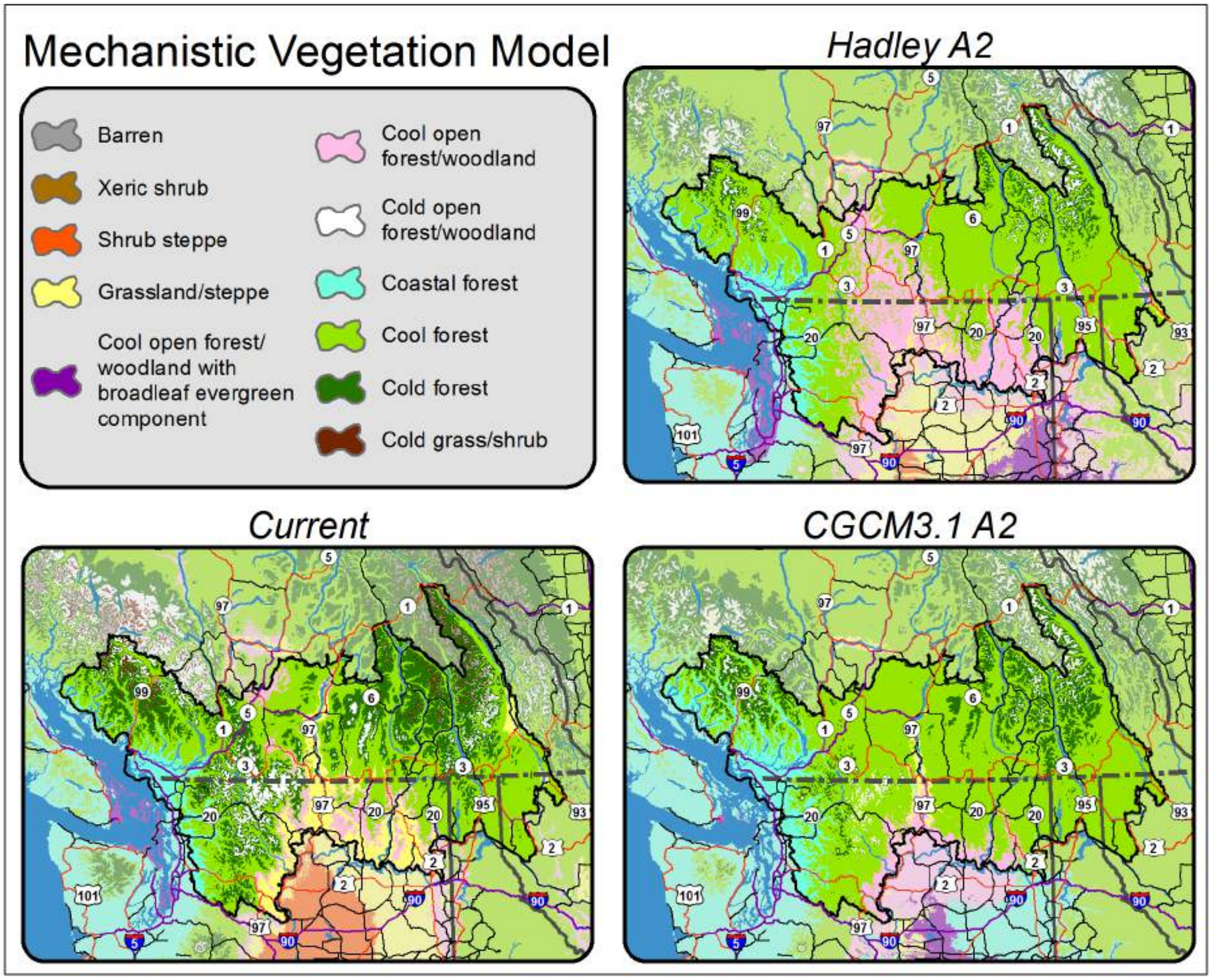
Appendix B.3b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix B.3b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix B.4. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on mountain goat connectivity.[xii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[8] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

b) **Length of Snow Season.** This map shows the projected change in the length of the snow season, defined as the number of days between the first and last days of the season with at least 10% of annual maximum snow water equivalent. Projected changes in snow season length are depicted by the yellow to red shading.

c) **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.

d) **Water Deficit, July-September.** This map shows the projected change, in percent, in water deficit. Water deficit is defined as the difference between potential evapotranspiration (PET) and actual evapotranspiration (AET), PET - AET. A positive value for PET – AET means that atmospheric demand for water is greater than the actual supply available.

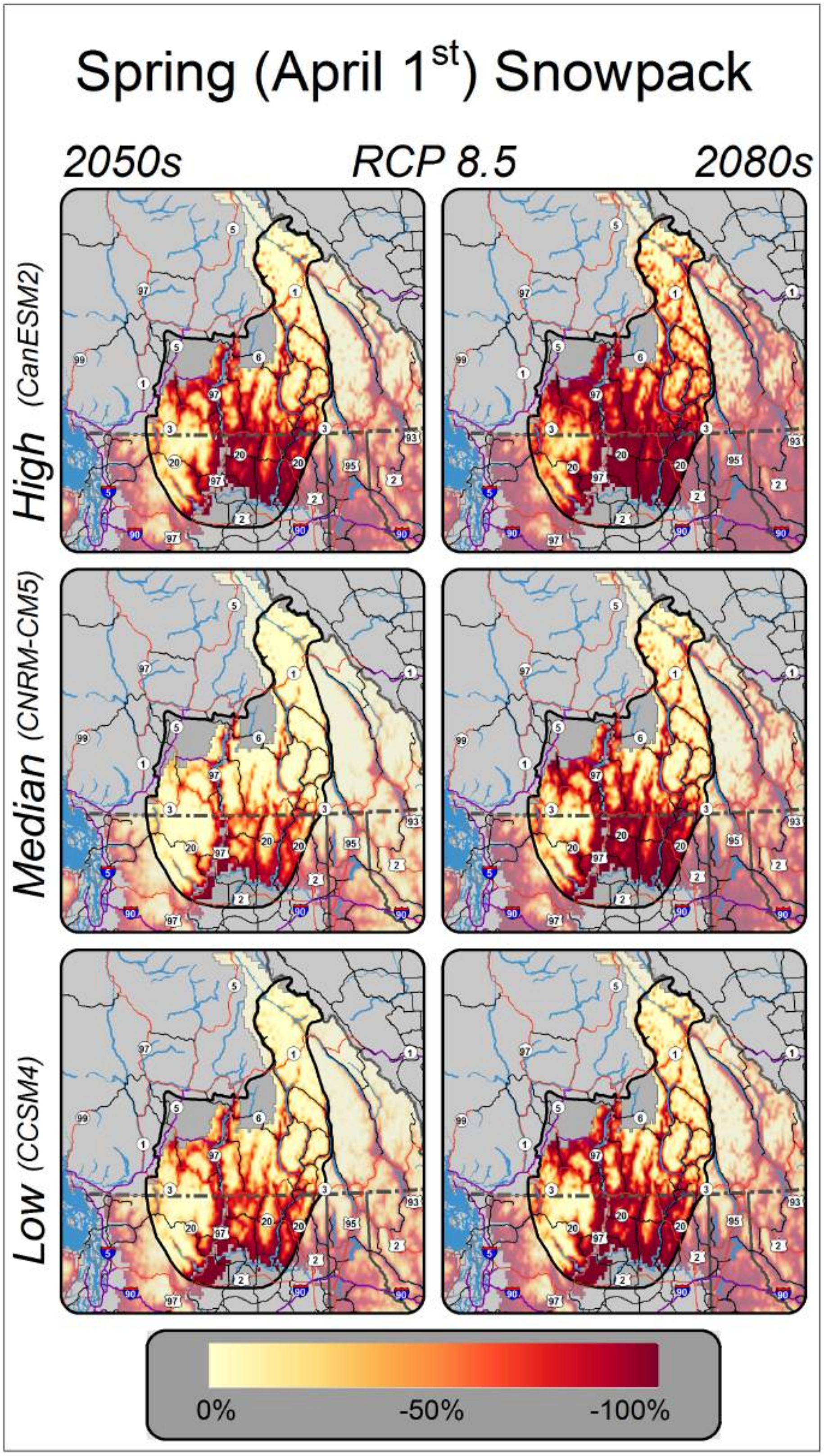
e) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[xiii] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

[xii] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)),[15,16] under a high greenhouse gas scenario (RCP 8.5).[17] "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5))[15,16] using the RCP 8.5 (high) emissions scenario.[17]

[xiii] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology* 33: 121-131.

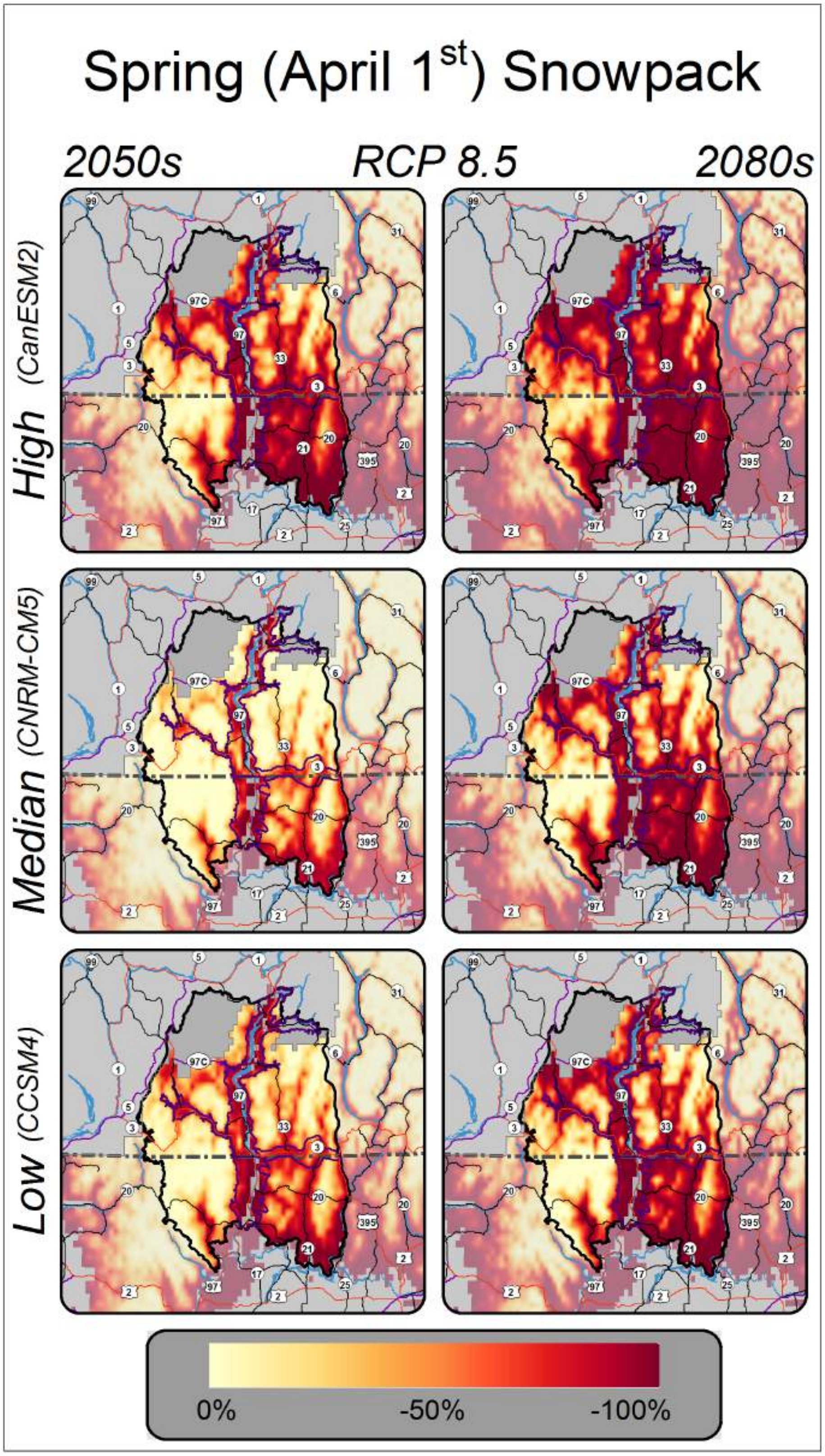
Appendix B.4a. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



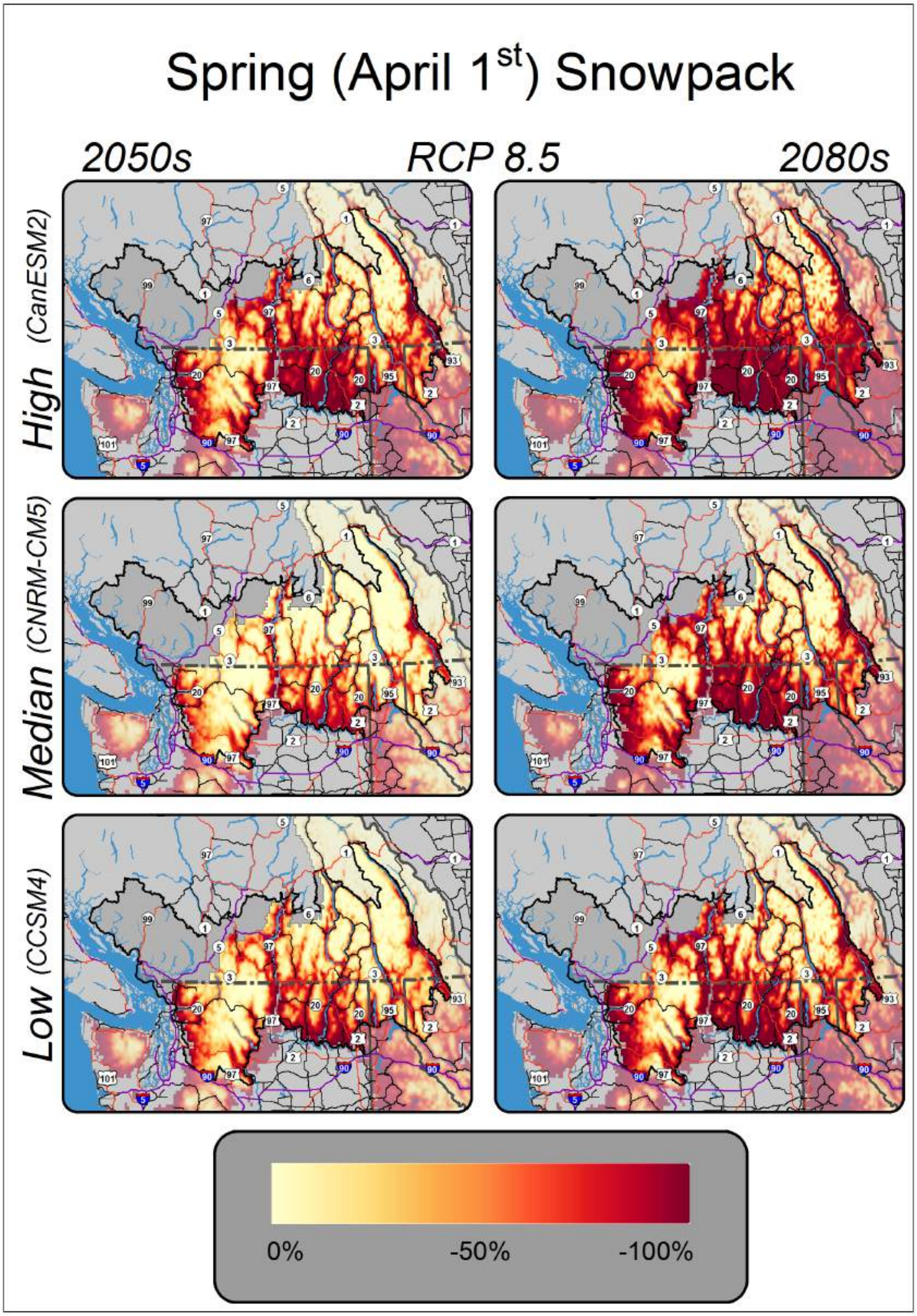
Appendix B.4a. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



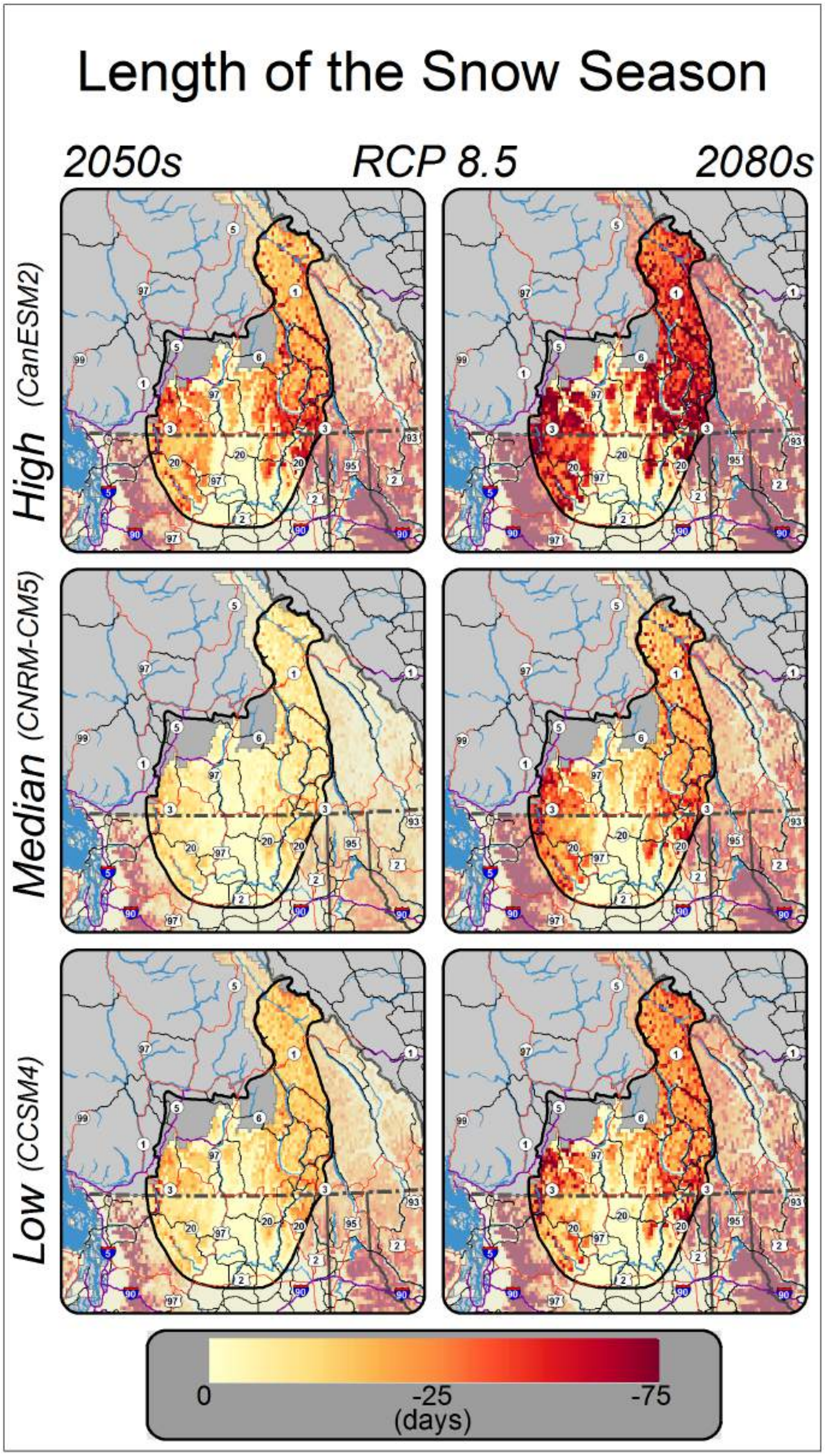
Appendix B.4a. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



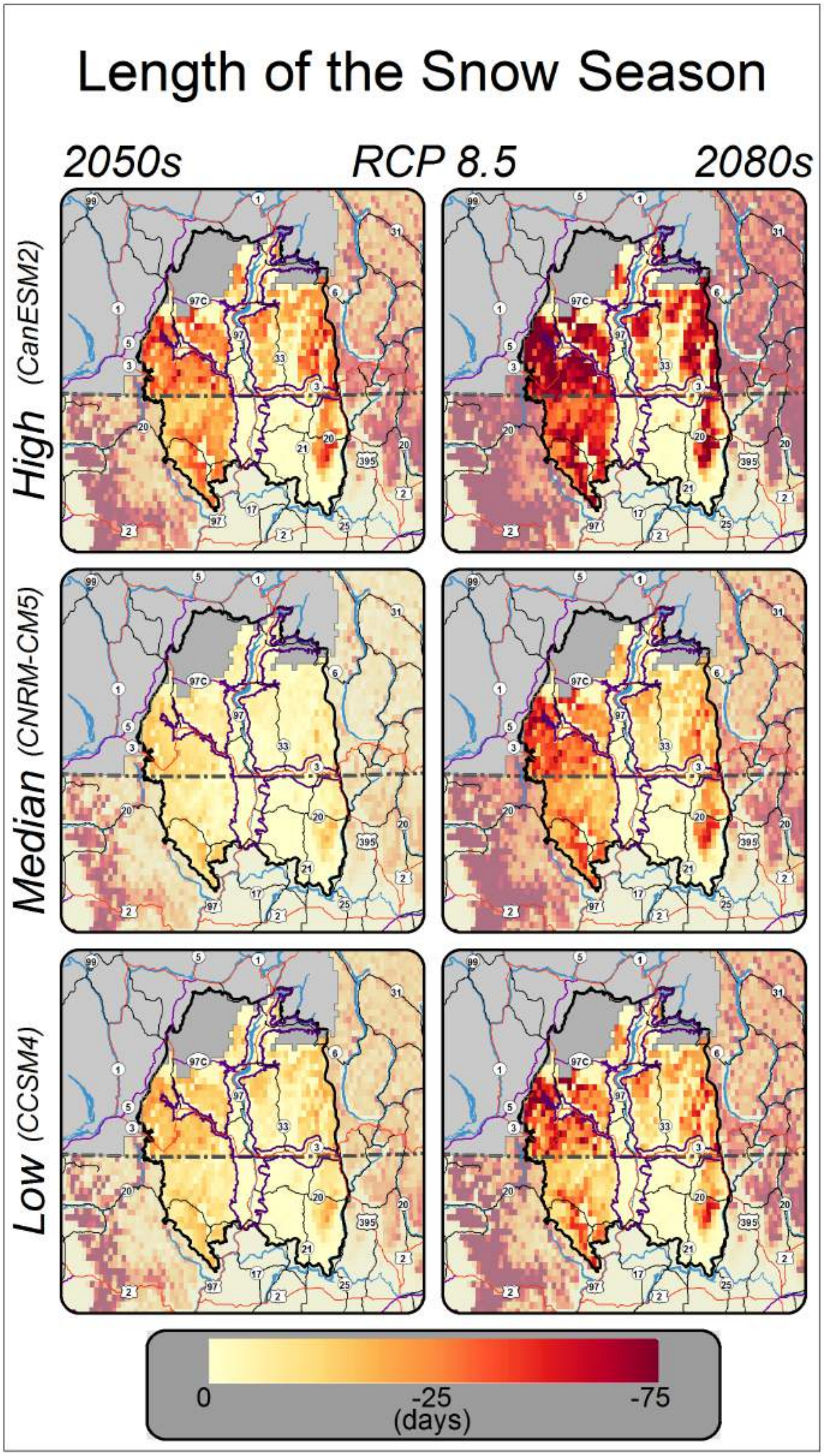
Appendix B.4b. Length of Snow Season

i) Extent: Okanagan Nation Territory



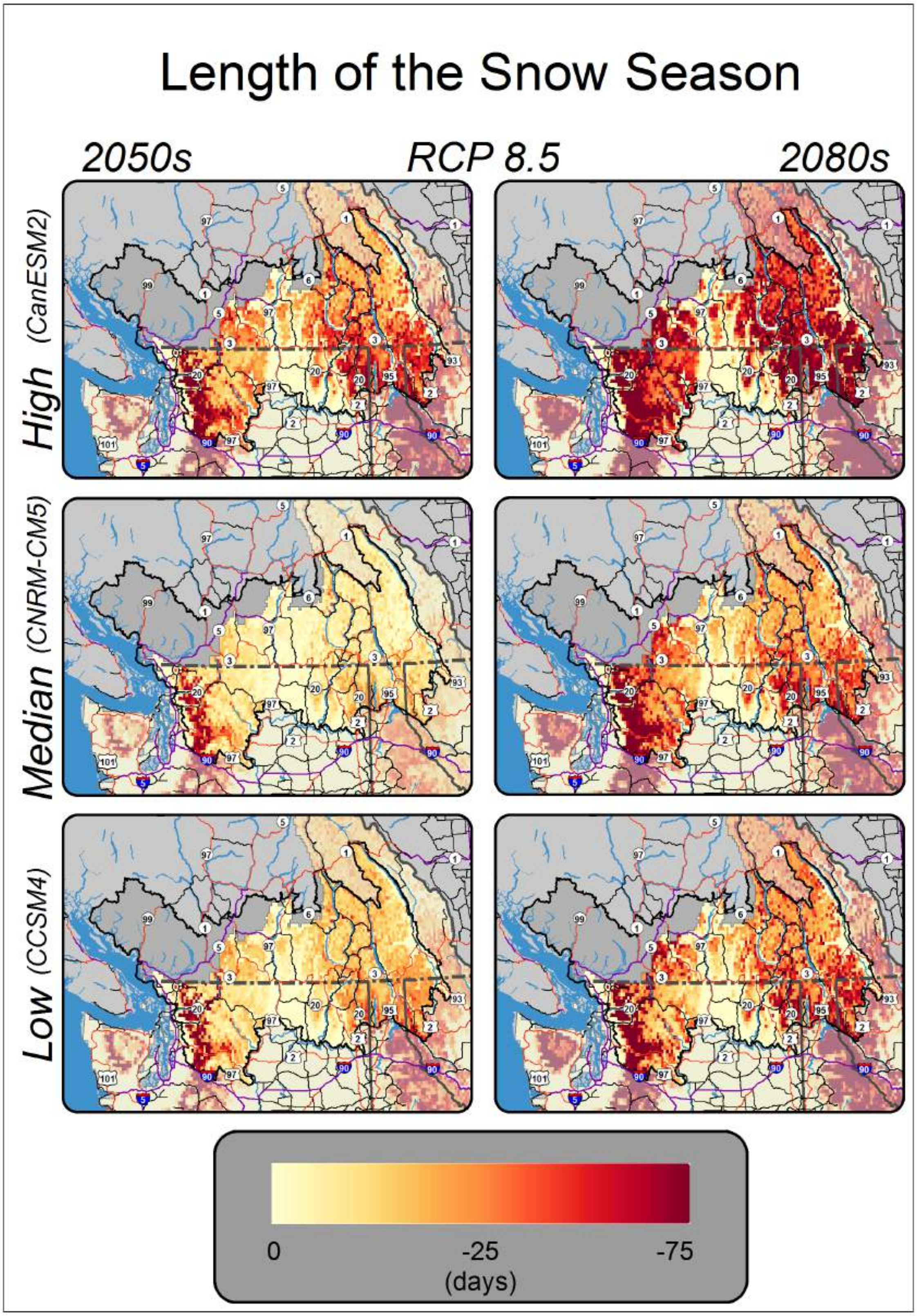
Appendix B.4b. Length of Snow Season

ii) Extent: Okanagan-Kettle Region



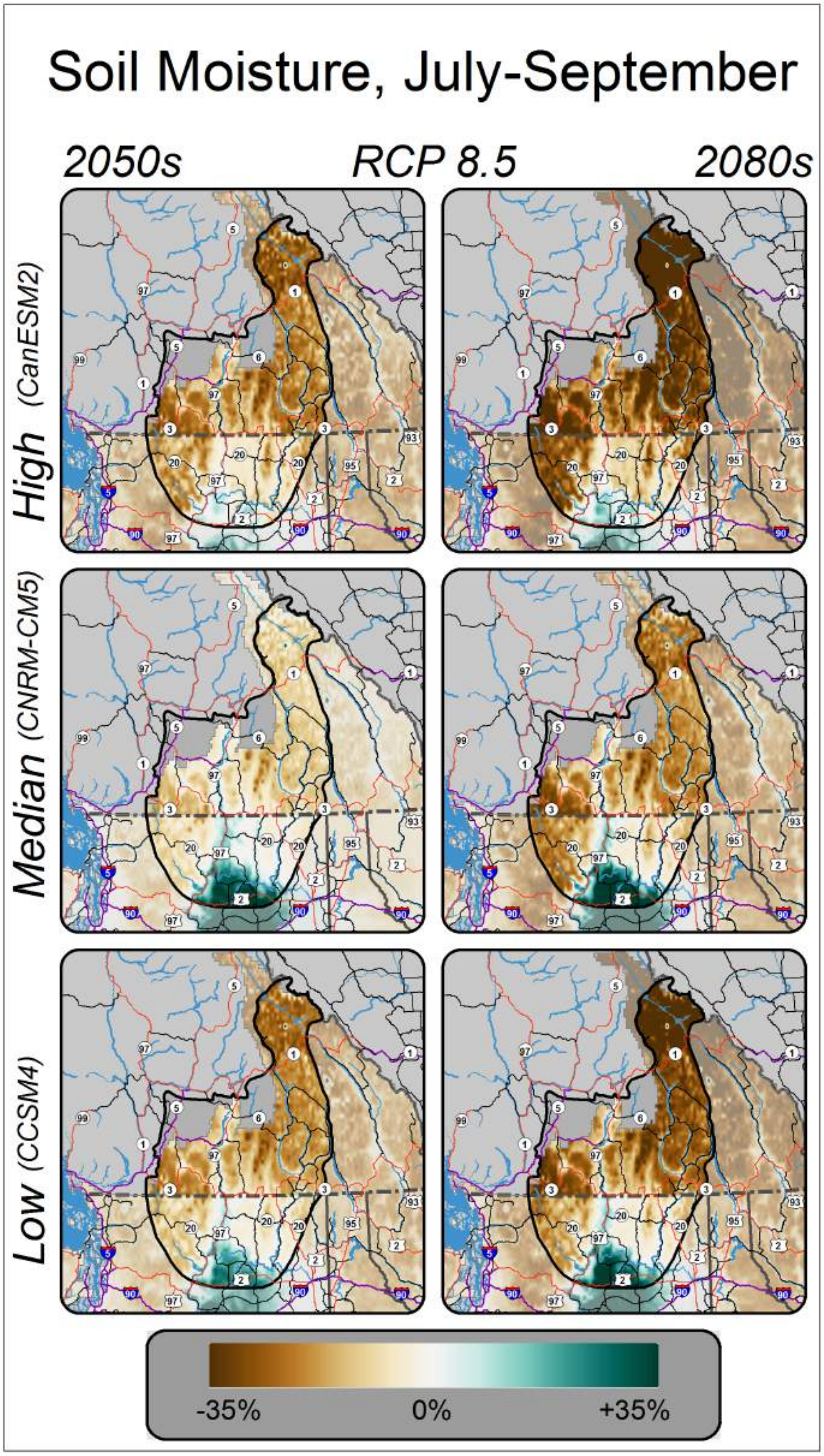
Appendix B.4b. Length of Snow Season

iii) Extent: Washington-British Columbia Transboundary Region



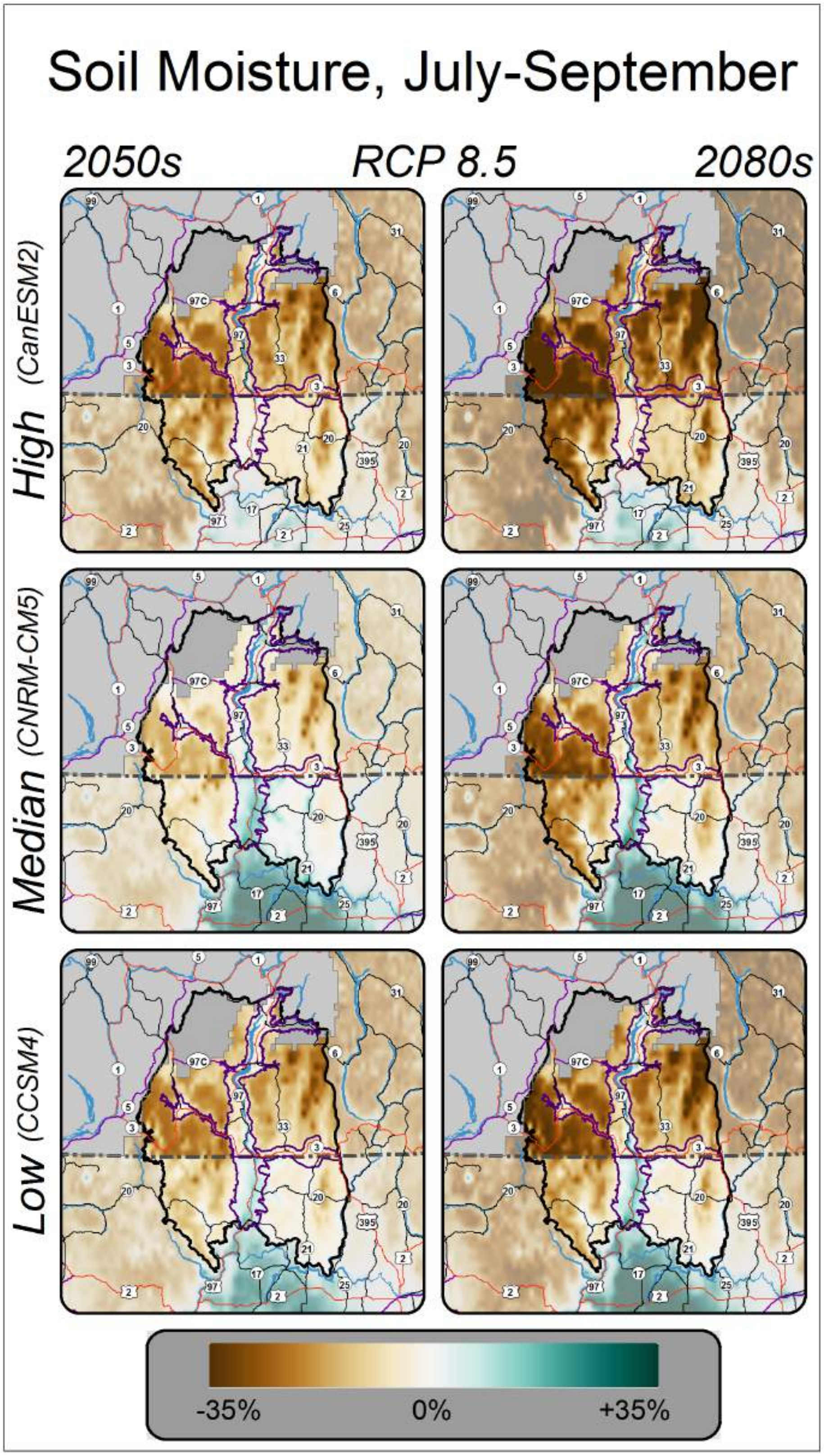
Appendix B.4c. Summer Soil Moisture, July-September

i) Extent: Okanagan Nation Territory



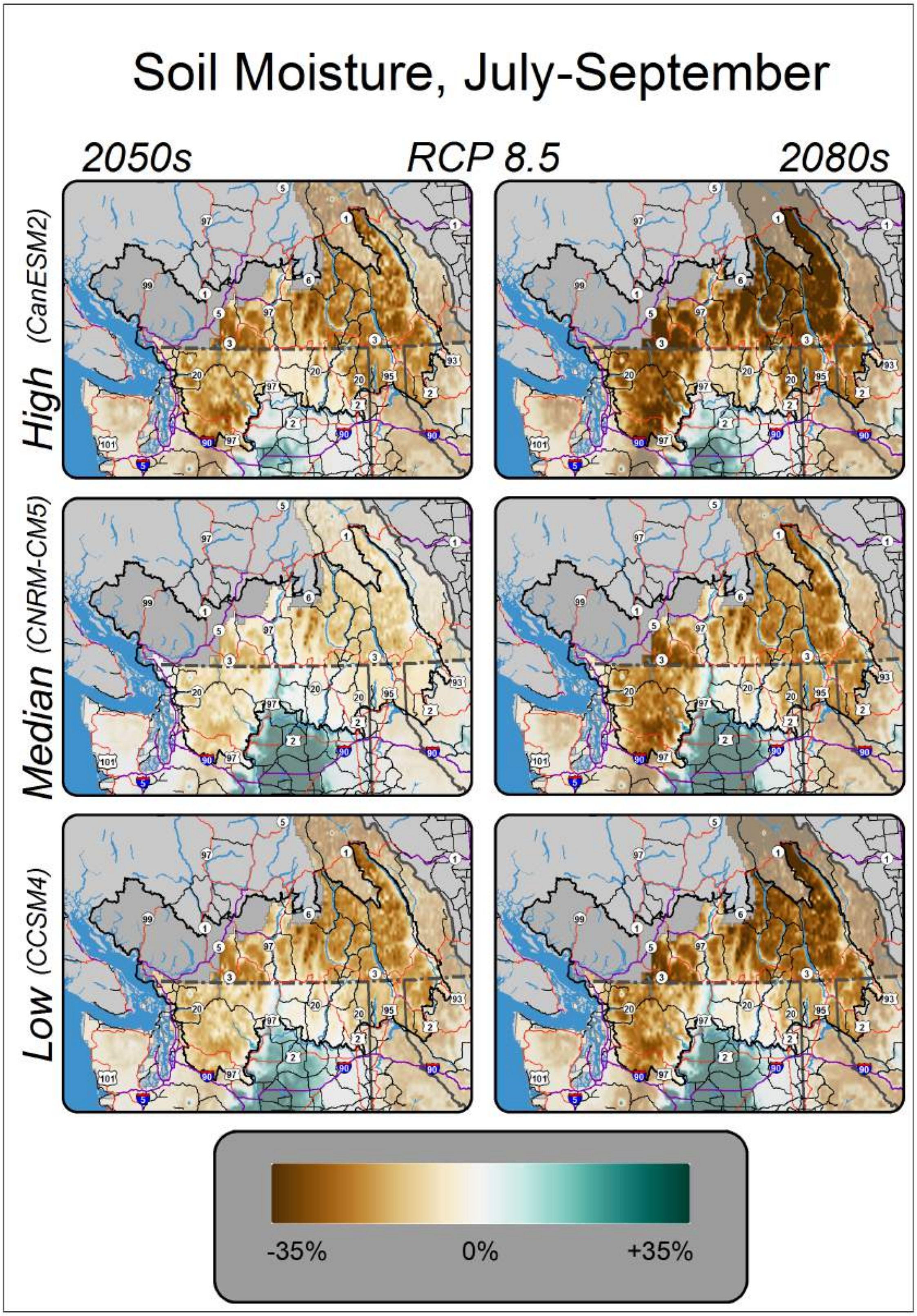
Appendix B.4c. Summer Soil Moisture, July-September

ii) Extent: Okanagan-Kettle Region



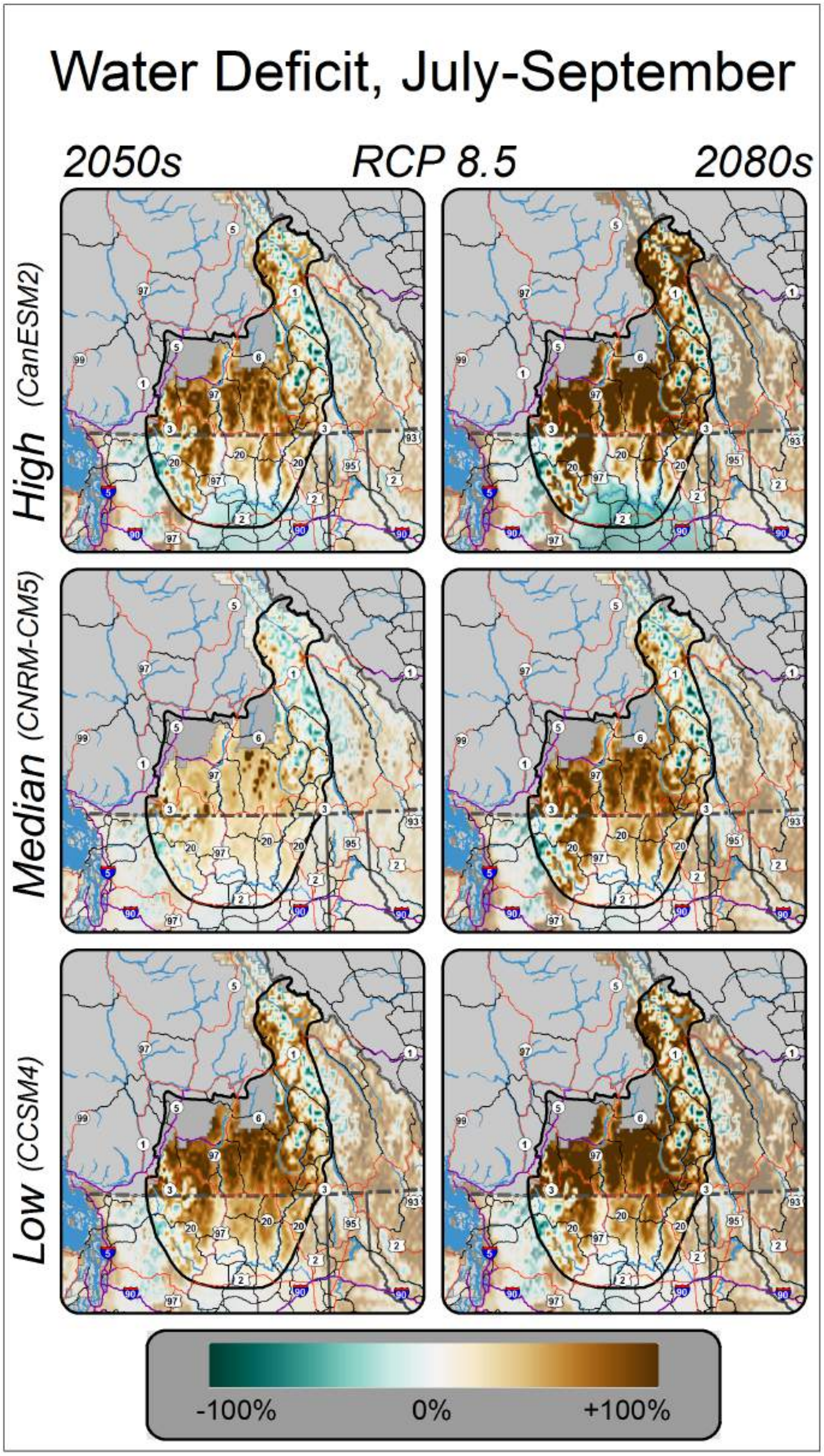
Appendix B.4c. Summer Soil Moisture, July-September

iii) Extent: Washington-British Columbia Transboundary Region



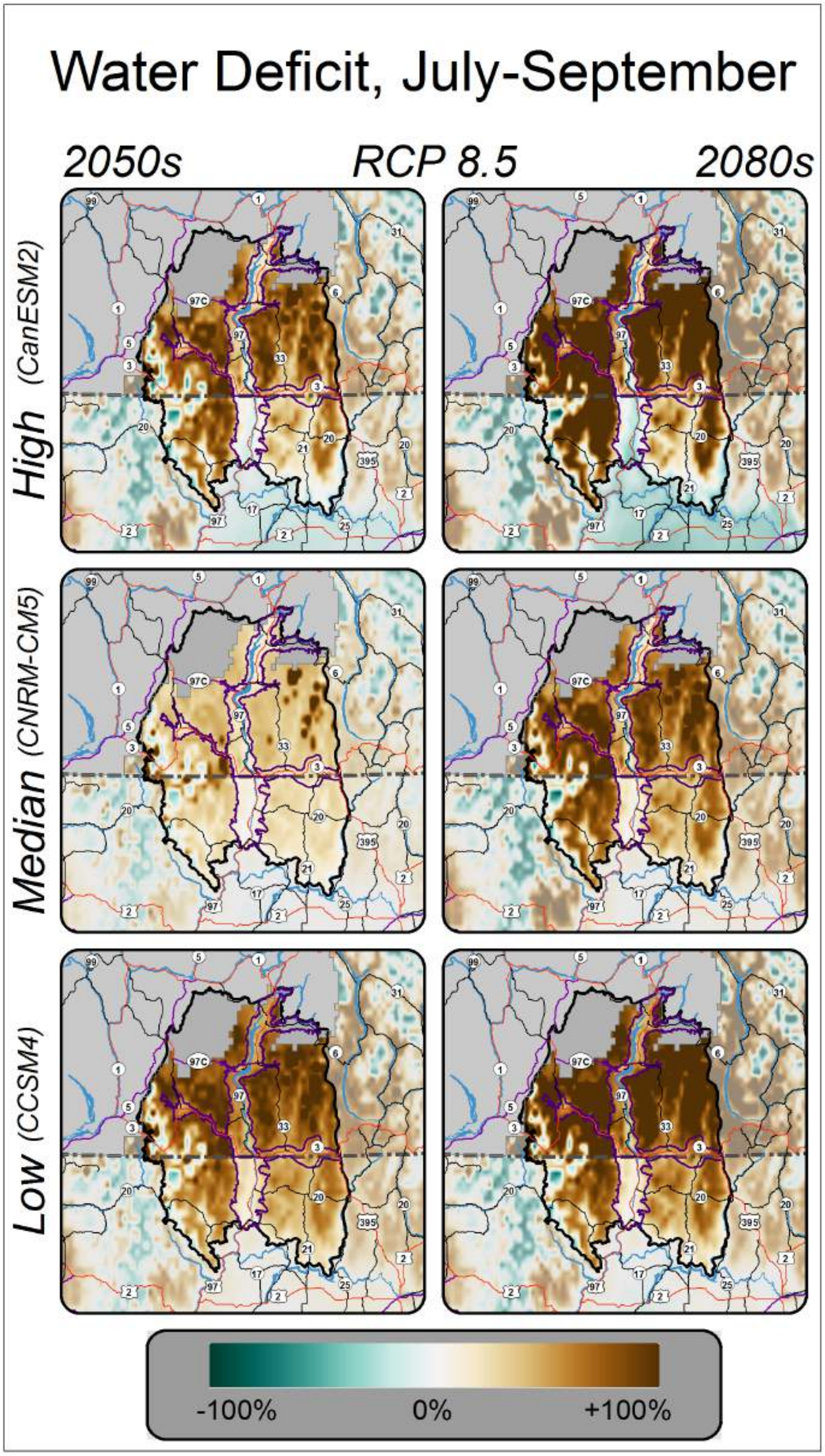
Appendix B.4d. Water Deficit, July-September

i) Extent: Okanagan Nation Territory



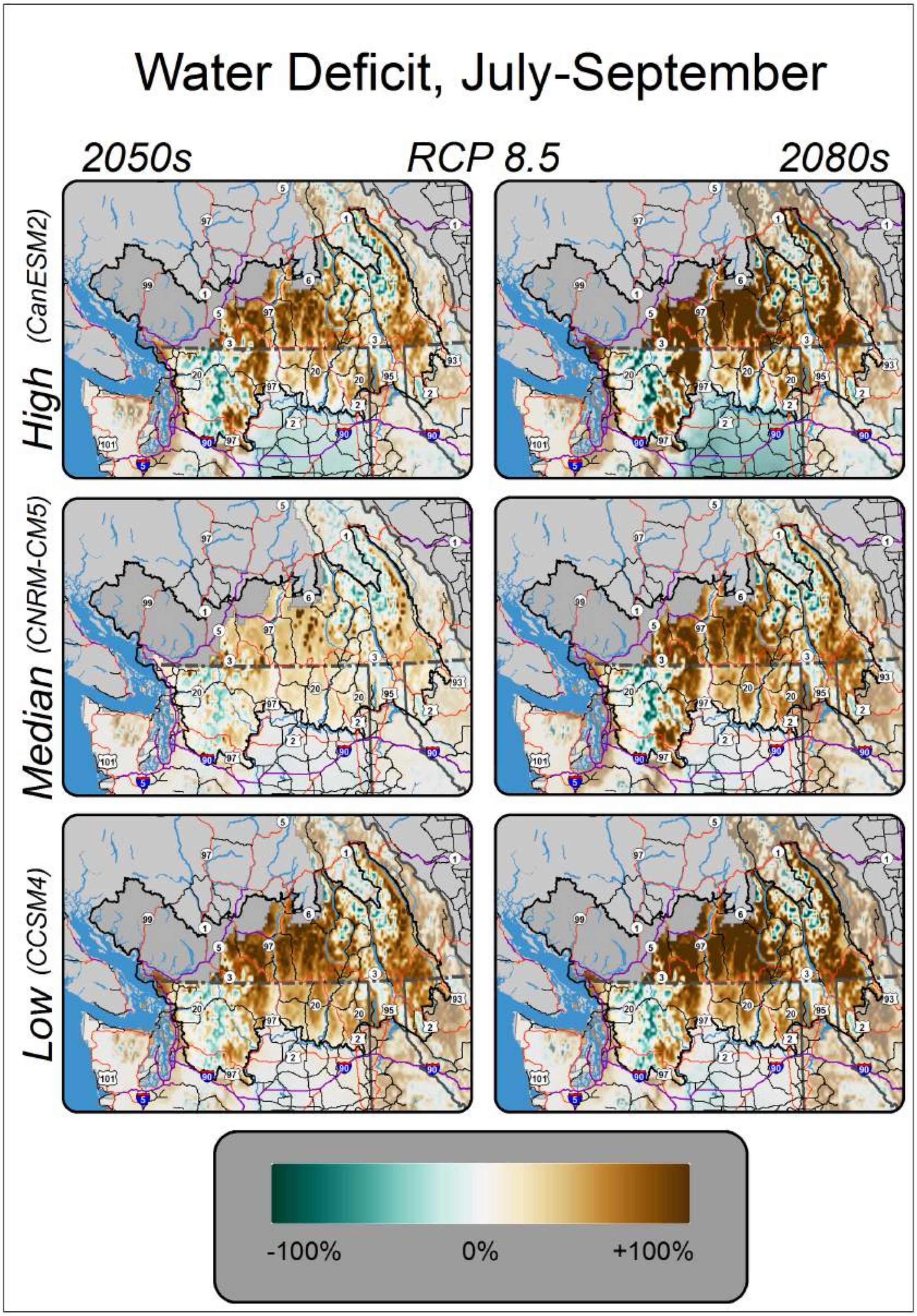
Appendix B.4d. Water Deficit, July-September

ii) Extent: Okanagan-Kettle Region



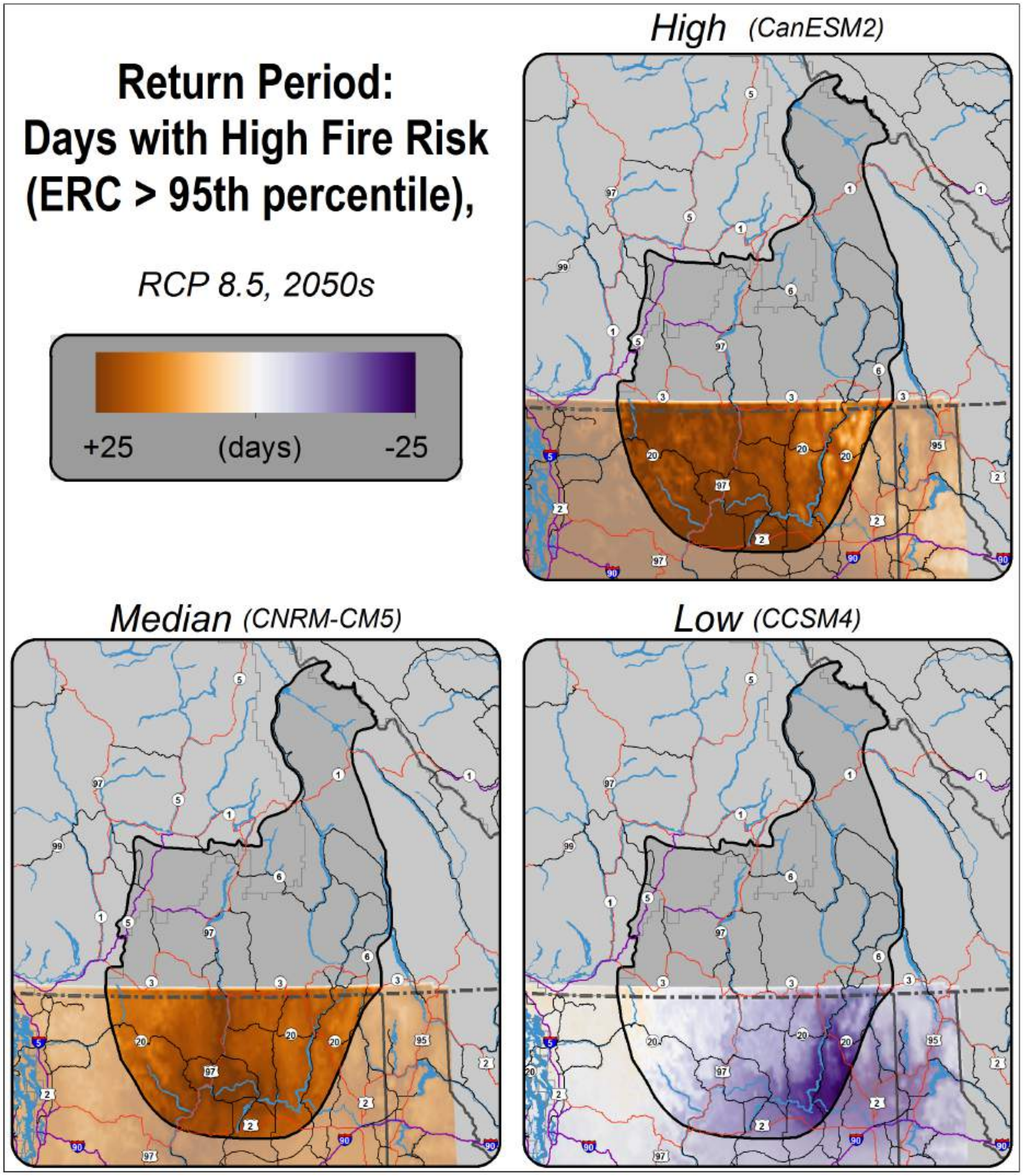
Appendix B.4d. Water Deficit, July-September

iii) Extent: Washington-British Columbia Transboundary Region



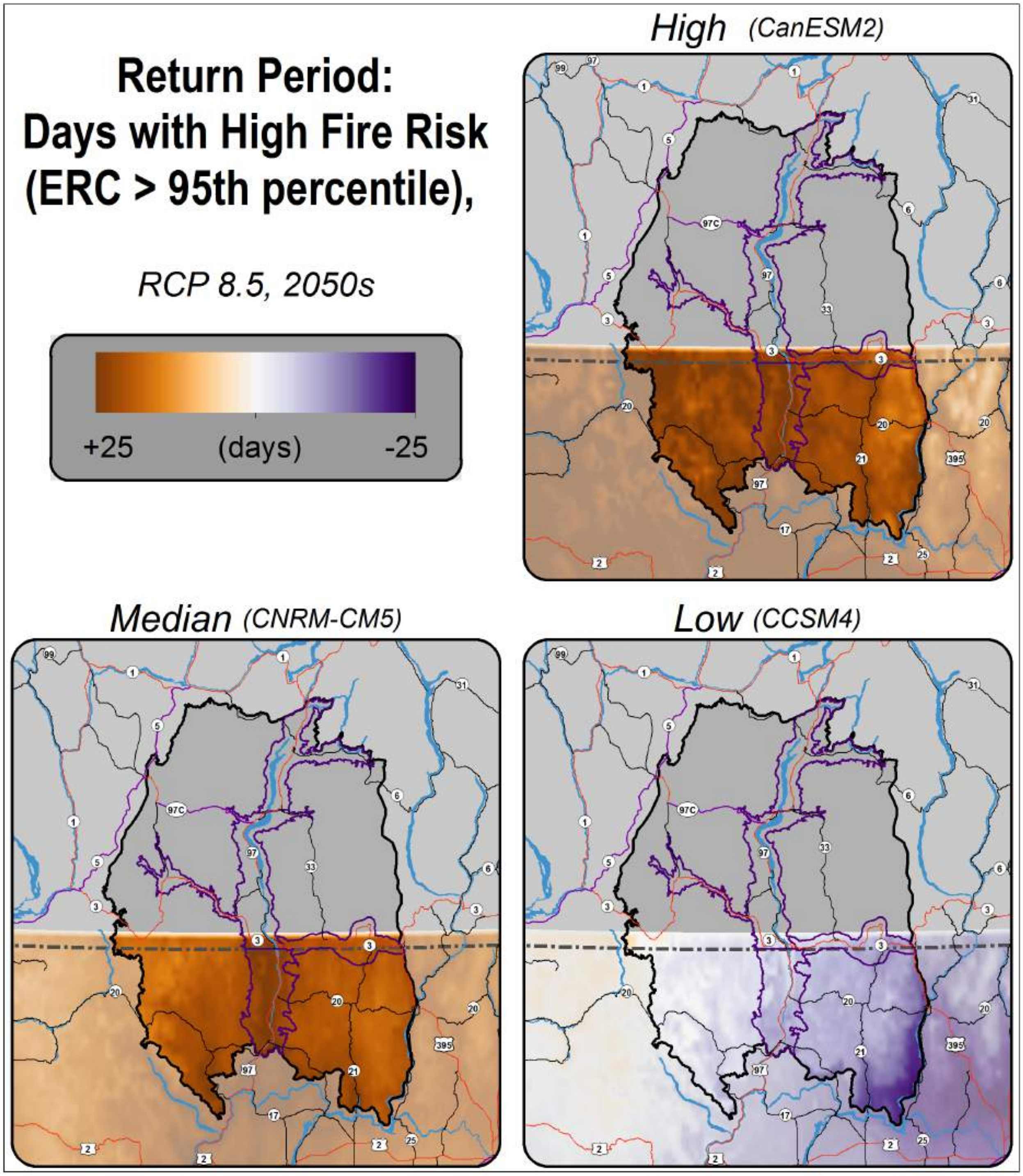
Appendix B.4e. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



Appendix B.4e. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



Appendix B.4e. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region