Present and Future Projected Changes to Human Population and Land Use affecting Columbia River Tribal Lands and First Foods

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June 2022

Introduction

Disruptive environmental change is occurring globally from a variety of anthropogenic causes, including climate change, resource extraction and depletion, air and water pollution, human population growth, and the development of natural areas. Climate and land use change are two major components of global environmental change with intersecting causalities and effects. To date, substantial effort has been made in the Columbia River Basin to assess the future effects of climate change on Tribal lands and to conduct climate adaptation planning. Lesser understood are future changes to land use, which will result in part from climate change, but also from demographic shifts and development patterns, and in some cases may amplify climate effects. For this study we sought to understand the future implications for land use on Columbia River tribal lands and first foods. This was accomplished principally by using data from the Integrated Climate and Land Use Scenarios (ICLUS) project of the U.S. Environmental Protection Agency (EPA). The ICLUS project was undertaken to produce spatially explicit future projections of demographic and land use change that are linked to the Intergovernmental Panel on Climate Change's (IPCC) scenarios (IPCC 2014).

The Columbia River Inter-Tribal Fish Commission (CRITFC) provides policy and technical support for four member tribes (The Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, and the Nez Perce Tribe), which have a combined ceded land territory of over 66,000 square miles in the Columbia River Basin. These tribes have a historic and profound connection to the first foods of the basin, including water, fish, game, cous, and berries. For this project we consider the combined influences of climate change and land use that may affect these first foods in the basin, in particular focusing on salmon and steelhead. Climate change presents an existential challenge to salmon and steelhead populations in the Columbia River Basin, which are already imperiled from loss of habitat and other limiting factors. Warmer water temperatures, lower summer stream flows, and other impacts are all predicted to become increasingly severe during this century. Freshwater habitat protection and restoration offers an opportunity to mitigate these impacts and increase the resilience of these fish, offering them time to adapt while larger scale solutions to the climate crisis are enacted. Human population growth and changes to land use may, however, may complicate these efforts, and it is thus important to understand the likely extent and nature of these changes.

Data and Methods

Data analyses were conducted to identify historic and future changes to land use and land cover on the territorial lands of our member tribes in the Columbia River Basin. Territorial lands are defined as the ceded areas where are our member tribes have treaty-protected hunting and fishing rights and are co-managers of these resources. Land use changes may have consequent effects for the first foods that are fished, hunted, and gathered on these lands. In particular we focused on the watersheds and habitat of salmon and steelhead, which are endangered or threatened throughout much of their native habitat.

To analyze recent historic change (1990 to 2020), we used the US Geological Survey National Land Cover Database (NLCD) and the US Census Bureau population counts. The NLCD employs a consistent method to periodically classify land cover from multi-resolution remote sensing over the United States at periodic intervals (USGS 2019). The US Census Bureau conducts periodic counts of county-level human population and makes this data available for a variety of uses (U.S. Census Bureau 2020). Taken together, these data provide a spatially explicit measure of population growth and land use change over time.

To analyze projected future change to land cover and population demographics, we used the results of the U.S. EPA ICLUS project (U.S. EPA 2017). This project produced population and land use scenario data across the U.S. using demographic and spatial allocation models. ICLUS scenarios contain population projections that were adapted with social, economic, and demographic storylines reflecting different assumptions about fertility, mortality, and immigration. A spatial interaction model simulated the annual migration of people within the United States, and the resulting population projections were used by the ICLUS project to determine the changing uses of land as captured with spatially explicit data. The ICLUS land use component included simulations of development from population growth and migration, market-based interactions, linked transitions between agriculture and forestry land owners, and climate influences (Morefield and Bierwagen 2019). Scenarios in ICLUS incorporate both socioeconomic and emissions scenarios (SSPs and RCPs).

ICLUS project output data were made available at decadal intervals for different socio-economic and climate scenarios (U.S. EPA 2009). The SSP2 socio-economic scenario is a "middle-of-the-road projection, where social, economic and technological trends do not shift markedly from historical patterns, resulting in a U.S. population of 455 million people by 2100. Domestic migration trends remain largely consistent with the recent past" (U.S. EPA 2018). The SSP5 socio-economic scenario describes a "rapidly growing and flourishing global economy that remains heavily dependent on fossil fuels, and a U.S. population that exceeds 730 million by 2100. ICLUS v2.1 land use projections under SSP5 result in a considerably larger expansion of developed lands relative to SSP2" (U.S. EPA 2018). Both socio-economic scenarios use local climate conditions (summer and winter precipitation and temperature) to influence migration patterns. The climate scenarios include projections from a well-reviewed general circulation

model used in the Fourth National Climate Assessment "HadGEM2-ES”) that has a relatively high sensitivity to greenhouse gases. Another general circulation model (“GISS-E2-R”) was described in the project documentation but was lacking spatially explicit data, so was not used here. The climate scenarios are available for two global emission pathways (RCP 4.5 and RCP 8.5) affecting divergent climate change. RCP 4.5 assumes that “global greenhouse gas emissions increase into the latter part of the century, before leveling off and eventually stabilizing by 2100 as a result of various climate change policies.” RCP 8.5 assumes that “global greenhouse gas emissions increase through the year 2100” (U.S. EPA 2018).

In order to assess a range of outcomes without generating results that were overly complex, we chose to analyze a combination of two different sets of demographic and climate scenarios to reflect low and high “bookends” of potential development, and land use change, as follows.

A) SSP2_RCP45: Low-end population growth and greenhouse emissions: SSP 2 and RCP 4.5
B) SSP5_RCP85: High-end population growth and greenhouse emissions: SSP 5 and RCP 8.5

In order to assess projected changes over the 21st century, we analyzed each of these scenarios at three intervals in time (the years 2020, 2040, and 2080).

In addition to providing a range of scenarios with differing assumptions, the ICLUS project also offered the advantage of similar classification and enumeration systems with the historic NLCD and Census Bureau data. However, the land use classes and methods differed somewhat, and leading us to analyze historic and future periods separately for land use. The (historic) land use classes from the NLCD are listed in Table 1.

Level I Classes	**Level II Classes**
Water	Open Water
	Perennial Snow/Ice
Developed	Low Intensity Residential
	High Intensity Residential
	Commercial/Industrial/Transportation
Barren	Bare Rock/Sand/Clay
	Quarries/Strip Mines/Gravel Pits
	Transitional
Forested Upland	Deciduous Forest
	Evergreen Forest
	Mixed Forest
Shrubland	Shrubland
Non-Natural Woody	Orchards/Vineyards/Other
Herbaceous Uplands (Natural)	Grasslands/Herbaceous
Herbaceous Planted/Cultivated	Pasture/Hay
	Row Crops
	Small Grains
	Fallow

	Urban/Recreational Grasses
Wetlands	Woody Wetlands
	Emergent Herbaceous Wetlands

Table 1: Modified Anderson Land Use/Land Cover Classification

For the purpose of this project, the term "land use" is used to synonymously describe the concepts of land use and land cover because in practice they may be assessed as a single characteristic, even if their definitions differ somewhat (land cover being the classification of cover type from remote images and land use being the description of how land is managed by people).

At the beginning of this project, we formulated a series of questions that analyses would be designed to answer (Table 2).

Question	**Rationale**
1. What have been the recent changes in human population and land use in territorial areas of the Columbia River Basin?	Recent years have witnessed increasing development in the Pacific Northwest, as people have migrated here. It's important to understand the magnitude of this growth to provide context for future projected changes. An important contemporary period is the one between the early-1990s and present, when Salmon and Steelhead runs have experienced large fluctuations in abundance, with many being listed as endangered or threatened.
2. What are the future projected changes in human population and land use in territorial areas of the Columbia River Basin?	Population growth and changes to land use affect natural resources in myriad ways. Development can entail greater consumption of water and energy, conversion of wild habitat, increase impermeable surfaces, and generate greater waste and pollution. Agriculture, grazing, and forestry also affect water, fish, and wildlife.
3. What is the projected change in developed area in salmon/steelhead spawning/rearing watersheds?	Watersheds where salmon and steelhead rear and migrate are the focus of many habitat restoration efforts intended to protect and restore these fish populations and ameliorate climate change impacts. Development in these watersheds can have negative effects on fish habitat and survival.
4. What is the projected change in developed area in riparian areas along salmon/steelhead spawning/rearing streams?	The riparian zones alongside creeks and rivers are most important to provide shade, nutrients, and help foster stream complexity for fish spawning and rearing habitat. Development in these zones can adversely affect fish habitat and survival.
5. What important ecological areas appear most likely to be developed during the future?	In addition to overall and zone-specific changes, it is helpful to know what specific areas are projected to be developed in the future in order to ensure that conservation plans are sufficiently in place in these areas before development occurs.

6. What are the projected changes to land use in the cold-water tributaries of and near Zone 6 on the Columbia River?	A current focus of CRITFC and its member tribes are the cold-water tributaries of and near "Zone 6", a fishing zone the lower Columbia River between Bonneville Dam and McNary Dam that is reserved exclusively for Indian commercial fishing. These tributaries provide important cold water refugia in their river mouths for migrating fish during hot summer months.
7. What is the projected change in irrigated acreage throughout the Columbia River Basin?	The withdrawal of water for irrigation is one of the principal uses of water from the Columbia River and its tributaries, especially during the warmer spring and summer months when both juvenile and adult salmon and steelhead are migrating.
8. How will changes in projected irrigation likely affect total water demand in the Columbia River Basin?	Translating irrigated acreage to total water demand is important to know the likely overall effect of irrigation on stream and river flows.
9. What is the variation between different scenarios (demographic and emissions) that are available for analysis?	Multiple demographic and global carbon emission scenarios have been made available for analyses because future changes are unknown. These analyses will focus on bookend (low and high) demographic and emission scenarios, so it is helpful to know the consequent range of effects these will have on Columbia Basin land use change.
10. Do the results shown in these analyses generally agree with other studies? Are there continental and/or global factors that may complicate these local projections of change?	Because these analyses rely primarily on data from the EPA ICLUS project, it is helpful to know if their findings agree with other studies. A literature review will be performed for this purpose.

Table 2: Project Questions and Rationale

To answer these questions, we primarily employed Geographic Information Systems (G.I.S.) methods to analyze the historic changes within defined areas from the NLCD and Census data, and the projected future changes from the ICLUS data. For questions #8 and #10, for which information was required that was not included with the ICLUS data, we performed a review of available literature.

Results

Spatially explicit results were produced through G.I.S. analyses designed to answer the study questions using the source data. These results are summarized below as statistics, tables, and maps.

Population Change – Historic and Projected (questions 1 and 2)

Population change was calculated by county for both a recent historic period (1990 to 2020) using actual census counts, and for a contemporary to future period (2010 to 2080) using the ICUS scenarios. Counties were grouped by tribe using the ceded territory extents. Figure 1 shows the 2010 population counts by county.

All of the four tribal ceded territories experienced population growth between 1990 and 2020. Counties within the ceded area of the Warm Springs Tribe had the greatest historical increase (+103.5%) between 1990 and 2020, while those of the Nez Perce Tribe experienced the smallest relative increase (+26.5%).

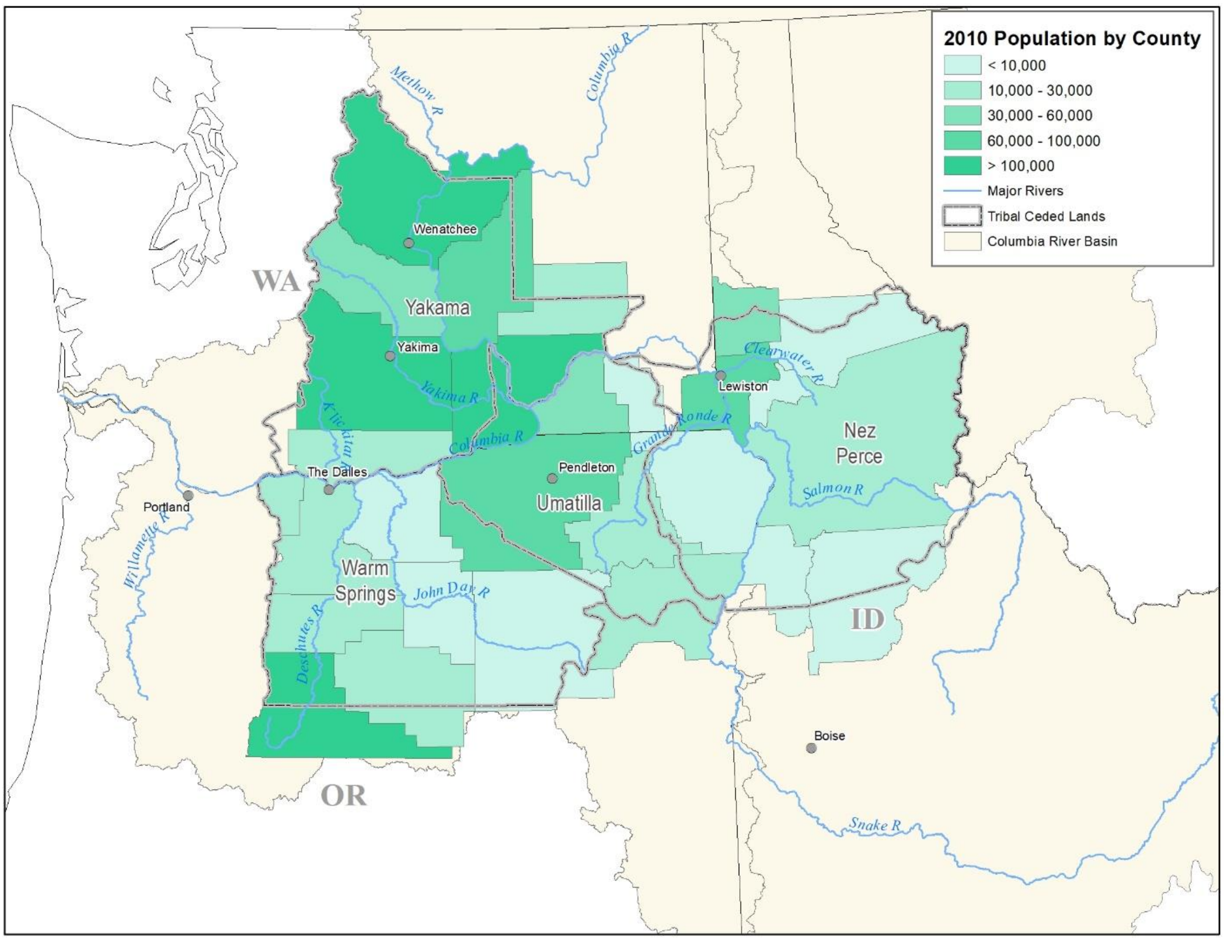

Figure 1. 2010 Population by county in tribal ceded areas.

Figures 2 and 3 show the absolute and relative projected growth by county and urban micro-area in the four tribal ceded areas between 2010 and 2080 in the SSP5 scenario. The Umatilla, Nez Perce, and Yakama tribal areas are projected to have the largest future population increases (between +70 and +82%), while the Warm Springs Tribe has

a much lower projected increase (+37.8%). For the Nez Perce Tribe, much of the growth is forecast to occur around the most populated lower-elevation areas including the urban area of Moscow, ID (+291%), while the less populous rural areas are forecast to remain stable or lose population. The other counties/urban areas with the highest projected growth throughout all of the ceded areas include Hood County, OR (Warm Springs, 382%), The Dalles, OR (Warm Springs, +356%), Moses Lake, WA (Yakama, +348%), LaGrande, OR (Umatilla, +345%), Prineville, OR (Warm Springs, +336%), Walla Walla, WA (Umatilla, +299%), and Pendleton, OR (Umatilla, +294%). Population trends forecast by the SSP2 (lower growth) scenario are similar but much smaller in magnitude (+38% growth in SSP2 vs +99% growth in SSP5 for entire ceded area).

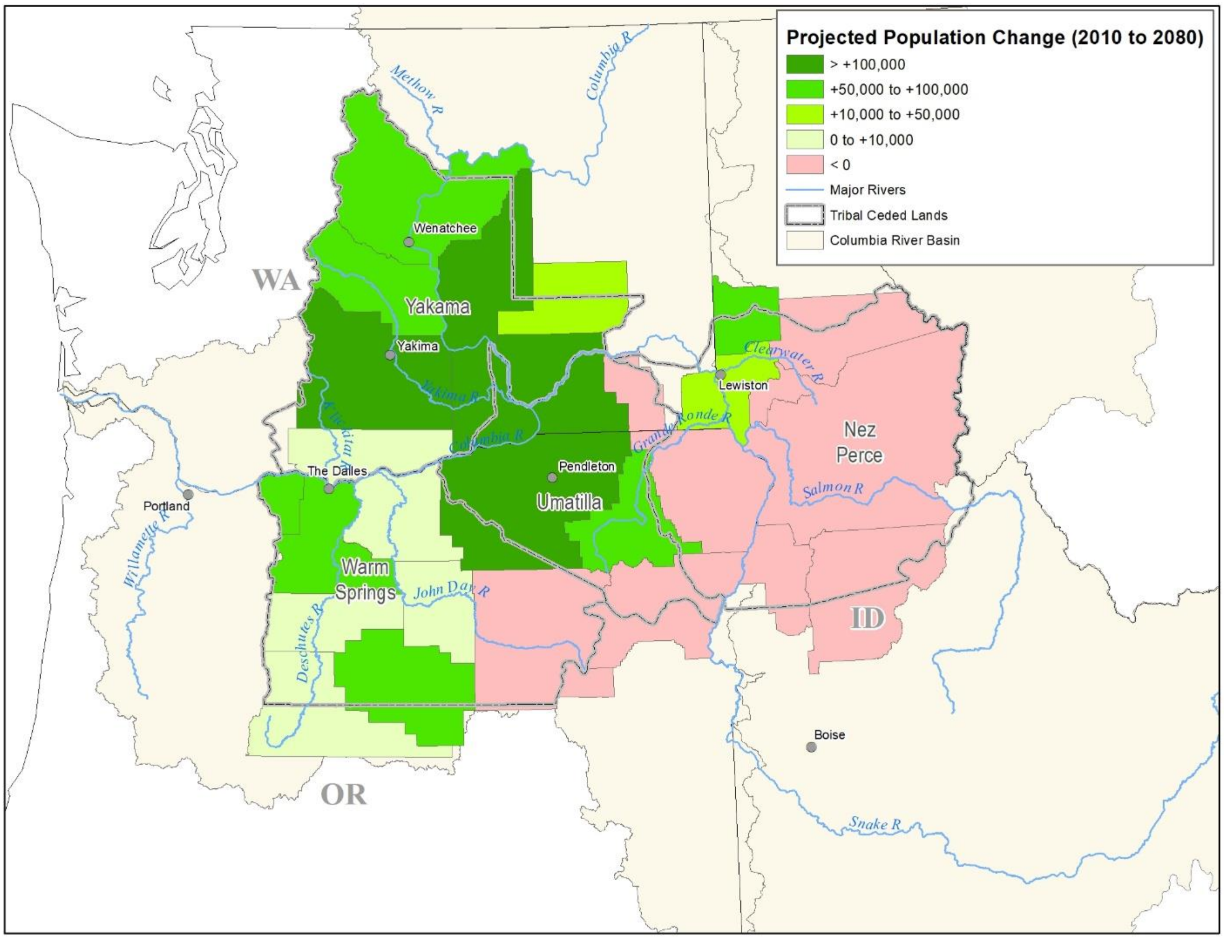

Figure 2. Projected Population Change by county in tribal ceded areas (2010 to 2080 SSP5 scenario)

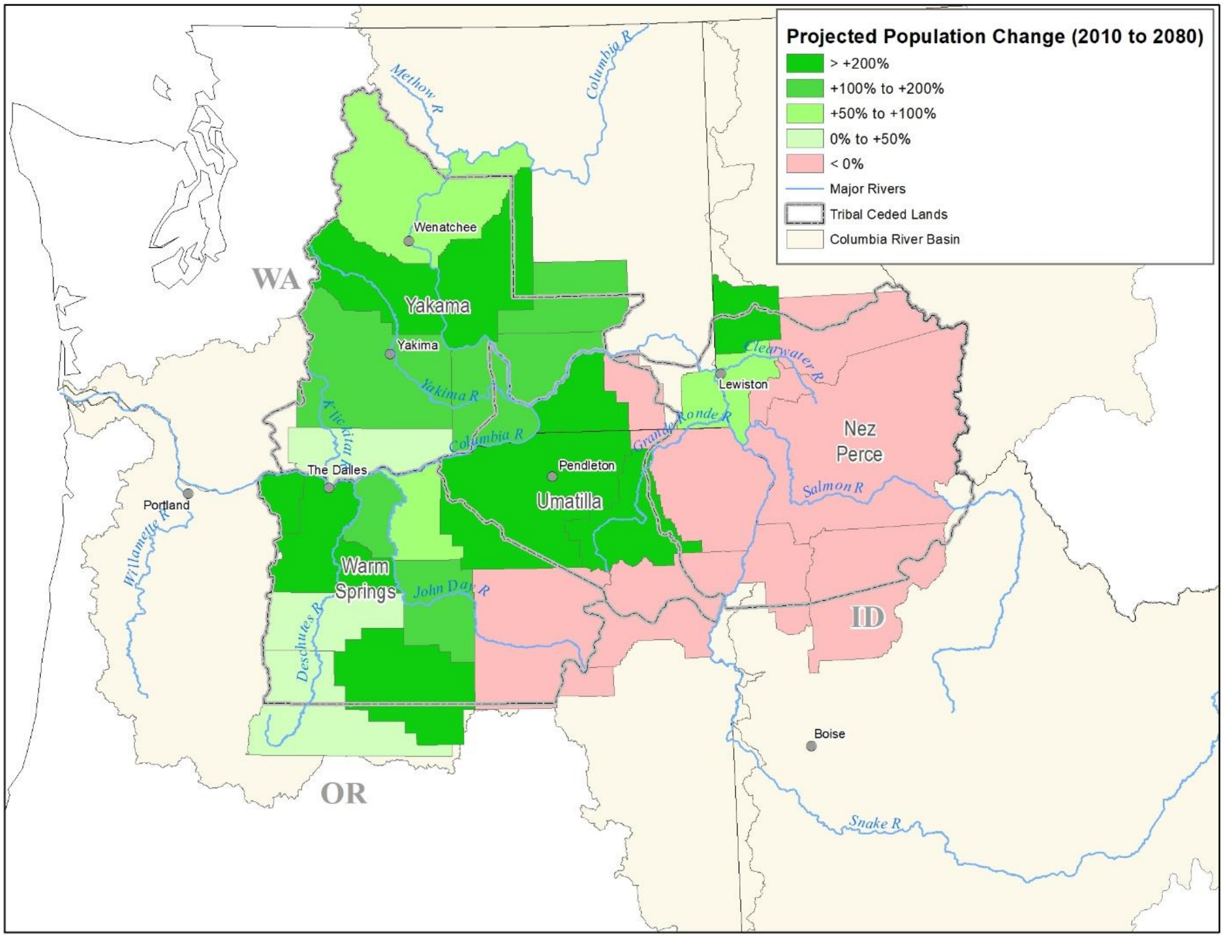

Figure 3. Projected Population Change by county (%) in tribal ceded areas (2010 to 2080 SSP5 scenario)

<u>Land Use Change – Historic and Projected (questions 1 and 2)</u>

Land Use change was calculated for a historical period (1992 to 2019) and a projected future period (2020 to 2080). For this effort, we focused mostly on transitions to developed land use (residential, commercial, industrial, or transportation infrastructure), and agricultural and forested land uses. Most other land uses were relatively static, and their variations were not deemed as likely to affect tribal natural resources. Table 3 shows the change in historical land use in tribal ceded areas, where increasing development and reductions in forested and planted/cultivated land occurred in all areas between 1992 and 2019.

Tribe	Developed (1992)	Developed (2019)	Forested (1992)	Forested (2019)	Planted/Cultivated (1992)	Planted/Cult. (2019)
WST	0.37%	2.03%	40.12%	28.30%	15.26%	8.40%
Yakama	1.31%	4.21%	28.98%	22.45%	32.67%	22.09%
Nez Perce	0.23%	1.00%	59.62%	49.49%	19.06%	7.57%
CTUIR	1.40%	3.50%	25.49%	25.38%	35.03%	29.66%

Table 3: Change in Land Use in Tribal Ceded Areas (1992 to 2019)

Table 4 and Figure 4 show the projected changes in Land Use between 2020 and 2080 in the U.S. portion of the Columbia River Basin, calculated as mean values from the low and high growth scenarios. Notably, developed area is projected to increase from 0.75% to 2.54% of the land area of the basin, accompanied with slight decreases in area devoted to cropland, grazing, and timber.

Year	Developed	Cropland	Grazing	Timber	Protected
2020	5.06%	9.03%	58.89%	9.69%	14.86%
2040	5.44%	8.97%	58.59%	9.66%	14.86%
2080	6.26%	8.86%	57.99%	9.57%	14.86%
Change	(+23.7%)	(-1.9%)	(-1.5%)	(-1.2%)	(+0.0%)

Table 4: Projected change in Land Use/Land Cover in Columbia River Basin, 2020 to 2080, mean of SP2/RCP45 and SP5/RCP85 scenarios

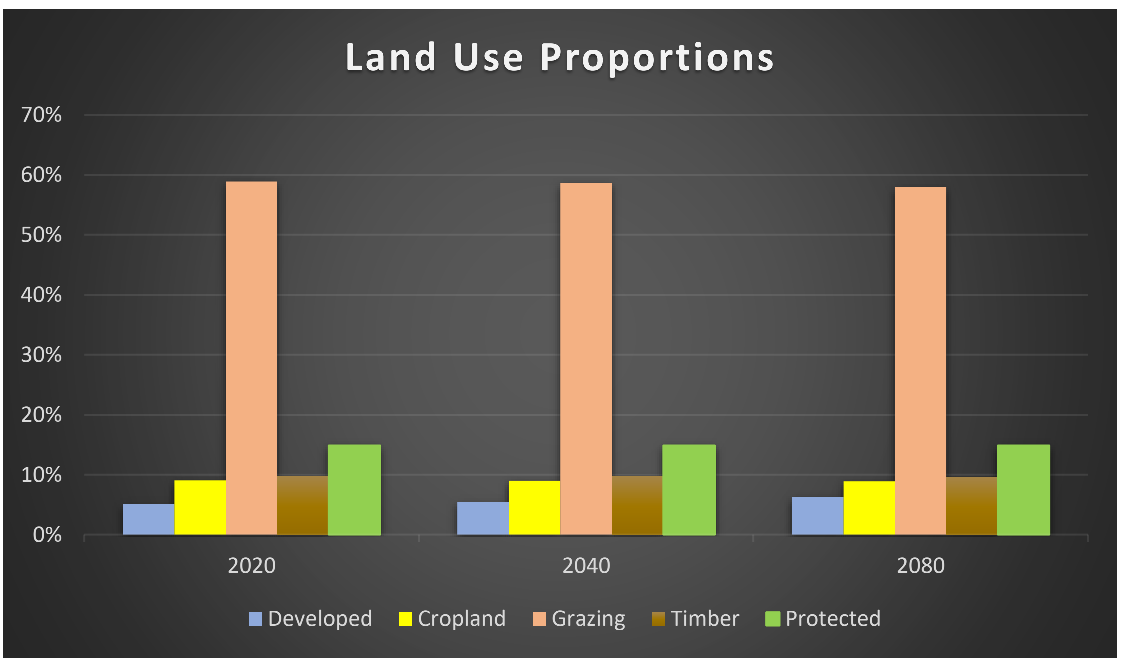

Figure 4: Projected change in land use proportions in Columbia River Basin, 2020 to 2080 (mean of SP2/RCP45 and SP5/RCP85 scenarios)

Table 5 shows the projected changes in Land Use between 2020 and 2080 in the tribal ceded areas with the mean scenario values, Figure 5 shows the projected 2020 land use from the low-growth scenario and for contrast, and Figure 6 shows the projected 2080 land use from the high-growth scenario. Figures 7 and 8 show these changes solely as applies to total developed area.

All tribal ceded areas show some similar projections (moderately increasing development and slight decreases in land devoted to grazing). Cropland increases slightly in the Warm Springs area, while decreasing slightly in others. Land devoted to timber is relatively static in the Warm Springs area, while slightly decreasing in the other areas. Yakama Nation has the largest developed area as a percentage of its total ceded area (9.42% in 2020), but the Warm Springs Tribal Area is projected to experience the largest increase in developed area from 2020 to 2080 (+65.1%, to increase from 3.01% to 4.97% of total area). The Nez Perce Tribe has the smallest developed area (1.15% in 2020), with a large proportion of its ceded area including large wilderness areas and associated forest land, but its developed area is still projected to increase by 29.6% between 2020 and 2080. The Umatilla ceded area is 5.43% developed in 2020 and projected to increase to 7.51% by 2080.

Tribe	Developed (2020)	Developed (2040)	Developed (2080)	Cropland (2020)	Cropland (2040)	Cropland (2080)
WST	3.01%	3.13%	4.97%	3.85%	3.89%	3.93%
Yakama	9.42%	9.83%	11.67%	19.24%	19.21%	18.92%
Nez Perce	1.15%	1.24%	1.49%	3.94%	3.94%	3.86%
CTUIR	5.43%	5.58%	7.51%	30.16%	30.12%	29.67%

Tribe	Grazing (2020)	Grazing (2040)	Grazing (2080)	Timber (2020)	Timber (2040)	Timber (2080)
WST	75.12%	74.88%	73.00%	7.93%	7.97%	7.96%
Yakama	49.82%	49.48%	48.01%	19.24%	19.21%	18.92%
Nez Perce	50.64%	50.55%	50.38%	8.52%	8.52%	8.51%
CTUIR	51.22%	51.10%	49.66%	6.73%	6.73%	6.69%

Table 5: Projected change in land use in tribal ceded areas, 2020 to 2080 (mean of SP2/RCP45 and SP5/RCP85 scenarios)

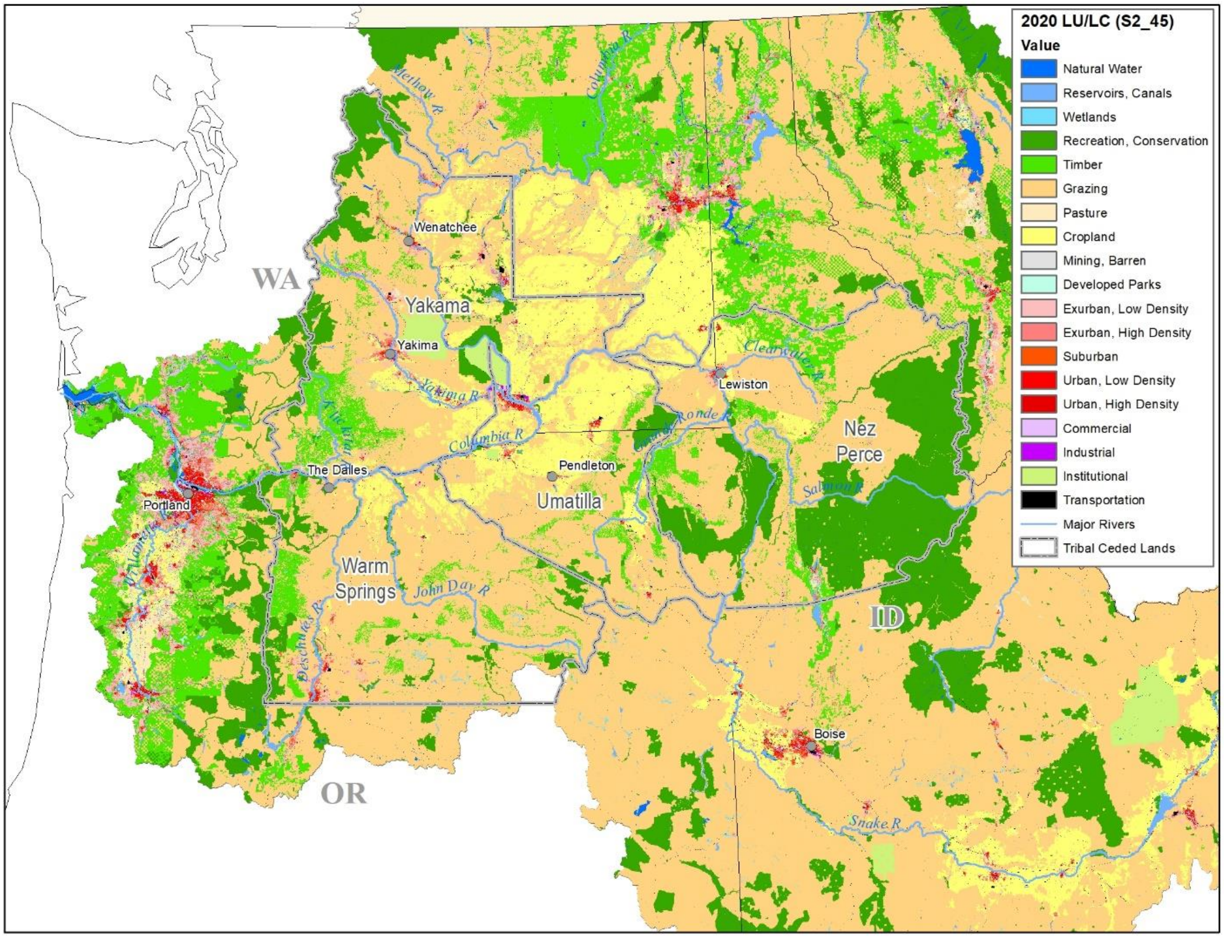

Figure 5: Projected 2020 land use (S2/RCP45 scenario)

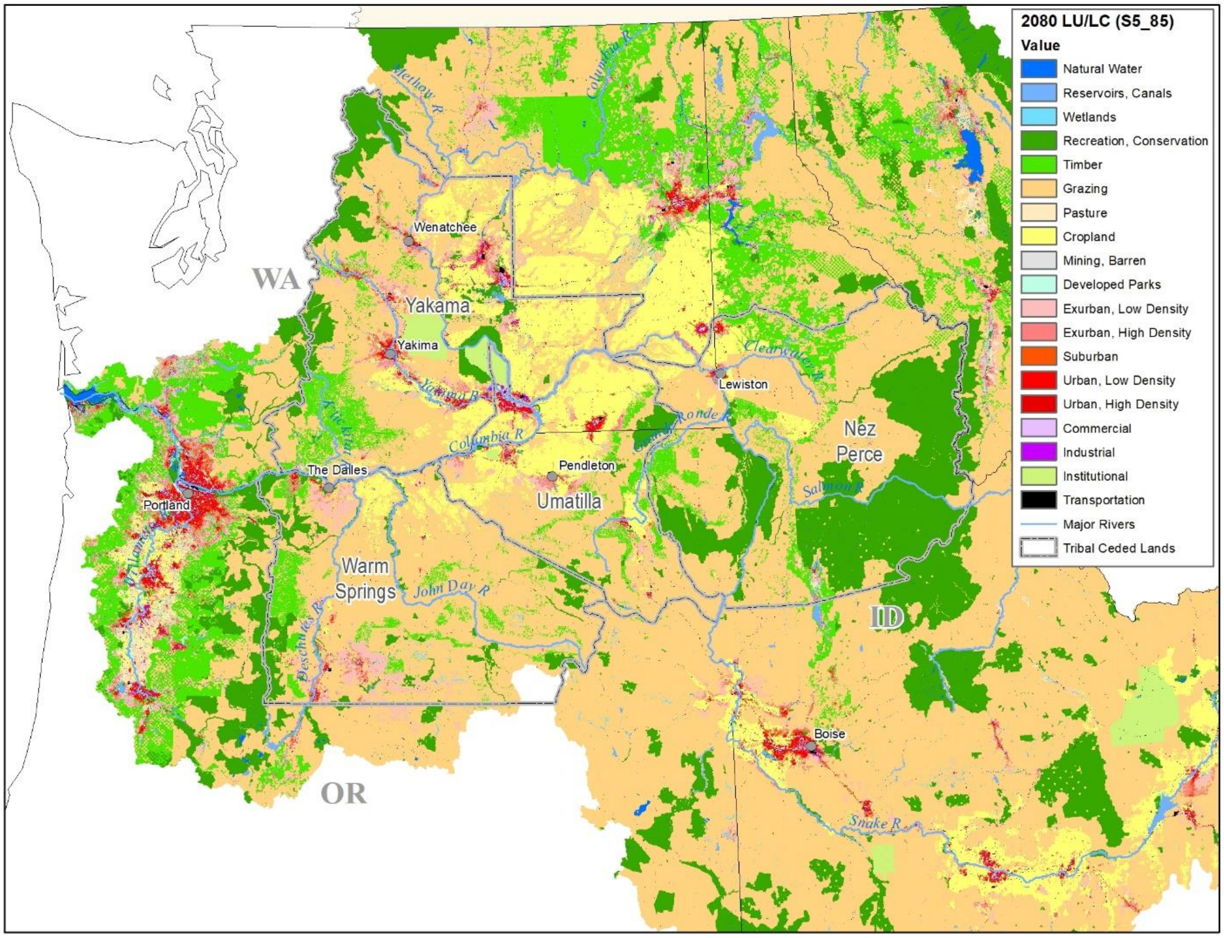

Figure 6: Projected 2080 land use (S5/RCP85 scenario)

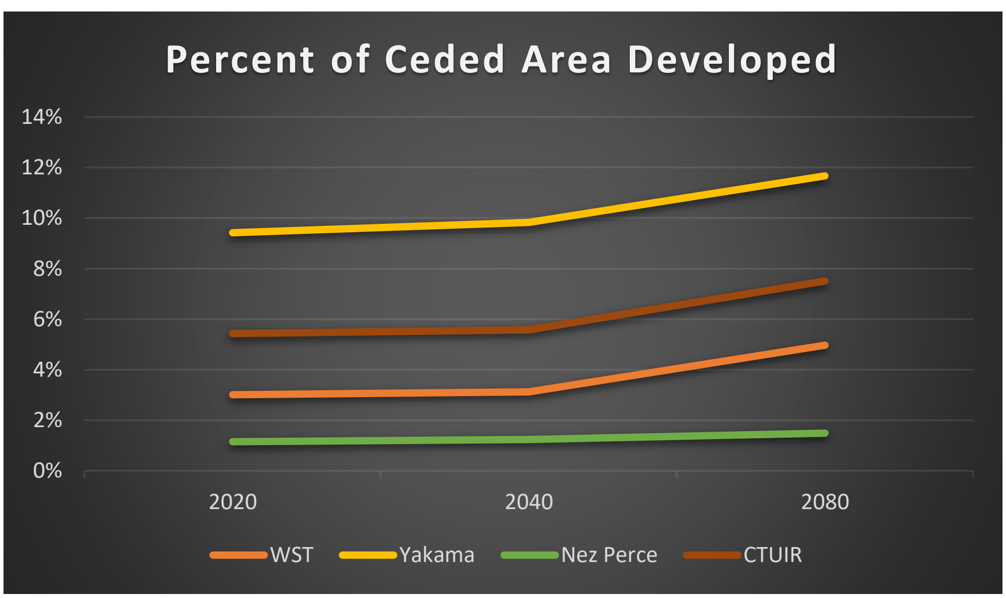

Figure 7: Projected change in Developed Area in Tribal Ceded Areas, 2020 to 2080 (S5/RCP85 scenario)

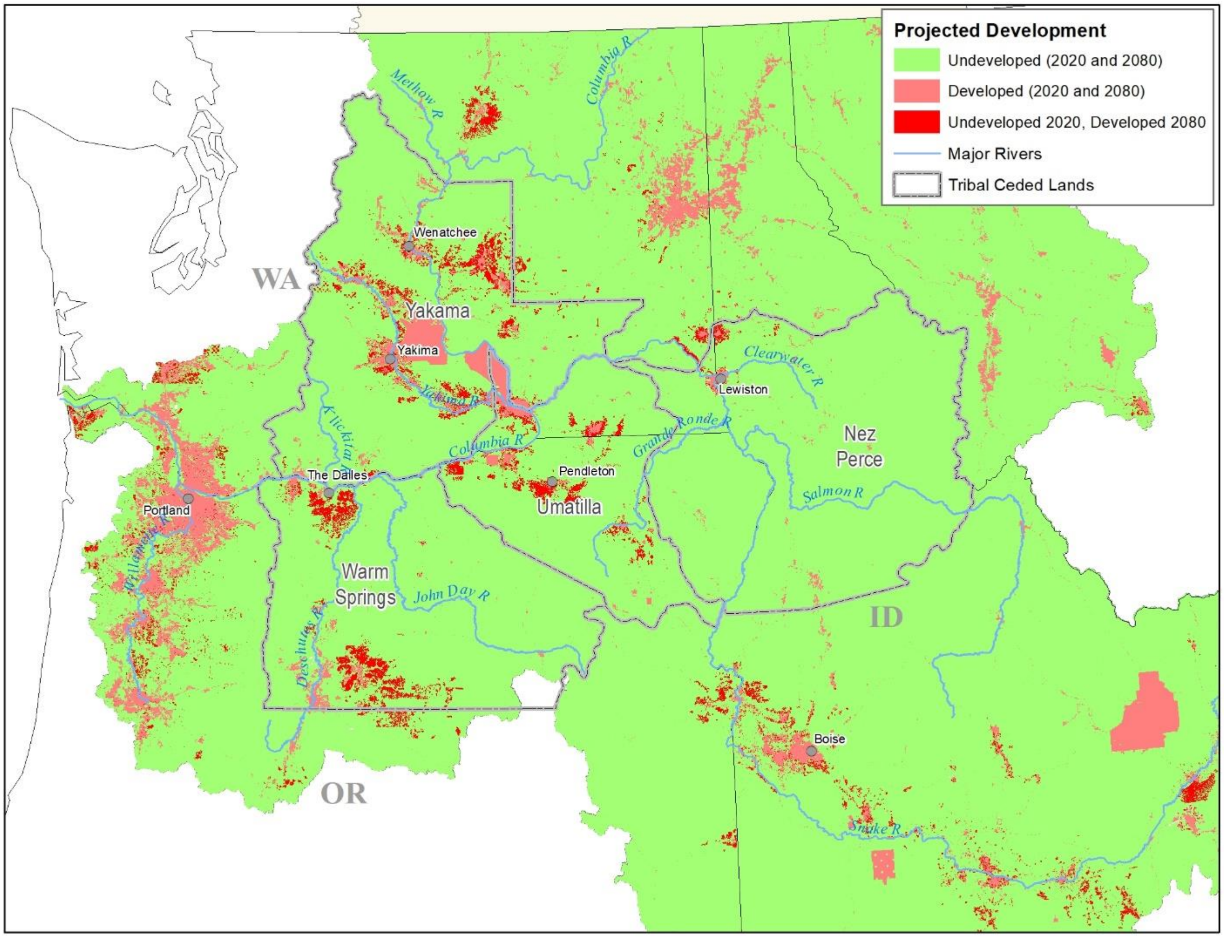

Figure 8: Projected change in developed areas, 2020 to 2080 (S5/RCP85 scenario)

<u>Change in developed area in watersheds with salmon/steelhead spawning and rearing (question 3)</u>

We also specifically analyzed the watersheds (6th field hydrologic units) that contain streams with salmon or steelhead spawning and rearing habitat. These tends to occur in mid-elevation zones with relatively undisturbed habitat and clean, cool water sources from mountainous headwaters. Most habitat restoration aims to preserve and restore these streams. Development in these watersheds can disrupt natural processes and impede spawning and rearing, although other land uses such as cattle grazing, mining, and deforestation also has deleterious effects and is generally more prevalent.

We found that developed areas are projected to increase in salmon-bearing watersheds by roughly one quarter from 2020 to 2080 using a mean of the two scenarios (projected developed area in these watersheds is 5.66% in 2020, 6.12% in 2040, and 7.05% in 2080). This rate of

development is greater than the rate of change in development projected for the entire Columbia River Basin. The amount of land devoted to grazing in these watersheds is projected to decrease slightly (-1.7%), from 51.6% in 2020 to 50.7% in 2080. Forested cover is also projected to decrease slightly (-2.2%), from 13.7% in 2020 to 13.4% in 2080.

Change in developed area in riparian zones along streams with salmon/steelhead spawning and rearing (question 4)

The riparian zones directly adjacent to streams with spawning and rearing are generally considered to be the most important for salmon and steelhead. These zones contribute to natural stream processes and healthy habitat, and development within this zone can directly impede these processes. We analyzed land use change in this zone, defined for this analysis as the cross-sectional area 100-meters wide around a stream. The developed areas of the riparian zone of these streams are projected to increase by 13.6% from 2020 to 2080, from 7.13% to 8.10% of the area. This change is less than the rate of increase in development in the entire Columbia River Basin. The amount of land devoted to grazing within the riparian zone is projected to decrease slightly (-2.7%), from 42.2% in 2020 to 41.06% in 2080. Forested cover in the riparian zone is also projected to decrease slightly (-2.3%), from 13.0% in 2020 to 12.7% in 2080.

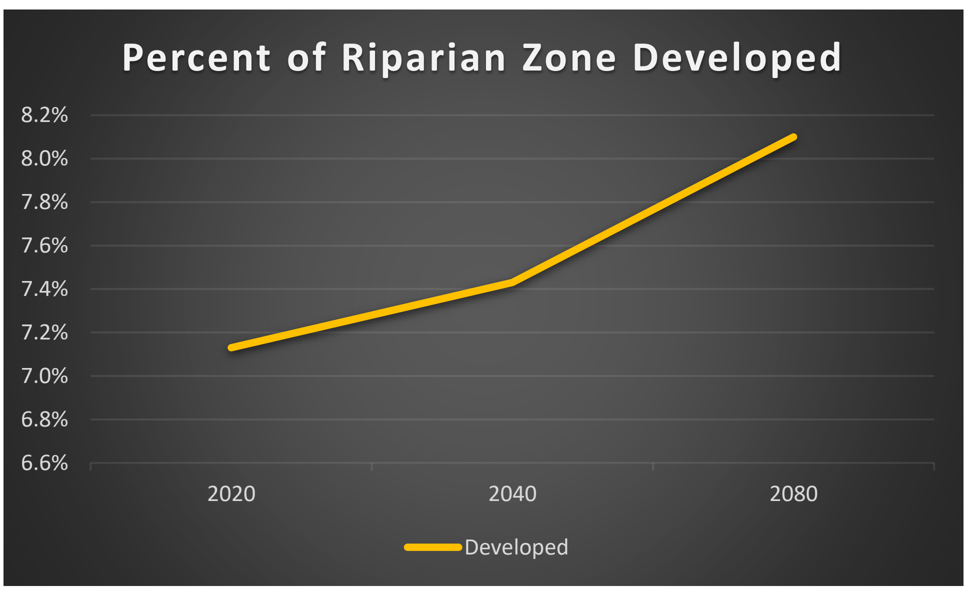

Figure 9: Projected change in Developed Area in Riparian Zones of Streams with Salmon/Steelhead Spawning or Rearing, 2020 to 2080 (S5/RCP85 scenario)

Important ecological or cultural areas that appear most likely to be developed in the future (question 5)

In addition to reporting overall trends in changes to land use, it is helpful to identify specific areas that are likely to be most impacted. For these analyses, we focused first on the streams with salmon/steelhead spawning and rearing habitat that are projected to be newly developed by 2080. This was done with a visual screening of the map to identify these stream sections, followed by a measurement of the stream length that was undeveloped in 2020 and projected to be encompassed by development by 2080. These results are reported in Table 6, where the streams with the largest concentrations of development are ordered from lower to higher in the Columbia and Snake basins. The majority of these streams were developed in the Lower Columbia River tributaries, with others being found in the Columbia Gorge, Yakima River, and Umatilla River Subbasins.

Stream Name	Geographic Section	Stream length projected to be encompassed by new development
Salmon Creek, Tributary to Lake River (Lower Columbia)	Mouth to Headwaters	4.74 km
East Fork Lewis River including Rock Creek Tributary	Near Rock Cr Confluence	1.90 km
Johnson Creek, Tributary to Willamette River	Headwaters Section	2.37 km
Lower Clackamas River	Mouth to Rkm 20	4.33 km
Coast Fork Willamette River and Tributaries (Martin Cr, North Fork Gettings Cr, Louis Slough)	Near Cottage Grove	12.69 km
Lower Washougal River/Little Washougal River	Mouth to Confluence	5.83 km
Beaver Creek, Tributary to Sandy River	Mouth to Headwaters	2.12 km
Neal Creek, including WF and Lenz Cr (Tributary to Hood River)	Mouth to Headwaters	4.95 km
Lower Yakima River	Prosser to Richland	6.63 km
Lower/Mid Columbia Oregon Tributaries (Mill, Threemile, Fivemile, Eightmile, Fifteenmile)	Above the Dalles	86.73 km
Naches River & Cowiche Creek	Confluence to Tieton	8.25 km

Upper Yakima River	Roslyn to Teanaway Confluence	4.78 km
Omak Creek	Mouth to Headwaters	1.52 km
Lower Ahtanum Creek	Mouth to Rkm 12	2.84 km
Lower Umatilla River including McKay Creek and Lower Birch Creek	Mouth to Birch Creek	36.95 km
Middle Umatilla River Tributaries (Cottonwood, Moonshine, Buckaroo)	Middle Tributaries	15.65 km
Mid Walla Walla River and Tributaries (Mission, Mill, Yellowhawk, Cottonwood)	Middle Forks	28.77 km
Upper Grande Ronde River Tributaries (Bear, Whiskey, Graves, Rock, Sheep)	Upper Tributaries	13.62 km
McKay Creek including Allen Creek (Tributary to Crooked River)	Mouth to RK 20	18.87 km

Table 6: Streams with salmon spawning/rearing habitat use, and riparian areas that are projected to be developed between 2020 and 2080 (S5/RCP85 scenario) for a significant proportion of their stream length.

A systematic analysis was used to identify the salmon/steelhead bearing watersheds (6th field hydrologic units) with the highest proportion of total land projected to be developed between 2020 and 2080. These results are reported in Table 7. Many of the watersheds with the highest projected rate of development are located in the Fifteenmile subbasin, above the city of the Dalles, Oregon, but others occur throughout different subbasins as depicted in the map in Figure 10.

HUC_12	Watershed Name	Subbasin	Developed
170701050201	Upper Eightmile Creek	Fifteenmile	1.16%
170701050202	Middle Eightmile Creek	Fifteenmile	1.12%
170900080202	Agency Creek	Willamette	0.98%
170701050204	Lower Eightmile Creek	Fifteenmile	0.94%
170800060204	Wallooskee River	Columbia Estuary	0.85%
170601040306	Rock Creek	Grande Ronde	0.80%
170701050305	Middle Fifteenmile Creek	Fifteenmile	0.68%
170701050302	Upper Fifteenmile Creek	Fifteenmile	0.64%
170701050306	Lower Fifteenmile Creek	Fifteenmile	0.60%

170900020401	Hill Creek-Coast Fork Willamette River	Willamette	0.57%
170800060207	Lower Lewis and Clark River	Columbia Estuary	0.56%
170701050505	Lower Middle Fork Hood River	Hood	0.54%
170701050701	Neal Creek	Hood	0.53%
170900110502	North Fork Eagle Creek	Willamette	0.52%
170701050403	North Fork Mill Creek-South Fork Mill Creek	Columbia Gorge	0.51%
170701050203	Fivemile Creek	Fifteenmile	0.51%
170800050304	Lower Salmon Creek	Cowlitz	0.48%
170800060201	North Fork Klaskanine River	Columbia Estuary	0.45%
170601070801	Almota Creek	Snake Lower	0.44%
170601040305	Whiskey Creek	Grande Ronde	0.44%
170900080204	Rogue River-South Yamhill River	Willamette	0.44%
170300020311	South Fork Cowiche Creek-Cowiche Creek	Yakima	0.42%
170900080102	Coast Creek	Willamette	0.41%
170900120403	Milton Creek	Columbia Lower	0.38%
170800010606	Lower Washougal River	Washougal	0.37%
170900020305	Martin Creek-Coast Fork Willamette River	Willamette	0.37%
170900100103	Lower Gales Creek	Willamette	0.36%
170701050404	Mill Creek	Columbia Gorge	0.35%
170601040903	North Fork Clark Creek	Grande Ronde	0.35%
170900120402	North Scappoose Creek	Columbia Lower	0.35%
170601040604	Lower Ladd Creek	Grande Ronde	0.35%
170900120101	Upper Johnson Creek	Willamette	0.32%
170800060208	Skipanon River-Frontal Columbia River	Columbia Estuary	0.32%
170900110607	Rock Creek-Clackamas River	Willamette	0.31%
170800060103	Bear Creek-Frontal Columbia River	Columbia Estuary	0.31%
170300031202	Badlands Lakes-Yakima River	Yakima	0.31%
170800010701	Gordon Creek	Sandy	0.31%
170300030105	Lower Ahtanum Creek	Yakima	0.30%
170800060206	Upper Lewis and Clark River	Columbia Estuary	0.29%
170900080203	Rock Creek	Willamette	0.28%
170800010401	Wildcat Creek-Sandy River	Sandy	0.26%
170800030202	Tide Creek	Columbia Lower	0.26%
170900080606	Baker Creek	Willamette	0.25%
170601040404	Haywire Canyon-Grande Ronde River	Grande Ronde	0.25%
170701050402	Threemile Creek	Columbia Gorge	0.24%
170900110605	North Fork Deep Creek-Deep Creek	Willamette	0.23%

170800010703	Beaver Creek-Sandy River	Sandy	0.23%
170601040303	Jordan Creek	Grande Ronde	0.22%
170800020506	Rock Creek-East Fork Lewis River	Lewis	0.21%
170900120303	Lower Salmon River	Columbia Lower	0.21%

Table 7: Salmon/Steelhead-bearing watersheds with the highest (top 20 percentile) percentage of land area projected to be newly developed between 2020 and 2080 (S5/RCP85 scenario)

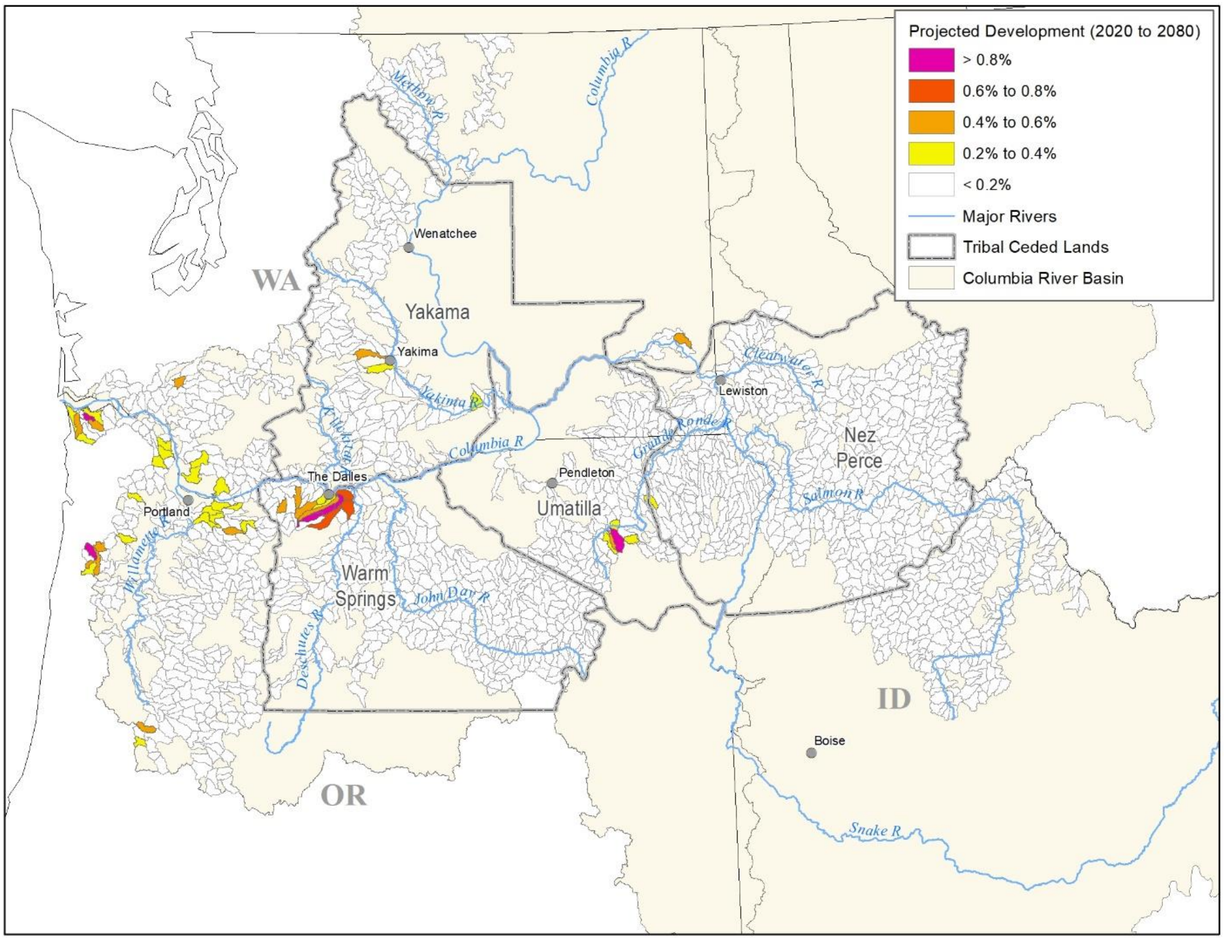

Figure 10: Salmon/Steelhead Bearing Sub-watersheds with the Highest Projected Change in Developed Area, 2020 to 2080 (S5/RCP85 scenario)

<u>Change in land use in Zone 6 watersheds (question 6)</u>

An additional focus of this project was Zone 6 of the Columbia River, and important Indian fishing zone located between Bonneville Dam and McNary Dam. It includes several tributaries that provide cold water refugia at their mouths, which aid salmon and steelhead during their migration. A concurrent effort is assessing the sediment and hydrology of these tributaries to predict future geomorphology in these refuges. For this project, we assessed the projected

changes to land use in the watersheds of these tributaries. These included the Deschutes River (OR), Klickitat River (WA), and White Salmon River (WA), as well as the Cowlitz River (WA), which enters the Columbia River below Zone 6 but also provides cold water refugia.

Table 8 displays the projected change in land use area in these watersheds at intervals between 2020 and 2080 and Figure 11 shows a map of the change in developed area in these watersheds during this period. Notably, developed area is projected to increase dramatically (+86%) in the Deschutes watershed (from 4% to 7.44% of total area), moderately (+25%) in the Cowlitz watershed (from 9.87% to 12.37% of total area), and to a lesser degree (+14%) in the Klickitat watershed (from 2.28% to 2.60% of total area) and remain unchanged (at 4.72% of total area) in the White Salmon watershed. Forested and grazing cover is projected to generally show small decreases, except in the White Salmon where these land uses are projected to remain stable.

COLDSHED	PERIOD	Water%	Conserved%	Timber%	Grazing%	Agriculture%	Developed%
Cowlitz	2020	1.81%	19.44%	38.51%	30.35%	0.01%	9.87%
Cowlitz	2040	1.81%	19.44%	38.14%	30.21%	0.01%	10.40%
Cowlitz	2080	1.81%	19.43%	36.28%	30.11%	0.01%	12.37%
Deschutes	2020	1.01%	12.68%	8.41%	73.33%	0.58%	4.00%
Deschutes	2040	1.01%	12.68%	8.41%	72.68%	0.58%	4.65%
Deschutes	2080	1.01%	12.68%	8.37%	69.93%	0.58%	7.44%
Klickitat	2020	0.26%	2.54%	52.37%	38.72%	3.83%	2.28%
Klickitat	2040	0.26%	2.54%	52.37%	38.71%	3.83%	2.29%
Klickitat	2080	0.26%	2.54%	52.36%	38.43%	3.82%	2.60%
White Salmon	2020	0.28%	12.08%	22.14%	60.76%	0.03%	4.72%
White Salmon	2040	0.28%	12.08%	22.14%	60.76%	0.03%	4.72%
White Salmon	2080	0.28%	12.08%	22.14%	60.75%	0.03%	4.72%
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 8: Projected Changes to Land Use in Cold Water Tributary Watersheds, 2020 to 2080 (mean of SP2/RCP45 and SP5/RCP85 scenarios)

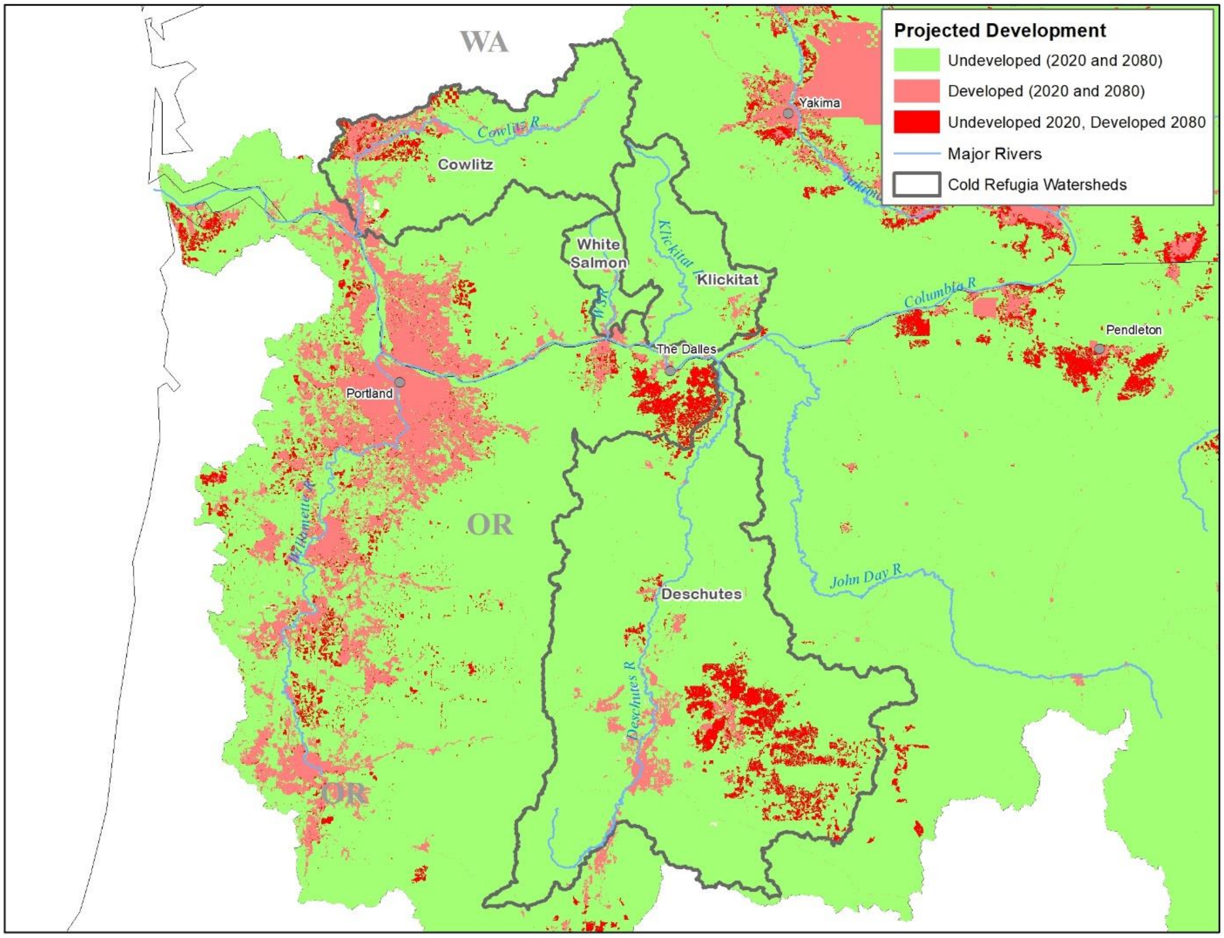

Figure 11: Projected change in Developed Areas, 2020 to 2080 (S5/RCP85 scenario) in Cold Water Refugia Watersheds of the Lower/Mid-Columbia River

Change in irrigated acreage in Columbia Basin and individual subbasins (question 7)

Irrigated acreage was not expressly included in the ICLUS project. The closest surrogate is the cropland class, which is composed of both irrigated and dryland acreage. Figure 12 shows the projected change in cropland area in the Columbia River Basin for the 2020 to 2080 period, and Table 5 breaks this category down by tribal ceded area. The percent of land devoted to cropland is projected to decrease slightly (-1.9%) in the Columbia River Basin over this period (from 9.03% in 2020 to 8.86% in 2080).

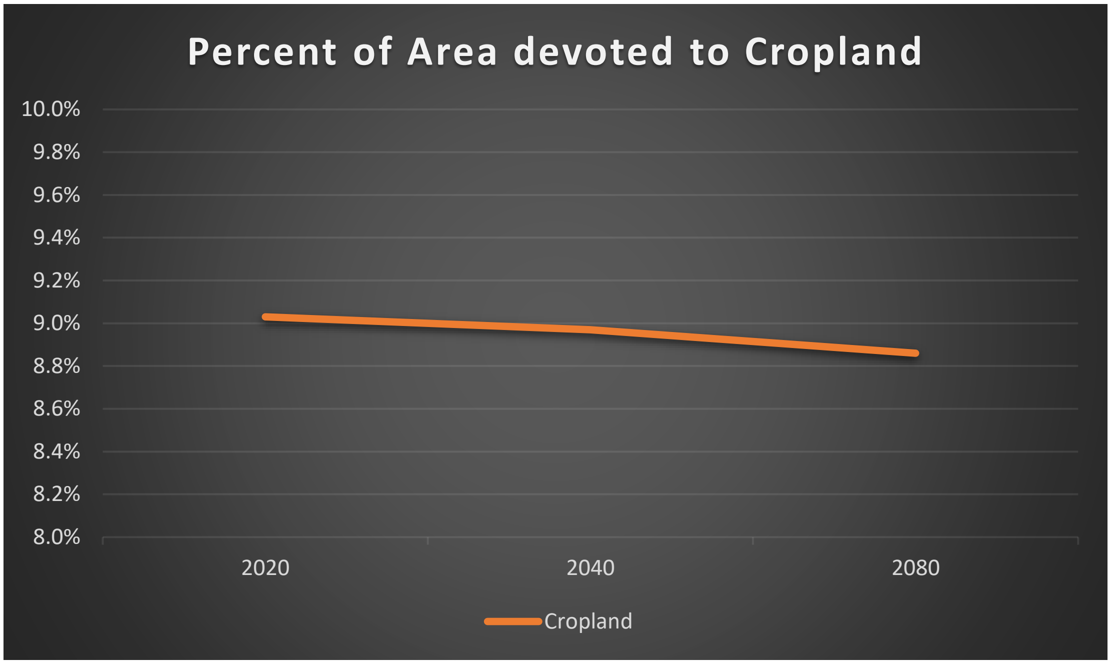

Figure 12: Projected change in Cropland in the Columbia River Basin, 2020 to 2080 (S5/RCP85 scenario)

Change to total water demand in the Columbia River Basin from changing agricultural use (question 8)

Please see discussion section for literature review findings – this data was not available for analysis.

Variation between scenarios and relative concentration pathways, and time periods (question 9)

In general, we chose to map change from a current estimate (2020) to a future estimate (2080) with the ICLUS data. To map the overall trend concisely, we used the S2_RCP45 data (lower growth scenario) for 2020 and the S5_RCP85 data (higher growth scenario). When summarizing status of land use at any interval, we used the mean of these two scenarios. It is, however, important to understand the variation implicit in these scenarios, as they include a range of assumptions. To compare the scenarios, the largest indicator of land use change (total developed area in the Columbia River Basin over time) was chosen. The table below compares the developed area for the S2_RCP45 and S5_RCP85 scenarios.

There is a negligible difference (1.2%) in development between the two scenarios in 2020, increasing to a moderate difference (7.2%) in 2040, and a relatively large difference (27.2%) in 2080. Thus, the projected changes in 2080 imply more uncertainty with a higher range of outcomes, and the 2080 mapped projections that display the 2080 S5_RCP85 results should

thus be consider truly high-end estimates with possible lower outcomes. The spatially explicit nature of the data makes it impossible to map the mean average of the scenarios, but an average is done for tabular results in these analyses. The interpretation of mean values from the two scenarios in the tabular results should be considered the center points of a range of possible outcomes rather than predictive values in themselves. Regardless, the increasing development at basin-wide and local scales is apparent in both the low and high scenarios and provide consensus trends of future conditions based on a range of demographic and climate outcomes.

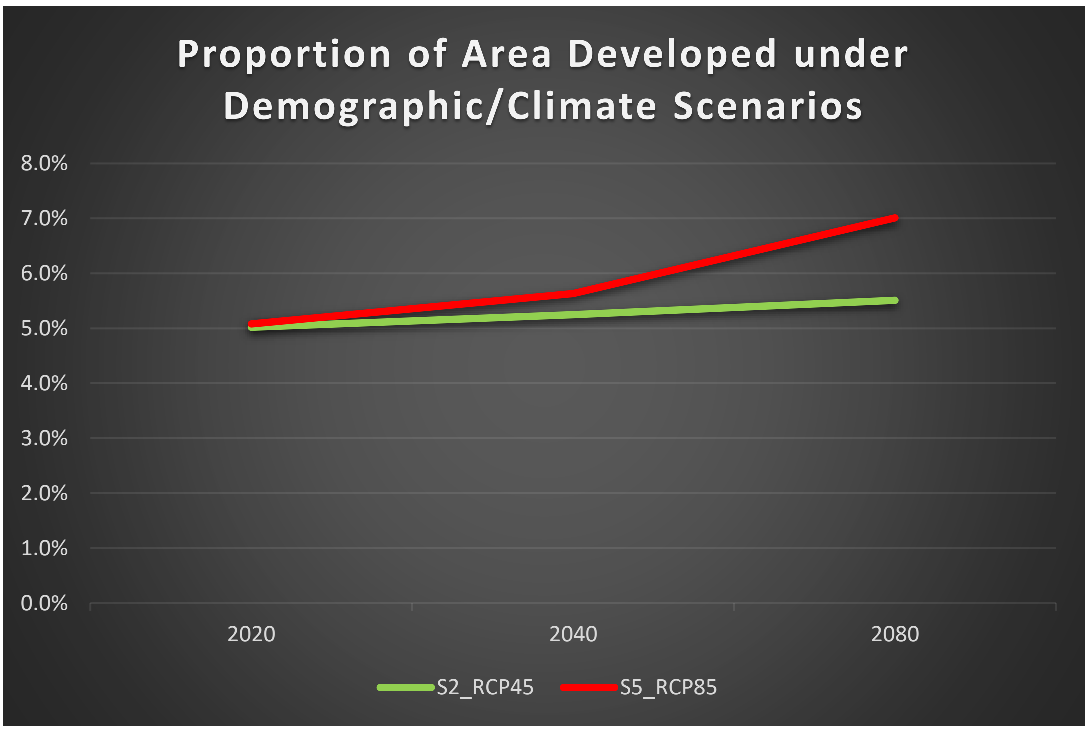

Figure 13: Projected proportion of Columbia River Basin as Developed Area under S2_RCP45 and S5_RCP85 Demographic/Climate Scenarios

<u>Do the results shown in these analyses agree with the findings of other studies and are there continental and/or global factors that may complicate these local projections of change (question 10)</u>

Please see discussion section for literature review findings as this question requires information outside of the ICLUS model results.

Discussion

The analyses of the recent historical and future projected population and land use data illuminated some clear trends in the tribal lands of the Columbia River Basin. Population has grown steadily in recent history and is projected to continue to do so throughout the next several decades. This growth is distributed throughout the basin, but certain areas are likely to receive more growth, including the areas located around small cities of west-central Idaho, the eastern Columbia Gorge, the mid-Columbia Basin, and the Yakima sub-basin. These areas have a favorable climate, a relatively low cost of housing, and abundant land. They are also located centrally within the ceded territories of the CRITFC member tribes. Land Use change has also shown steady trends that are projected to continue for the foreseeable future. Development has been accompanying population growth in the basin and will likely continue to do so. This development results in a slightly declining trend in other land uses including cropland, timber, and grazing. While all of the ceded areas of our member tribes reflect these projected trends, the rate of change is not uniform. Development is projected to occur at a greater pace in pockets of desirable areas that have available land for conversion proximate to towns and cities. In particular, the eastern Columbia Gorge, which falls in the Warm Springs tribal ceded area, is projected to experience higher rates of growth and development. Rural areas located at a greater distance to urban amenities, such as much of the interior Nez Perce ceded area are projected to develop more slowly. In the Yakima and Umatilla ceded areas, development is also projected to occur at a faster rate near existing cities including Yakima and LaGrande. While nearly 15% of the area of the Columbia River Basin is classified as protected, many other areas of importance to tribal first foods are not, including the watersheds and riparian areas of salmon and steelhead habitat, which are vulnerable to development.

Water consumption may be considered a consequence of land use and is of great importance in the region. Water supplies are used for hydropower, agriculture, and recreation, but are also of critical importance to anadromous fish and other aquatic species. Irrigation is the largest consumptive use of water in the Columbia River Basin where approximately 5% of all annual flows are diverted for agriculture (USACE et al. 2020). The effects of irrigation can be readily seen along the Columbia River, where arid lands bloom green with varied crops including potatoes, hops, wine grapes, fruit, vegetables, hay, alfalfa, and grain that could not be grown without irrigation. Additional irrigation occurs through withdrawals from major tributaries of the Columbia, such as the Yakima and Snake Rivers, and in total, 5.1 million acres of agricultural land are estimated to be irrigated, a reduction from the historic high (9.2 million acres in 1980) (NWPCC 2021). Irrigated land was not expressly captured in the ICLUS project, but total cropland was projected to decrease slightly between from 2020 to 2080. While immensely beneficial for its agricultural production, irrigation from the Columbia River reduces overall hydroelectric capacity and diminishes and diverts spring and summer stream flows away from salmon and other native fish. Many tributaries in the Columbia Basin are “substantially depleted” by water diversions for irrigation, and it has been estimated that over half of these have low flow issues caused at least in part by irrigation (USACE et al. 2020).

Recent literature suggests some contrasts in predicted outcomes for future irrigation in the Columbia Basin, but common themes do occur. Climate change will shift the timing of flow to earlier in the year, and despite year-to-year variability will generally mean more water available during the spring and less during the summer, but no net loss in overall Columbia River volume (RMJOC 2018). This may encourage changes to crop mix and the shifting of more irrigation demand to the spring, and possibly an increase in double-cropping (Rajagopalan et al. 2018, Washington Department of Ecology 2020). Increases in irrigation efficiency will likely reduce water demand from existing acreage but may be offset by increases to regional and global food and biofuel demand, and crops choices (Hall et al. 2019). Tributary sub-basins where water supplies are often contested and supplied by mid-elevation snowpack (such as the Yakima and Snake Rivers) will be more vulnerable and may face more difficult allocation choices (Hall et al. 2019). Changes to hydro system operations will continue to occur, with possible reductions in irrigations in some locales, but are unlikely to significantly reduce basin-wide irrigation withdrawals (USACE et al. 2020. Innovations to improve water use efficiency and conserve resources will likely present opportunities to counteract some of the negative effects of irrigation on fish and water quality (Hall et al. 2019).

The projections contained in ICLUS about future migration and development are robust and use a well-vetted set of models and input data to provide a range of outcomes. Examining comparable literature generally confirms these results, but also illustrates some of the uncertainty in making these projections about future activities, which are the result of a complex set of societal effects and individual decisions. There is widespread recognition that climate change is already causing human migration and that this trend will accelerate in the future (Piguet et al. 2011). Much research is focused on forced migrations, when climate conditions become so dire that residents are forced to flee their homes, such as from areas inundated by sea level rise, destroyed by forest fires, or made uninhabitable due to drought. But additionally, rational choices are made to more subtle climate influences, such as excessive heat conditions, increasingly frequent but smaller-scale floods, droughts, or wildfire/smoke events, or increases in the prices of insurance or utility bills. Globally, the "human climate niche" that best supports human civilization is predicted to shift further in the next 50 years than it did in the last 6,000 years because of a rapidly changing climate (Xu et al. 2020). Migration in response to these climate shifts may occur in incremental steps but may also become non-linear when sudden events or perceptions act as triggers (McLeman 2018).

In North America, the general expectation is that climate change will be most influential in causing people to move from (i) hot areas such as the southern states to cooler northern states, and (ii) in response to natural disasters. In 2020, ProPublica published a series of maps that predicted climate migration in North America during the 21st century from a variety of climate influences including heat and humidity, sea level rise, and shifts in agricultural viability (Shaw et al. 2020). They found that by the 2070, the "suitable zone" will generally move northward, favoring migration from the southern states to the midwestern and northwestern states. Fan, et al. (2018) also predictied a similar migration, estimating that 1 in 12 Americans living in

Southern States will move into the Northwest or Mountain West states over the next 45 years solely because of climate effects. This research confirms the projections from the analyses here of increasing population and development in the Columbia River Basin, but also highlight the potential that if some of the climate effects occur more rapidly than expected, that this in-migration and consequent development could also occur earlier and/or at a higher rate.

Shifts in land use projected in these analyses are also based on a complex set of factors that entail uncertainty. Agriculture, grazing, and timber production respond to a national and global market conditions, as well as local environmental conditions such as seasonal air temperature, precipitation, humidity, soil moisture, and freshwater availability. While developed area from local population growth will require consequent cessation of other land uses to accommodate it, the balance between these other uses may also shift because of local and global factors. Climate change will likely reduce global agricultural productivity (Tai, et al. 2014), perhaps pressuring the expansion of agriculture and grazing in the Columbia River Basin, even as development also increases the value of land here. In particular, crop production currently occurring in California may need to shift northward in response to water shortages there (Pathak et al. 2018). Globally, forest land is most often converted to agriculture and urban areas to accommodate the growth of human populations. Nowak and Walton (2005) identified how human population growth in the U.S. coincides nationally with forest loss, and projected forest loss the Northwestern States by 2050 to accommodate urbanization, which was mostly concentrated West of the Cascades, in Washington and Oregon. In the interior Columbia Basin, there was little projected forest loss in their study with the exceptions of the areas surrounding the Yakima and Spokane valleys. But substantial forest loss has occurred historically in the Columbia River Basin, and has been connected to changes in hydrology, in particular less retention of winter precipitation to sustain summer flows (Matheussen et al. 2000). In all, it seems likely that the Columbia River Basin, an area with a relatively abundant amount of freshwater, temperate conditions, and large expanses of undeveloped land will likely face increasing pressures for human habitation and food production as climate change decreases the potential of other more vulnerable areas both inside the U.S. and globally to provide for these uses.

Conclusion

Climate change, population growth, and land use change are interrelated conditions that are occurring in the Columbia River Basin as elsewhere and will likely accelerate during this century. People will likely continue to move to this region for its many amenities, and also to escape climate change impacts in other regions. This will encourage development in the landscape, as forested and agricultural lands are converted to accommodate residential, commercial, and industrial uses. This development will occur on the ceded lands of all four of the CRITFC member tribes but will likely be concentrated most in some areas over others. Land use change

will also continue to occur throughout the ceded territories but will respond to local conditions as well as the national and global economies. Land use change will also affect the timing and availability of freshwater in basin, which is of paramount importance to fish and other aquatic species. Understanding the location and magnitude of these changes is important for ensuring the health of the natural resources of the Columbia River Basin and the first foods of the native tribes in the region. In particular, the riparian areas and watersheds of endangered and threatened salmon and steelhead must be protected to assist in their survival and restoration. Climate change adaptation for natural impacts should also consider the regional population growth, development, and land use changes that are projected to occur, in order to create robust and realistic plans that can be most successful.

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