

SECTION 10

How Will Climate Change Affect Freshwater Ecosystems?

Freshwater ecosystems in the Puget Sound region are projected to experience a continued increase in water temperatures, a shift to earlier peak streamflows, and declining snowmelt. These changes have widespread implications for ecosystem composition and aquatic species. Changes are expected to be most pronounced in mid-elevation basins that have historically received a mix of rain and snow during the winter. Increasing stream temperatures, increasing winter streamflow, and declining summer streamflow are projected to affect salmon growth and survival across many life stages and habitats, particularly for populations where juvenile development occurs in freshwater streams. Wetland ecosystems are projected to decline in both extent and number as a result of decreasing water availability in summer. Efforts to address impacts on freshwater ecosystems are increasing, and many local organizations, agencies, and tribes have already begun to develop adaptation strategies and plans.

Climate Drivers of Change

Projected changes in the Puget Sound region's^A freshwater environment are driven by increasing air temperature, reduced snow accumulation, and declining summer precipitation.

- *Observations show a clear warming trend, and all scenarios project continued warming during this century.* Most scenarios project that this warming will be outside of the range of historical variations by mid-century (see Section 2).^{1,2,3} Warming will cause more precipitation to fall as rain instead of snow. The resulting decrease in summer water availability can have negative consequences for freshwater wetlands. Increasing water temperatures could prove stressful for several freshwater organisms, including salmon and some amphibians.
- *Heavy rain events are projected to become more intense.* Current research is consistent in projecting an increase in the frequency and intensity of heavy rain events.⁴ Along with temperature-induced increases in winter flood risk, higher flood

^A Throughout this report, the term “Puget Sound” is used to describe the marine waters of Puget Sound and the Strait of Juan de Fuca, extending to its outlet near Neah Bay. The term “Puget Sound region” is used to describe the entire watershed, including all land areas that ultimately drain into the waters of Puget Sound (see “How to Read this Report”).

flows can be harmful to certain fish populations.

- *Most models are consistent in projecting a substantial decline in summer precipitation.* Projected changes in other seasons and for annual precipitation are not consistent among models, and trends are generally much smaller than natural year-to-year variability.² Projected decreases in summer precipitation would exacerbate the temperature-driven decrease in summer streamflow.

Warming Streams, Changing Flow

STREAMFLOW *Projected decreases in summer streamflow, and increases in water temperature, winter streamflow, and winter flood risk (see Section 3) will affect the freshwater ecosystems in the Puget Sound region.*

- *Stream temperatures are projected to increase substantially during the 21st century.* In the Puget Sound region, stream temperatures are projected to increase by +4.0°F to +4.5°F by the 2080s (2070-2099, relative to 1970-1999).^{B,5} As streams warm, suitable temperature conditions for many aquatic species are projected to shift upstream (see Section 3). Smaller shifts may occur along relatively steep streams with high temperature gradients, and larger shifts along relatively flat streams with gentle temperature gradients.^{C,6}
- *Increasing winter streamflow.* Total winter streamflow for Puget Sound basin is projected to increase by +40% to +49% on average by the 2080s (2070-2099, relative to 1970-1999).^{D,E,7}
- *Declining summer streamflow.* Total summer streamflow for Puget Sound basin is projected to decrease by –32% to –40% on average by the 2080s (2070-2099, relative to 1970-1999).^{D,7}
- *Multiple factors combine to drive large increases in flood risk.* The highest river flows are expected to increase by +18% to +55%, on average, for 12 Puget Sound watersheds by the 2080s (2070-2099, relative to 1970-1999), based on a moderate greenhouse gas scenario (see Section 3).^{D,F,7} These increases are compounded by

^B Based on a composite of ten global climate model projections for a moderate (A1B) greenhouse gas scenario.

^C Based on mountain streams in central Idaho and a warming of 3.6°F under a low greenhouse gas scenario.

^D Projected change for ten global climate models, averaged over Puget Sound. Range spans from a low (B1) to a moderate (A1B) greenhouse gas scenario.

^E Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts. These are described in the text as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "moderate" refers to RCP 6.0 or SRES A1B; and "high" refers to RCP 8.5, SRES A2, or SRES A1FI – descriptors are based on cumulative emissions by 2100 for each scenario. See Section 1 for details.

^F Projected changes in streamflow were calculated for 12 Puget Sound watersheds. Listed in clock-wise order, starting at the US-Canadian border, they are: the Nooksack, Samish, Skagit, Stillaguamish, Snohomish, Cedar, Green, Nisqually, Puyallup, Skokomish, Dungeness, and Elwha Rivers.

projected increases in both heavy rainfall events (see Section 2) and sea level affecting the coasts (see Section 4).

STREAMFLOW *Streamflow is projected to change the most in watersheds that are strongly influenced by both rain and snow.* These “mixed-rain-and-snow” basins, currently found on the north Olympic Peninsula and at middle elevations in the Cascades (see Section 3, Figure 3-1), are projected to experience large increases in winter flows and flooding, and more severe declines in summer low flows. Higher-elevation “snow dominant” basins are projected to completely disappear from the Puget Sound region by the 2080s, while many mixed-rain-and-snow watersheds transition into rain-dominated basins (see Section 3).⁷

Salmonids

SALMONIDS *Many Pacific salmonid populations are projected to be harmed by warming stream temperatures, increasing winter peak flows, and decreasing summer low flows.* These changes could affect growth and survival across many life stages and habitats,⁸ particularly for salmonid populations for which juvenile development occurs in freshwater streams (e.g., steelhead, stream-type Chinook salmon, sockeye salmon, and Coho salmon).⁹ Some species and sub-populations may remain relatively unharmed by climate change or may have access to cold water “refugia” within their normal range, affording them some protection from increased water temperatures elsewhere. Population diversity may also provide a buffer for species decline, as populations that are more adapted to warm conditions survive and reproduce in greater numbers. Estuarine influences on Pacific salmon in Puget Sound are discussed in Section 11.

- *Increasing stream temperatures are projected to thermally stress adult salmon and charr.* Some salmonid species and populations that rely on freshwater habitat (e.g., adult spawning migrations and juvenile rearing) during summertime may be affected by increasing summer stream temperatures.¹⁰ Projections indicate that Puget Sound rivers will more frequently exceed thermal tolerances for adult salmon (64°F) and charr (54°F).^{G,11} By the 2080s (2070-2099), the number of river miles with August stream temperatures in excess of these thermal tolerances is projected to increase by 1,016 and 2,826 miles, respectively.^{B,5} One study examining 37 Puget Sound stream monitoring stations found that 12 streams currently experience weekly average stream temperatures in excess of 64°F.^{G,11} By the 2080s (relative to 1970-1999), these 12 streams are projected to experience an increase in the frequency and duration of stream temperatures above the 64°F threshold, ranging from an average annual increase of +0 to +7.5 weeks.^{H,9} Optimal water temperature

^G In this report we use regulatory thresholds listed in EPA (2007),¹¹ which defines 12°C (54°F) and 17.5°C (64°F) as the criteria for protecting adult charr and salmon, respectively. Note that some analyses consider the average monthly temperature for August, which will likely result in an underestimate of the implications for maximum weekly August temperatures.

^H Based on an average of 10 global model projections and a moderate (A1B) greenhouse gas scenario.

ranges for Pacific salmon are species-, life-stage-, and size-dependent, so individual responses to warming streams will vary.

- *Warm stream temperatures can delay or prevent salmon migration.* Previous studies have shown that thermal barriers can block migration, but also that salmon can adapt the pace of their migration to take advantage of times with lower water temperatures.¹² For example, a modeling study of sockeye salmon in the Okanogan River^I found that warmer temperatures routinely lead to delays in upstream migration.¹³
- *Increasing stream temperatures may lead to increased growth in juvenile salmonids in western Washington.* One study projects that by the mid-21st century (relative to a 2010 baseline), juvenile salmonid growth will increase in many western Washington streams as a result of increasing water temperatures. In the Skagit River, Chinook salmon and steelhead are both projected to experience weight increases of more than +15% by 2050 (relative to 2010). The projected increase in juvenile growth was not uniform across all sites evaluated in the study. Growth was projected to decrease in streams that currently experience warm summer water temperatures, and increase in streams with cooler summer water temperatures. For example, some sites in the lower Columbia River Basin and northern California are projected to experience decreases in salmonid growth in response to warming.¹⁴
- *High stream temperatures increase the susceptibility of salmonids to certain diseases.* Increasing stream temperatures can alter the geographic ranges of pathogens and thermally stress aquatic species, reducing their ability to mount an effective immune response against the disease or pathogen.¹⁵ One example is the death of more than 33,000 adult salmon (mainly fall-run Chinook) and steelhead in California's Klamath River in September of 2002 as a result of an outbreak of *Ichthyophthirius multifiliis*^J and columnaris disease^K. The outbreak occurred during a period of warm water temperatures, low flows, and high fish densities, which likely contributed to disease transmission.¹⁶ Additional research is needed to accurately quantify the effect of climate change on the complex interactions among hosts, pathogens, and disease vectors.^{L,17}
- *Increasing water temperatures and altered streamflow regimes could lead to species introductions and alter predator-prey relationships, negatively affecting salmonid*

^I Many characteristics of Puget Sound's climate and climate vulnerabilities are similar to those of the broader Pacific Northwest region. Results for Puget Sound are expected to generally align with those for western Oregon and Washington, and in some instances the greater Pacific Northwest, with potential for some variation at any specific location.

^J Commonly known as "ich", *Ichthyophthirius multifiliis* is a common disease affecting freshwater fish. This is a highly contagious disease, which can spread rapidly through a population. Outbreaks can be especially severe when fish are crowded, for example due to low streamflow.

^K A disease caused by *Flexibacter columnaris* bacterium, which infects both coldwater and warmwater fishes. The disease can result in significant population losses, and outbreaks can be especially severe in regions with warm water temperatures.

^L "Vector" refers to the agent that carries and transfers an infective agent from one organism to another.

populations. Increasing water temperatures and decreasing summer streamflow may favor the spread of warm-adapted invasive fish, which compete with or prey on native salmonid species.^{18,19,20} This could exacerbate the effect of native predators on resident populations. For example, a study based in the Columbia River projected that a 4°F increase in summer water temperature would increase consumption of salmon by northern pikeminnows (*Ptychocheilus oregonensis*, a native predator of juvenile salmon) by +26% to +31%.^{M,21} Additionally, these shifts resulting from climate change could intensify the effect that non-native predators are currently exerting on native populations.¹⁸ The same study in the Columbia River found that a 2°F increase in annual river temperatures near the Bonneville Dam could result in a +4% to +6% increase in per capita consumption of salmonids by walleye and smallmouth bass, both non-native species which prey upon native salmonid species.^M

- *Cold-water streams at high elevations may provide refuge for cold-water fish species, such as bull trout and cutthroat trout.* Although a comparable study has not been conducted in Puget Sound, one study found that cold-water refugia remain abundant in the Northern Rocky Mountains. Specifically, while the length of cold-water habitat in the Northern Rockies (water temperature <51.8 °F) is projected to decline between –33% and –61% (relative to 1970-1999), 68 bull trout stream refuges^N and 1,425 cutthroat trout stream refuges are projected to remain by the 2040s (by the 2080s the projected number of stream refuges drops to 33 and 917 for bull trout and cutthroat trout, respectively).^{O,22,23}
- *Decreasing summertime streamflows are projected to reduce the habitat, health, and survival of Pacific salmon.* For some species, the amount and quality of spawning habitat may decline due to projected reductions in summer flows.^{9,24} Rearing habitat for juveniles may also be reduced, as the number of pools and small side channels that act as thermal shelters decline. Along with higher water temperatures (lower flows are more susceptible to warming), these changes could lead to increased competition for resources and a greater vulnerability to predators.^{9,25} Reduced flows during migration periods may result in timing shifts or reduced migration success.²⁶ In addition, fish densities in streams will increase as flow is reduced, increasing the probability of infection.²⁷

^M This is similar to the warming projected by the 2080s, relative to 1970-1999, for a moderate (A1B) greenhouse gas scenario (see Section 3).

^N Cold-water habitats that will be able to withstand the effects of climate change while still supporting fish populations.

^O Based on >25,000 stream kilometers in the Northern Rocky Mountains and a fish probability of occupancy of >90% determined by species-specific criteria. Summer flow projections are based on 10 global climate models, assessed for the 2040s and 2080s (2030-2059 and 2070-2099 relative to 1970-1999) for the A1B greenhouse gas scenario. Average August stream projections were obtained from the NorWeST stream temperature statistical model, and an ensemble of 10 global climate models and the moderate (A1B) greenhouse gas scenario⁵ for the same future time periods, but compared to 1993-2011.

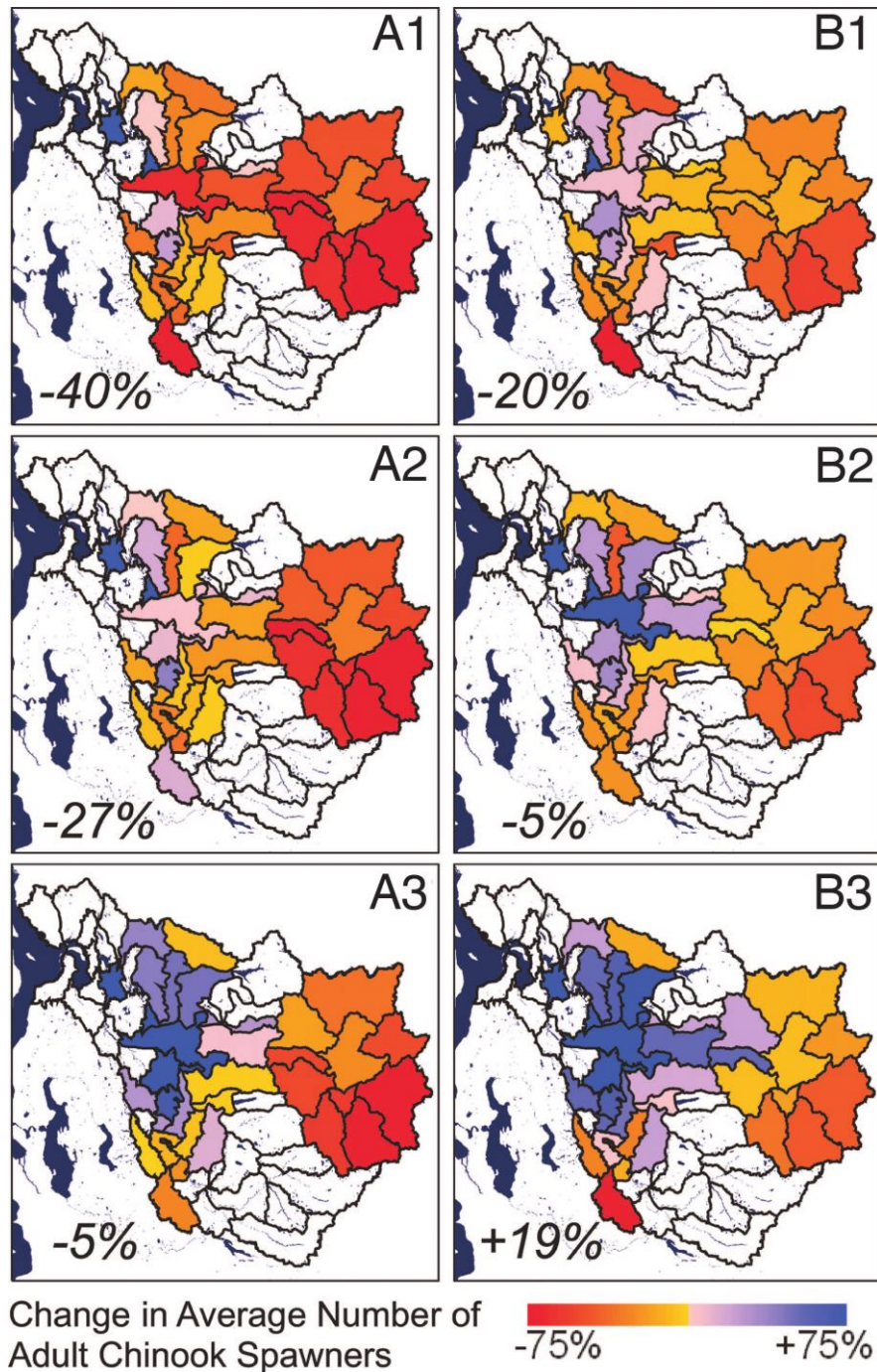


Figure 10-1. Declining salmon populations, mixed benefits of restoration. Projected change in spawning Chinook salmon abundance for the Snohomish River Basin in 2050 relative to 2000. Results are shown for three future land-use scenarios (top: current land-use; middle: moderate restoration; bottom: full restoration) and two climate model projections (left: GFDL R30; right: HadCM2), both based on a high (A2) greenhouse gas scenario. The basin-wide total change in spawning Chinook salmon abundance is in the lower left corner of each map. Figure source: Battin et al. 2007.³⁶

- *Projected shifts towards earlier springtime snowmelt and increasing summer water temperatures may negatively affect the success of smolt^P migration.* In snow-influenced streams the timing of seaward migration in salmon has evolved to align with peak flows in spring. The projected shift to earlier peak flows, along with warming streams, could potentially advance smolt migration timing.⁹ Some salmon have adapted migration timing earlier in the year to align with historical shifts in flow timing. For example, populations of Chinook salmon in the Salmon River Basin in Idaho have been observed to advance their migration timing in response to shifts in environmental cues.^{1,28} While the advance in migration timing may enhance upstream survival, these shifts may have negative consequences for survival in estuary or coastal regions.²⁹
- *Salmonids have advanced migration timing to align with favorable freshwater conditions occurring earlier in the year.* For example, sockeye salmon (*Oncorhynchus nerka*) migration up the Columbia River has shifted 10.3 days earlier from 1949 to 2010. Researchers hypothesize that the 4.7°F rise in mean July water temperatures over that same time period (due to the combined effects of reservoir management, land use change, and warming) have resulted in a genetic selection for earlier migration timing.³⁰
- *Flooding may increase egg and fry mortality, reduce return rates, and reduce the availability of slow-water habitat.* High flows can scour the streambed and remove or crush salmon eggs.^{10,31,32,33} In the Skagit River, egg survival is largely driven by flood magnitudes during incubation, with large floods reducing survival.³⁴ Flooding also temporarily reduces the extent of slow-water habitat in rivers, potentially washing juvenile salmonids downstream prematurely.³⁵ For instance, large floods have been observed to reduce Chinook salmon returns to the Skagit River.^{Q,8} Similarly, flooding is projected to inhibit incubation and migration life stages for steelhead in the western Cascades,^{R,24} and reduce salmon habitat and productivity in the Snohomish River (Figure 10-1).^{S,36}
- *Increasing sediment loads may reduce egg survival.* Sediment loads in rivers reduce oxygen availability to eggs, can physically damage eggs,³⁷ and could mobilize contaminants in some locations.³⁸ Projected increases in winter floods (see Section 3) and winter sediment loads (see Section 5) could result in

^P A juvenile salmon approaching the time of seaward migration. During this developmental stage camouflage bars are lost and physiological shifts enable them to survive the transition from freshwater to saltwater.

^Q Based on annual maximum peak discharge data from the U.S. Geological Survey stream gauge near Concrete, Washington.

^R Steelhead exposure estimated based on comparison of duration, intensity, and timing of temperatures and flows between historical (1970-1999) and projected (2030-2059) conditions. Based on Elsner et al. (2010) climate projections under the A1B greenhouse gas scenario (IPCC 2007).

^S Global climate projections used from GFDL R30 and HADCM3 under the SRES A2 greenhouse gas scenario for 2025 and 2050 compared to 2001. The global climate models were downscaled using the Wiley quantile mapping method to 11 locations near the Snohomish River basin.

increased sediment deposition,^{T,39} potentially reducing egg survival further.

- *Although declining snowpack may lead to increased winter streamflow variability (i.e., more extreme peak and low flows within each season), no study has specifically quantified the change.* Increased winter flow variability is associated with decreased population growth in Chinook salmon.⁴⁰
- *Population diversity within a species may improve salmon resilience.* Individual sub-populations of a species have diverse characteristics and adaptations. The diversity among sub-populations helps stabilize and sustain the overall population size.⁴¹ As climate conditions fluctuate, certain sub-populations will thrive more than others, which often reduces the overall change. For instance, variability in sockeye salmon returns to Bristol Bay would be more than twice as high if there was only a single population, instead of hundreds of diverse sub-populations.^{U,42} This population diversity, known as the “portfolio effect”, is critical for maintaining resilience for current and future climate-related effects.⁴¹

Lake Temperatures

LAKES *Warming of lakes may alter the timing of critical biological events, such as the spring plankton bloom.* The spring plankton bloom, which supports the food web in lakes, occurs after the onset of thermal stratification.^V The onset of stratification has been shown to occur earlier in the season with increasing water temperature. For example, the water temperature in March to June in the upper 33 feet of Lake Washington increased by +2.5°F between 1962 and 2002.⁴³ This warming has resulted in earlier water column stratification and an earlier spring phytoplankton bloom. The onset of stratification in Lake Washington occurred 21 days earlier in 2002 compared to 1962, and the spring phytoplankton bloom advanced 27 days over that period.⁴³

- *The timing of many predator-prey interactions will continue to overlap, while others will be altered.* The timing of peak abundance of *Keratella* (a microscopic “rotifer”) and its phytoplankton food source have both shifted 21 days earlier between 1962 and 1995 in Lake Washington, closely tracking changes in the timing of onset of stratification.⁴³ In contrast, the timing of peak abundance of the water flea *Daphnia pulicaria* has not shifted to match that of its phytoplankton food source, contributing

^T Both the patterns of sediment deposition and the types of sediment that are deposited depend on complex relationships between the local geology, streamflow patterns, and characteristics of the stream channel. Although changes in the water cycle will undoubtedly affect sediment patterns, additional research is needed to understand how sediment deposition may change over time.

^U Interannual variability of sockeye salmon returns calculated for each of the major rivers in Bristol Bay, Alaska, determined from visual counts since 1956 and compared to variability in total returns to Bristol Bay.

^V Stratification is the division of the water column into sections based on water temperature. In Lake Washington, thermal stratification generally occurs from April to November when a warm water layer (upper 33 feet) overlays a cool deep layer. Stratification prevents large vertical mixing so nutrients remain in the warm upper layer, facilitating phytoplankton blooms.

to a recent population decline of *D. pulicaria*.⁴³ *D. pulicaria* is the keystone herbivore in Lake Washington and is an important link in food chain.

Wetland Ecosystems

WETLANDS *The area of freshwater wetlands is projected to decline with increases in air temperature and changes in precipitation.* Freshwater wetlands are threatened by declining snowpack and summer precipitation, and increasing evaporation, all of which contribute to the decline in water availability, especially at high elevations.

- *Montane wetlands are projected to be highly sensitive to climate change.* Snowmelt is an important determinant of montane wetland extent and water level. The extent of montane wetlands is projected to decline due to both the reduction in winter snowpack and earlier spring melt. As a result, the frequency, magnitude, and duration of wetland drying in the summer are projected to increase. These changes are projected to be greatest for ponds that dry late in the year or only in years with low water availability (i.e., intermediate hydroperiod ponds). However, there is limited research on the distribution of montane wetlands or their physical, chemical, and biological dynamics, making future projections difficult and uncertain.⁴⁴
- *Sea level rise is projected to change the area of freshwater wetlands located near the coast* (see Section 11). Sea level rise is projected to alter coastal inland freshwater marsh between -29% and 0%, and freshwater swamp between -33% and +3% by 2100 (relative to 1980-1999).^{W,45}

WETLANDS *Amphibians are threatened by the loss of wetland habitat due to projected shifts in temperature and precipitation regimes* (Figure 10-2). Wetland amphibians are expected to be highly sensitive to climate change,^{X,46} but the species- and population-specific influence of climate change is uncertain and more research is needed to improve future projections.

- *Increased wetland temperatures may increase mortality rates.* Amphibians are cold-blooded, and thus particularly sensitive to temperature. Effects of increased temperature and amphibian desiccation will vary among species and populations. Some populations may be able to adapt to temperature changes, while others will become too warm or too dry, resulting in increased mortality, reduced growth, or other negative effects.^{44,47,48}
- *Many amphibian species are projected to experience geographical shifts in latitude*

^W Using a projected 27 in. (69 cm, about the middle of the range projected for 2100) increase in global sea level by 2100 relative to 1980-1999 under the A1B maximum greenhouse gas scenario (IPCC 2001), the Sea Level Affecting Marshes Model (SLAMM 5.0) was applied to 10 sites within Puget Sound and one site along the Oregon and Washington coast.

^X Projected climate data for 2001- 2100 for 10 global climate models from CMIP3 under the B2 SRES and A2 greenhouse gas scenarios compared to data from 1961-1990 for 50 x 50 km grids of the western hemisphere.

and elevation ranges. These range shifts may result in range expansions or range contractions, depending on species' dispersal capacities and migration barriers.⁴⁶

- *Reductions in water permanence, alterations in seasonal water levels, and decreases in water availability are projected to negatively affect wetland amphibians due to habitat loss and increased desiccation stress.* More frequent drying of wetlands is projected to harm amphibians and invertebrates that require multiple years of permanent water to complete metamorphosis.^{44,49} Additionally, climate change may cause mismatches of the timing of peak predator and prey abundances, altering food web dynamics in ways that may negatively affect amphibians.⁴⁴

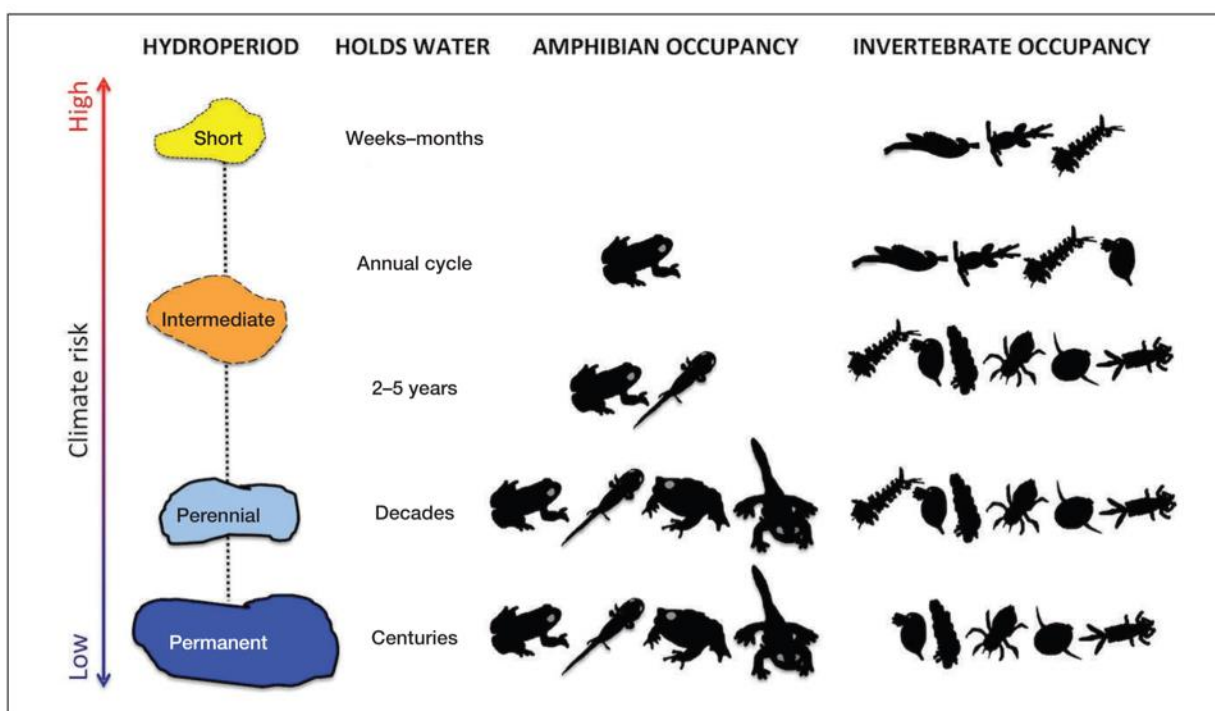


Figure 10-2. Ephemeral wetlands are at much higher risk than permanent freshwater wetlands.

The above figure shows the species occupancy across a range of wetland types, each with a different likelihood of experiencing a temporary dry period (i.e., “hydroperiod”). This figure does not address the risk to organisms associated with shifts of hydroperiods (e.g., amphibians that require several years of permanent water to complete metamorphosis will likely experience increased larval mortality as a result of more frequent pond drying events). Organism icons represent dominant species in each wetland pond type, including (from left to right): Cascades frog, long-toed salamander, western toad, Northwestern salamander, mosquito larva, cladoceran, caddisfly larva, dragonfly larva, beetle, and mayfly larva. The short and intermediate hydroperiods also include icons for fairy shrimp and copepods. *Figure source: Ryan et al. 2014.⁴⁴ Reproduced with permission.*

^Y Republished with permission of Ecological Society of America, from [Amphibians in the climate vise: loss and restoration of resilience of montane wetland ecosystems in the western US, Ryan, M.E., Palen, W.J., Adams, M.J., Rochefort, R.M., volume 12, issue 4, 2014]; permission conveyed through Copyright Clearance Center, Inc.

Climate Risk Reduction Efforts

CLIMATE RISK REDUCTION Various communities, government agencies, and organizations are planning for the effects of climate change on freshwater species and ecosystems in the Puget Sound region. Examples include:

- *The North Cascadia Adaptation Partnership (NCAP) is a science-management collaboration focused on climate change adaptation strategies in U.S. Forests and National Parks,⁵⁰ including the Mount Baker-Snoqualmie National Forest, Okanogan-Wenatchee National Forest, Mount Rainier National Park, and North Cascades Complex National Park. Fish and fish habitat are one of the four focus sectors of NCAP for which adaptation strategies and tactics were developed based on three impact pathways. These impact pathways include increasing stream peak flows, decreasing low flows, and warming stream temperatures. For instance, adaptation strategies for mitigating the effects of increasing peak flows include restoring spawning habitat and removing migration barriers in order to enhance habitat resilience. <http://www.northcascadia.org/>*
- *The Swinomish Climate Change Initiative was a two-year project to identify vulnerability of the Swinomish Indian Tribal Community to climate change effects and prioritize planning areas in order to create an action plan. The Initiative was based on the 2007 Proclamation of the Swinomish Indian Senate to respond to climate change challenges. An Impact Assessment Technical Report⁵¹ and a Climate Adaptation Action Plan⁵² were published from the Initiative. The decline and degradation of upland wetland habitat, water quality, and streamflow were identified as medium-high freshwater risks. Adaptation strategies included in-stream and riparian enhancement. http://www.swinomish-nsn.gov/climate_change/climate_main.html*
- *The Washington State Integrative Climate Change Response Strategy⁵³ developed a framework to aid decision-makers in state, tribal, and local governments; public and private organizations; and businesses prepare for climate-related effects on natural resources and economy. Climate change effects on freshwater streams included warming temperatures and lower summer streamflows. Adaptation strategies included managing freshwater withdrawals to maintain and restore streamflows and lake levels, restoring riparian zones, reconnecting rivers and floodplains, and taking early action to control non-native invasive species.*
- *The Forest Service Aquatic Guidebook (forthcoming) builds on existing approaches to adaptation planning and surveys of U.S. Forest Service aquatic habitat managers and scientists in the PNW to develop a resource-specific guide for: 1) synthesizing information about climate effects to assess the sensitivity of aquatic habitats to climate change, 2) evaluating the resource's climate change-related adaptive capacity, 3) identifying priority planning areas, goals and actions related to preparing for climate change, and 4) developing measures of resilience to track progress and update plans over time.*

Additional resources for evaluating and addressing the effects of climate change on freshwater ecosystems in Puget Sound.

The following tools and resources are suggested in addition to the reports and papers cited in this document.

- **Climate Change Sensitivity Database.** Produced by the University of Washington and partners, this database summarizes the results of an assessment of the inherent climate-change sensitivities of species and habitats of concern throughout the Pacific Northwest.
<http://climatechangesensitivity.org/>
- **Climate Shield.** Geospatial data on potential cold-water refuge streams for native Cutthroat Trout and Bull Trout in the Pacific Northwest.
<http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html>
- **NorWeST.** Historical and projected future stream temperature data and geospatial map outputs from a regional stream temperature model for the Pacific Northwest and other parts of the Western U.S.
<http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html>
- **Western U.S. Streamflow Metrics.** Modeled flow metrics for streams in the Western U.S. for historical and future climate change scenarios. Data available for the Pacific Northwest, which includes the Puget Sound catchment.
http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml
- **USGS Water Watch.** Map of current streamflow compared to historical flow for Washington.
<http://waterwatch.usgs.gov/?m=real&r=wa>

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