PREPARING WASHINGTON DEPARTMENT OF FISH AND WILDLIFE FOR A CHANGING CLIMATE:

Assessing Risks and Opportunities for Action

Washington Department of FISH and WILDLIFE

CLIMATE IMPACTS GROUP
UNIVERSITY of WASHINGTON
College of the Environment

A collaboration of the Washington Department of Fish and Wildlife and the University of Washington Climate Impacts Group

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Table of Contents

INTRODUCTION

The Washington Department of Fish and Wildlife (WDFW) recognizes that climate change poses challenges to fulfilling its mission to "preserve, protect, and perpetuate fish, wildlife, and ecosystems while providing sustainable fish and wildlife recreational and commercial opportunities." The agency is already experiencing climate-related impacts, which will be exacerbated as the pace of climate change accelerates over the coming decades.

Concerns regarding the projected impacts of climate change to the agency motivated the adoption of Policy #5408: Addressing the Risks of Climate Change. The purpose of this policy is to provide guidance for managing risks to WDFW investments due to current and future impacts of climate change. The policy led to the establishment of the Climate Action Team, which recently held a series of workshops which resulted in a climate risk assessment for each program[1] within the agency. This report furthers that work by including a discussion of how climate change might affect species and ecosystems in Washington (Section 1) and summarizing the overarching vulnerabilities to agency operations and investments identified in the workshops (Section 2). As a next step towards building climate resilience across the agency it also summarizes potential opportunities for action (Section 3) that were identified by the Climate Action Team.

[1] Habitat, Fish, Capital & Asset Management Program, and Wildlife

How to Read this Report

This report is written to serve as a reference for agency staff and individuals interested in understanding:

1. State of the science on climate and the implications of those changes on Washington ecosystems and natural resources of relevance to WDFW,
2. Four climate-related vulnerabilities that are common across the Fish Program, Wildlife Program, Habitat Program and the CAMP program.
3. Potential opportunities for action to address these climate-related vulnerabilities.

The above topics comprise the three main report sections. Written to serve as an easy-to-read resource, each section employs a nested hierarchy of bolded text, italicized text, and bullet points to facilitate information accessibility in a skimmable format. Bold text presents higher-level overarching statements, italicized text provides key words or phrases covered in each bullet, and bullet points provide a specific example or concept that is representative of the bolded statement (Figure 1). For example, if a reader was solely interested in the high-level takeaways from each section, they should center their skimming on the bolded statements within each subsection.

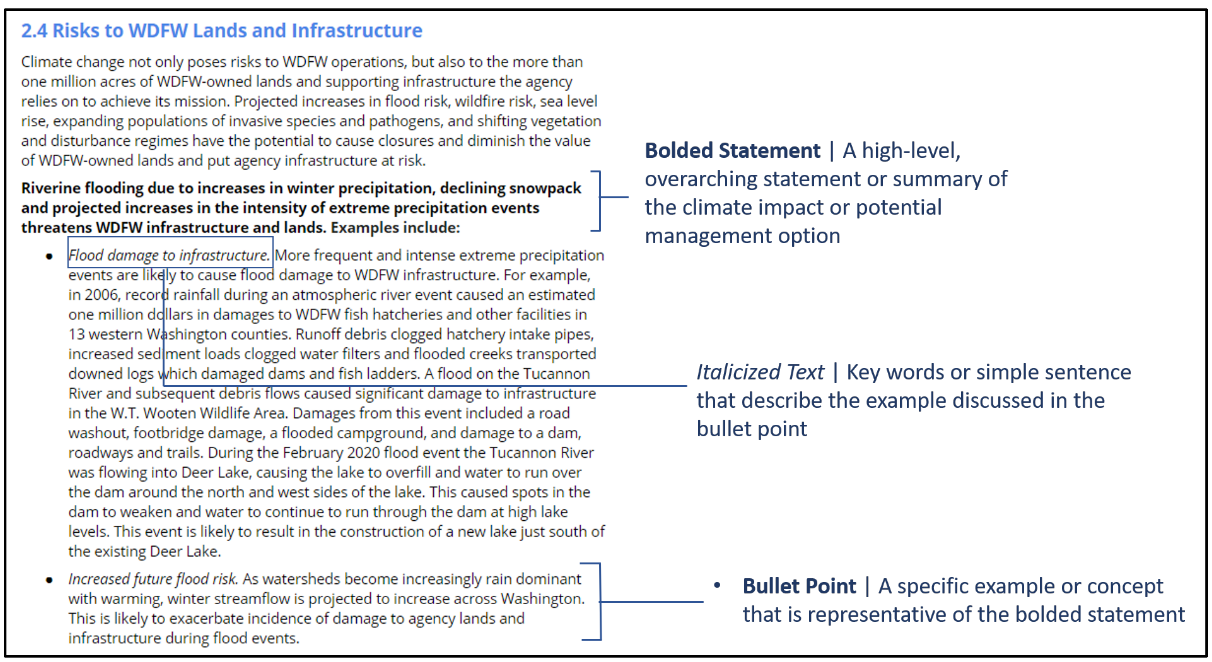


Figure 1. A schematic illustrating the organizational structure of each report section.

SECTION 1 - ECOSYSTEM AND RESOURCE IMPACTS

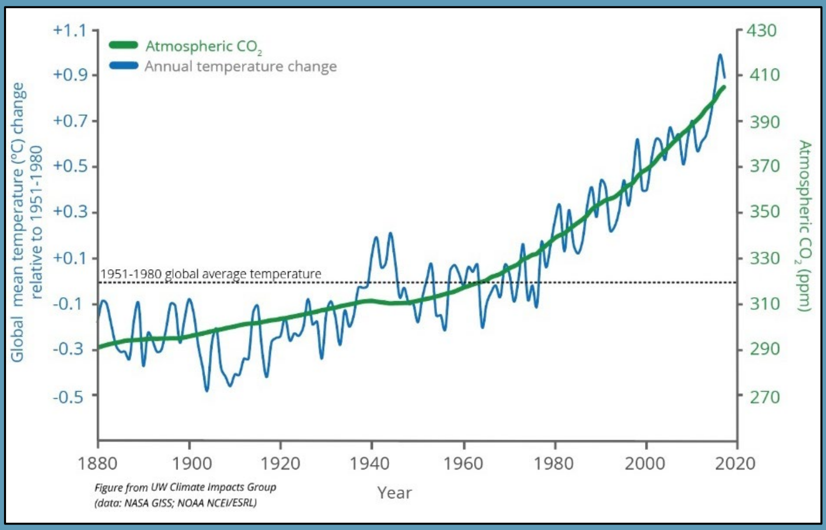
This section provides a summary of key observed and projected changes in climate (Section 1.1) and the impacts of those changes on Washington ecosystems and natural resources of relevance to WDFW (Sections 1.2 - 1.6). Bold statements within each subsection highlight key drivers and impacts, while the bullets below each statement provide additional detail through examples. Where possible, specific examples of impacts on Priority Habitats and Species (PHS) and game species are provided.

Box 1. Observed and Projected Greenhouse Gas Emissions

The world has already warmed as a result of human activity. Since the industrial revolution, atmospheric concentrations of CO_2 and global temperatures have increased significantly as a result of human activities. Atmospheric CO2 increased from about 290 ppm in 1880 to over 405 ppm today. Over the same period, global temperatures increased approximately 1.8°F.

Human-caused warming resulting from continuing emissions of greenhouse gases is adding around 0.4°F to global average temperatures every decade. If this continues, global average warming is likely to reach 2.7°F between 2030 and 2052, which is within the lifetime of most people on Earth.

To make projections of future climate, scientists use ‘what if ’ scenarios of plausible future greenhouse gas emissions to drive computer model simulations of the earth’s climate. Greenhouse gas (GHG) scenarios affect how much and how fast the earth warms -- higher GHG concentrations will cause more rapid warming than lower GHG scenarios.



Box 1 Figure. Since the industrial revolution, atmospheric concentrations of CO_2 and global temperatures have increased significantly as a result of human activities. Atmospheric CO_2 increased from about 290 ppm in 1880 to over 405 ppm today, as shown by the green line. Over the same period, global temperatures increased approximately 1°C (1.8°F) – the blue line shows global annual temperature compared to the average global temperature for the period 1951-1980. Data from: NASA (data.giss.nasa.gov), NOAA (www.ncei.noaa.gov/access & www.esrl.noaa.gov/gmd/ccgg/trends).

Reproduced from:

Snover, A.K., C.L. Raymond, H.A. Roop, H. Morgan, 2019. No Time to Waste. The Intergovernmental Panel on Climate Change’s Special Report on Global Warming of 1.5°C and Implications for Washington State. Briefing paper prepared by the Climate Impacts Group, University of Washington, Seattle.

1.1 Physical Drivers of Impacts on Ecosystems and Natural Resources

Air and water temperatures are warming throughout the Pacific Northwest. The magnitude of recent and projected future warming varies across different parts of our region and across seasons.

- *Warming surface air temperature*. Over the past century, average annual temperature in the Pacific Northwest has increased by about 1.3°F. All GHG scenarios project continued warming during this century, and most scenarios project future warming will be outside the range of historical variation by mid-century.[2] Across the Pacific Northwest, temperatures are projected to increase by 5°F under a low GHG scenario and 8.5°F under a high GHG scenario by late century (2071-2100). The magnitude of projected future warming varies by region and by time of year. Warming is generally expected to be slightly higher east of the Cascades compared to west of the crest, and greatest during the summer months. The amount of warming will also vary with land cover and topography.[3]
- *Increasing water temperature in streams and lakes.* Stream temperatures are projected to increase in response to warming air temperatures and decreases in summer streamflow. By the 2080's under a higher GHG scenario, stream temperatures in eastern Washington show higher warming at lower elevations (5°F increase below 500m and 4.1°F increase between 500-1000m) compared to higher elevations (2.7°F increase above 1000m), on average. In western Washington, stream temperatures are projected to warm an average of about 3°F by 2080 across all elevations.[4] The actual magnitude of future warming will be strongly influenced by local-scale factors.
- *Increasing ocean temperature and prevalence of marine heat waves.* Globally, sea surface temperatures have warmed by about 1.3°F per century from 1900 to 2016.[5] Under higher GHG scenarios, a global increase in average sea surface temperature of 4.9°F is projected by 2100.[5] By the end of the century, under a high GHG scenario, marine heatwaves (occasional short-term influxes of warm surface water into a cold-water region like the North Pacific) could occur 50 times more frequently globally and be ten times more intense than they were historically (1850-1900).[6]

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[2] Mote, Philip W, & Salathé, Eric P. (2010). Future climate in the Pacific Northwest. Climatic Change, 102(1), 29-50.

[3] USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp.

[4] Isaak, D., S. Wenger, E. Peterson, J. Ver Hoef, D. Nagel, C. Luce, S. Hostetler, J. Dunham, B. Roper, S. Wollrab, G. Chandler, D. Horan, S. Parkes-Payne. 2017. The NorWeST summer stream temperature model and scenarios for the western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. Water Resources Research, 53: 9181-9205.

[5] USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp.

[6] IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)].

The form, amount and seasonality of precipitation is changing, but with greater variability compared to warming air and water temperatures. Precipitation patterns are projected to increasingly depart from historical patterns in the future under higher GHG scenarios.

- *Continued variability in annual precipitation.* Changes in precipitation are generally projected to fall within Washington's high range of historical year-to-year variability, with some years that are abnormally wet, and others that are abnormally dry. For the foreseeable future, Washington will continue to experience years and decades with conditions that temporarily mask or amplify the projected changes in water resources, even as long-term trends continue.[2]
- *Seasonal changes in precipitation.* Though no significant observed trends in annual precipitation are apparent in our region due to high year-to-year variability, precipitation is projected to depart from historical norms in some seasons. Winter precipitation is projected to increase by up to 10%, with larger increases expected in eastern Washington compared to western Washington. Conversely, summer precipitation is projected to decrease by 10 to 15% statewide.[3]
- *Increasing frequency and severity of dry summers.* Projected increases in summer temperature and decreases in summer precipitation will result in larger climatic water deficits (the annual evaporative demand that exceeds available water) in the coming decades. Years with widespread dry conditions are projected to become 3 times more common by 2050, however, year-to-year and decadal patterns of climate variability will continue into the future and some years will be wetter than average.[7] Summer droughts will continue to end every year in our region with the onset of fall rains (i.e., multi-year droughts that occur in more arid climates are not projected for the Pacific Northwest).[3]
- *More rain, less snow.* Though many Washington watersheds have historically received a significant portion of their winter precipitation as snow, rain will become the dominant form of precipitation in most watersheds by the end of the 21st century. The one exception to this is the North Cascades, where snow accumulation is projected to predominate at higher elevations through the end of the century.[8]
- *Increasing frequency of atmospheric rivers and extreme precipitation events.* Atmospheric rivers bring heavy snow and rain to the Pacific Northwest, often causing widespread flooding and landslides. The frequency of days with atmospheric river conditions is projected to increase by over 275% by the end

[7] https://statesatrisk.org/washington/all
[8] Salathé, Eric P, Leung, L Ruby, Qian, Yun, & Zhang, Yongxin. (2010). Regional climate model projections for the State of Washington. Climatic Change, 102(1-2), 51-75.

of the century. During days with atmospheric river conditions, precipitation is projected to increase by 15% to 39%.[9]

Regional warming is causing declines in winter snowpack in many watersheds and accelerating glacial recession across the region. Future projections show increasing rates of loss as the climate warms.

- *Declining snowpack.* Pacific Northwest snowpack is strongly influenced by annual and interdecadal variability of circulation patterns over the north Pacific Ocean as well as long-term trends driven by anthropogenic global warming. With all sources of variability taken into account, spring snowpack in the Cascade Range has declined by 48% from 1950 to 1997. Most of that decline was driven by regional climatic variability, however, anthropogenic global warming has been linked to a relatively steady annual loss rate of 2%. The loss due to the warming trend amounts to a 16% decline between 1930 and 2007. By mid-century, warming is expected to reduce winter snowpack over much of the Cascades and Olympics to a degree that exceeds historical variability except at very high elevation sites that will remain sufficiently cold for snow to accumulate.[10] Average spring snowpack (April 1 snow water equivalent) in Washington is projected to decline by 56% (10-model average for a low GHG scenario) to 70% (10-model average for a high GHG scenario) by the 2080s (2070-2099, relative to 1916-2006).[11] The largest changes are projected for mid-elevation basins that historically have seen significant snow accumulation but have moderate winter temperatures.[10]
- *Receding glaciers.* Most Northwest glaciers are in decline. For example, glacier area in the North Cascades declined by 56% from 1900 to 2009.[11] One study found that only 3 of the 12 North Cascades glaciers with annual measurements are expected to persist in the face of projected warming.[12]

Projected future warming is expected to reduce snowpack, affecting the timing and amount of snowmelt, and altering hydrologic regimes across the region. Changes in the amount and seasonality of precipitation are expected to exacerbate these hydrologic impacts.

- *Shifts in spring peak flow.* The spring peak in streamflow is projected to occur earlier in mid-elevation basins due to earlier snowmelt. For example, peak streamflow is projected to occur four to nine weeks earlier by the 2080s (2070-2099, relative to 1917-2006) in four Puget Sound watersheds (Sultan, Cedar,

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[9] Warner, M.D., et al., 2015. Changes in winter atmospheric rivers along the North American west coast in CMIP climate models *J. Hydrometeeor,* 16, 118-128: doi: http://dx.doi.org/10.1175/JHMHDH14H0080.1

[10] Vano, J. A., Nijssen, B., and Lettenmaier, D. P. (2015), Seasonal hydrologic responses to climate change in the Pacific Northwest, *Water Resour. Res.*, 51, 1959– 1976

[11] Roop, H.A., G.S. Mauger, H. Morgan, A.K. Snover, and M. Krosby, 2020. "Shifting Snowlines and Shorelines: The Intergovernmental Panel on Climate Change's Special Report on the Ocean and Cryosphere and Implications for Washington State." Briefing paper prepared by the Climate Impacts Group, University of Washington, Seattle. DOI: doi.org/10.6069/KTVN-WY66. Updated 01/2020.

[12] Pelto, M.S. 2011. Methods for assessing and forecasting the survival of North Cascade, Washington glaciers, Quaternary International, Volume 235, Issues 1–2 (70-76)

Green, Tolt) and the Yakima basin. Most of the projected changes in the timing of peak streamflow are the result of increasing temperatures that shift precipitation from snow to rain.[13]

- *Increasing annual streamflow.* Total annual streamflow is driven primarily by total annual precipitation. Annual streamflow is projected to increase by 4.0% to 6.2% on average for Washington State by the 2080s (2070-2099, relative to 1970-1999).[13] These changes are likely to be dwarfed by natural year-to-year variability in streamflow totals through the end of the century.[13]
- *Reduced summer streamflow.* Low summer streamflow conditions are projected to become more severe in about 80% of watersheds across Washington State due primarily to reduced snowpack (the effects of other influences like summer precipitation, evapotranspiration, and groundwater have less of an effect on summer streamflow, though they can be locally important). Rain-dominant and mixed rain and snow basins show the greatest and most consistent decreases in minimum flows, while changes for snow-dominated basins are smaller. Changes are more pronounced west of the Cascade Range mountains because there is “less water to lose” east of the Cascades – historical conditions are already very arid in interior Washington. Statewide, summer (Apr-Sep) streamflow is projected to decrease by 34% (10-model average based on a lower GHG scenario) to 44% (10-model average based on a higher GHG scenario) on average by the 2080s (2070-2099, relative to 1970-1999).[13]
- *Increasing winter streamflow.* Winter streamflow is projected to increase by 25% to 34% on average for Washington State by the 2080s (2070-2099, relative to 1970-1999). Projected changes range from modest decreases to large increases in winter flows depending on location and the relative influence of rain and snowmelt on streamflow in the watershed. The highest increases in river flows are generally expected to occur in rain-dominated and transitional (i.e., mixed rain and snow) watersheds. Some snow-dominant watersheds will see flood increases, while others will experience decreases depending mainly on elevation (i.e., streams in higher elevation basins that will remain cold in the future and retain their winter snowpack will not experience increases in winter streamflow).[13]

Rising sea level will increase coastal flooding, inundation, and bluff erosion across coastal Washington.

- *Sea level rise (SLR).* Globally, between 1902 and 2015, mean sea level rose 6.3 inches.[6] The likely amount of projected relative sea level rise by 2050 and 2100 is shown in the below table for three locations along Washington’s coastline.

[13] Elsner, Marketa M, Cuo, Lan, Voisin, Nathalie, Deems, Jeffrey S, Hamlet, Alan F, Vano, Julie A, . . . Lettenmaier, Dennis P. (2010). Implications of 21st century climate change for the hydrology of Washington State. Climatic Change, 102(1-2), 225-260.

The sea level rise projections in this table represent the 17-83% probability range, often referred to as the 'likely range'.[14]

- *Variability in sea level rise*. Vertical land movement (i.e., uplift or subsidence) can exacerbate or mediate SLR, creating variability in the magnitude of projected change along the coast.[14] Vertical land movement explains the majority of the variability in the projected SLR magnitudes for the three different Washington locations shown in the table above.

  Table 1. The likely amount of relative sea level rise by 2050 and 2100 for three locations along Washington's coastline for low (RCP 4.5) and high (RCP 8.5) greenhouse gas scenarios (relative to 1991–2009 sea level). The sea level rise projections represent the 17-83% probability range, known as the 'likely range.' For example, the likely range of sea level rise in Aberdeen by 2050 under a high greenhouse gas scenario is 0.2-0.7 feet. This means there is an 83% chance that sea level will increase 0.2 feet or more and a 17% chance that sea level will increase 0.7 feet or more by 2050. Projections are available for 171 locations in coastal Washington. Miller et al., 2018 (http://bit.ly/waslr).

Location	Greenhouse Gas Scenario	Relative Projected Sea Level Rise	
		2050	2100
Tacoma	Low	0.6–1.1 ft	1.5–2.7 ft
	High	0.7–1.2 ft	1.9–3.3 ft
Aberdeen	Low	0.2–0.7 ft	0.6–1.9 ft
	High	0.2–0.7 ft	0.9–2.4 ft
Port Angeles	Low	0.3–0.7 ft	0.8–2.0 ft
	High	0.3–0.8 ft	1.2–2.5 ft

- *Increasing frequency of coastal flooding.* Though future storm surge is not projected to get bigger, sea level rise will exacerbate coastal river flooding by allowing storm surges to travel further inland. Higher sea level can also increase the extent and depth of flooding by making it harder for flood waters in rivers and streams to drain to the ocean or Puget Sound. Initial research suggests that the amount of area flooded in the Skagit valley would increase by up to 74% by

[14] Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E. 2018. Projected Sea Level Rise for Washington State – A 2018 Assess-ment. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geologi-cal Survey. Prepared for the Washington Coastal Resilience Project.

the 2080s when accounting for the combined effects of sea level rise and larger floods.[15]

Increasing atmospheric concentrations of carbon dioxide result in increased formation of carbonic acid in oceans, driving ocean acidification. Future emissions of carbon dioxide from continued burning of fossil fuels will continue to accelerate this trend.

- *Increasing ocean acidification.* Over the last 250 years, the upper-ocean has experienced a 26% increase in acidity (from a pH of about 8.2 to 8.1; note pH is on a log10 scale), a rate of change that is 10 times faster than any time in the past 300 million years. Future projections of ocean acidification are for a nearly 170% decrease (to a pH of 7.75) relative to pre-industrial levels by the end of the century under a high GHG scenario. [16]
- *Local variation in ocean acidification.* Ocean acidity varies locally and seasonally based on other factors such as the amount of organic carbon (which increases acidity during decomposition) introduced to surface waters from freshwater inputs (e.g., the Columbia River) and from the frequency and intensity of upwelling on the outer coast (which brings deeper, more acidic waters to the surface.[17]
- *Reduced availability of carbonate ions.* Increased ocean acidity is reducing the availability of carbonate ions (an essential component of the shells of shellfish species when combined with calcium) in seawater.

Increasing air temperatures and drier summer conditions are resulting in larger and more frequent wildfires. Future projections of additional warming and drying will increase wildfire impacts in many areas.

- *Increasing fire frequency and area.* Increasing summer drought conditions driven by warmer temperatures, lower summer precipitation and earlier spring snowmelt are creating conditions favorable for wildfire. Across the western US, large fires are almost 4 times more common now than they were in the 1970s, burning seven times more acreage in an average year.[18] Increasing aridity of the western US is partially driving this trend in wildfire activity, with about 55% of the observed increase in fuel aridity since 1979 attributed to climate change.[19]

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[15] Hamman, J., Hamlet, A.F., Lee, S.Y., Fuller, R., and Grossman, E.F. 2016. Combined Effects of Projected Sea Level Rise, Storm Surge, and Peak River Flows on Water Levels in the Skagit River Floodplain. *Northwest Science* 90(1):57-78.

[16] IGBP, IOC, SCOR 2013. Ocean Acidification Summary for Policymakers – Third Symposium on the Ocean in a High-CO2 World. International Geosphere-Biosphere Programme, Stockholm, Sweden.

[17] Kapsenberg, Lydia, and Tyler Cyronak. "Ocean acidification refugia in variable environments." Global change biology 25.10 (2019): 3201-3214.

[18] Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. Warming and earlier spring increase western US forest wildfire activity. Science 313, 940–943 (2006).

[19] Abatzoglou, J and AP Williams 2016. Impact of anthropogenic climate change on wildfire across western US forests. PNAS. 113 (42).

- *Fire risk variability.* Future changes in fire risk are expected to vary across the state. In dry forested ecosystems, area burned by wildfire is projected to increase by a factor of four by the 2040s (relative to 1980-2006)[20], and wildfires are expected to burn with greater severity due to the effects of fire exclusion and associated fuel accumulation. In moist conifer forests west of the Cascade Crest, where historically fire return intervals have been long, increases in wildfire risk are also expected but less certain because the relationship between wildfire and climate is weaker. Wildfire risk will remain low relative to dry fire-adapted forests, yet severity will be high when fires do burn as is characteristic of these systems.[21]

1.2 Impacts on Marine and Near-Shore Habitats

Rising sea surface temperatures and marine heatwaves are driving changes in the survival, abundance and distribution of native fish and marine invertebrates as well as the prevalence of invasive species and disease.

- *Altered upwelling and marine food webs.* Warm surface waters are less nutrient rich than cold upwelling waters. A large influx of warm water (referred to as a marine heatwave) into the cold water upwelling system that occurs along the north Pacific coast adversely affects phytoplankton and zooplankton throughout the region. Plankton form the base of the marine food web, so a reduction in plankton biomass cascades up the food web and results in poor survival and recruitment of higher-level consumers like salmonids and other game fish species as well as marine mammals and seabirds, many of which appear on the PHS list.[22]
- *More frequent marine heat waves.* In years such as 2015, when a large area of warm surface water appeared off the north Pacific coast, widespread declines in fish, marine mammals and seabirds occurred. This event was estimated to have killed 62,000 common murres (*Uria aalge*) and at least 22 murre colonies completely failed to produce offspring over several breeding seasons afterwards.[23]
- *Increasing spread of invasive species.* Invasive marine species like the European green crab (*Carcinus maenas*) typically tolerate a broader range of climatic conditions. Warming oceans may allow invasive species to expand and gain additional competitive advantages over native species.[24]

[20] Littell, JS. et al. 2010. Climatic Change. Forest ecosystems, disturbance, and climatic change in Washington State, USA. 102:129-158.
[21] Halofsky, JE, DL Peterson and BJ Harvey. 2020. Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. Fire Ecology 16:4.
[22] Xiu, P., Chai, F., Curchitser, E.N. et al. Future changes in coastal upwelling ecosystems with global warming: The case of the California Current System. Sci Rep 8, 2866 (2018).
[23] Piatt JF, Parrish JK, Renner HM, Schoen SK, Jones TT, Arimitsu ML, et al. (2020) Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016. PLoS ONE 15(1).
[24] Sorte, C.J.B., Williams, S.L. and Zerebecki, R.A. (2010), Ocean warming increases threat of invasive species in a marine fouling community. Ecology, 91: 2198-2204.

- *Increased prevalence of disease*. When fish and shellfish pathogens and parasites gain a relative advantage over their hosts by warming ocean conditions and other stressors (e.g., ocean acidification, hypoxia), climate change may increase the prevalence of disease.[25]
- *Increasing frequency of harmful algal blooms*. Warmer oceans are expected to make harmful algal blooms (HABs) more likely to occur. By the end of the century under a moderate GHG scenario, warmer waters in the Puget Sound are expected to lead to an average of 13 more days per year with favorable conditions for HABs. The season suitable for HABs is projected to begin up to two months earlier and last up to one month longer than in the past (1970–1999). Warm ocean conditions in the North Pacific (e.g., warm phases of the Pacific Decadal Oscillation, El Niño events, and marine heatwaves) have been strongly linked to elevated domoic acid levels in shellfish.[26]

Warming oceans increase the respiration of marine bacteria, reducing oxygen availability. Hypoxia (low oxygen) can lead to die-offs of fish and marine invertebrates, particularly in shallow, constricted waters with less exchange to the open ocean.

- *Increasing frequency of hypoxia-induced disease*. Hypoxia has been identified as a key driver of sea star wasting syndrome. Since 2013, warming oceans have been linked to an epidemic of sea star wasting disease that resulted in 80%-100% mortality of sea star populations along 3000 km of coast from California to Alaska.[27]
- *Changes in marine community composition*. Hypoxia driven die-offs can alter marine communities. For example, sea stars are key predators of sea urchins, which feed on kelp. The loss of sea stars leads to expansion of sea urchin populations and, in turn, declines in kelp forests. Kelp is a key structural element in nearshore habitats; loss of kelp forests has been tied to local collapses in the diversity and abundance of fish, seabirds and marine mammals.[28]

Oceans are acidifying as atmospheric carbon dioxide increases. This reduces the availability of calcium carbonate in marine waters, impairing the growth, survival and reproduction of many near-shore calcifying shellfish species. Virtually every major biological function has been shown to respond to seawater

[25] Burge CA, Eakin CM, Friedman CS, Froelich B, Hershberger PK, Hofmann EE, Petes LE, Prager KC, Weil E, Willis BL, Ford SE, and Harvell CD. Climate Change Influences on Marine Infectious Diseases: Implications for Management and Society. Annual Review of Marine Science 2014 6:1, 249-277

[26] Moore, S.K., Mantua, N.J., Salathé, E.P. 2011. Past trends and future scenarios for environmental conditions favoring the accumulation of paralytic shellfish toxins in Puget Sound shellfish. *Harmful Algae* 10:521-529.

[27] Harvell, C. D., et al. "Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (Pycnopodia helianthoides)." Science advances 5.1 (2019): eaau7042.

[28] Rogers-Bennett, L., and C. A. Catton. "Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens." Scientific reports 9.1 (2019): 1-9.

acidification, including rates of photosynthesis, respiration, growth, calcification, reproduction and recruitment.

- *Shellfish declines due to ocean acidification.* Marine invertebrates that form calcium carbonate shells (including all recreationally and commercially harvested clams, mussels, oysters, shrimp and crabs) are projected to experience population declines. Larval life stages are particularly vulnerable.[29]
- *Altered marine food webs.* Zooplankton and phytoplankton larval development and survival are also sensitive to ocean acidification. Future acidification could drive widespread declines in plankton, which form the base of the marine food web, resulting in cascading effects to higher-level consumers like fish, shellfish, seabirds and marine mammals. Pteropods and copepods - zooplankton that are an important food resource for young salmon, seabirds and whales - are experiencing ocean acidification-related declines.[30]
- *Declines in corals.* Corals are also sensitive to ocean acidification; their decline results in loss of coral habitats that support many species including rockfish and sharks. [31]

Continued sea level rise along much of Washington's coast will increase the frequency or magnitude of extreme coastal water level events. Although the magnitude of storm surges are not expected to increase, higher sea level means that the same storm events would result in higher water levels and potentially more damage. This is increasing the risk of coastal flooding and erosion, which negatively impact near-short habitat.

- *Loss of coastal wetlands.* Globally, nearly half of coastal wetlands have been destroyed over the past 100 years due to land use changes, sea level rise and extreme weather events. Sea level rise will increase rates of saltwater inundation in coastal wetlands and lakes, leading to increasing prevalence of saltwater-tolerant species in nearshore vegetation communities, relative to saltwater-intolerant species.[32]
- *Loss of coastal tidal flats and beaches.* A 44% projected loss of tidal flats across the Pacific Northwest coastline due to sea level rise will negatively impact many species of shorebirds that rely upon them, particularly during their winter migration. In some cases, coastal habitats can move inland with sea level rise, but in many inland areas, development will block these shifts, driving future declines in near-shore habitats. Losses of estuarine beaches will negatively impact critical

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[29] Wittmann, Astrid C., and Hans-O. Pörtner. "Sensitivities of extant animal taxa to ocean acidification." Nature Climate Change 3.11 (2013): 995-1001.
[30] Orr, James C., et al. "Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms." *Nature* 437.7059 (2005): 681-686.
[31] Hoegh-Guldberg, Ove, et al. "Coral reefs under rapid climate change and ocean acidification." science 318.5857 (2007): 1737-1742.
[32] Li, Xiuzhen, et al. "Coastal wetland loss, consequences, and challenges for restoration." Anthropocene Coasts 1.1 (2018): 1-15.

spawning habitat for forage fish including surf smelt (*Hypomesus pretiosus*) and sand lance, which play a key role in the marine food web.[33]

- *Altered shoreline and tidal river dynamics.* Shoreline armoring, a common response to sea level rise, is expanding, negatively impacting shoreline dynamics and near-shore fish habitat. Sea level rise also alters stream flow dynamics in tidally influenced reaches, threatening fish habitat and fish passage.[34]
- *Loss of freshwater marshes and increasing pollutants.* Coastal freshwater marshes play a crucial role in regulating nutrients and filtering pollutants. The loss of coastal freshwater marshes due to sea level rise will increase nutrient and pollutant inputs from inland to marine systems.[35]

1.3 Impacts on Freshwater, Wetland and Riparian Habitats

Warming water temperatures are reducing habitat quality and connectivity for native coldwater fish species while improving conditions for non-native fish and pathogens.

- *Impaired habitat quality.* Thermal stress from elevated water temperature increases mortality of native cold-water fishes, including PHS-listed species of trout and salmon as well as white sturgeon (*Acipenser transmontanus*), eulachon (*Thaleichthys pacificus*) and lamprey (*Entosphenus tridentatus*).[36] Native trout habitat in the western US is projected to decline in extent by 33% to 77% by the end of the century (relative to 1985-2004) under a higher GHG scenario.[37] Studies suggest that one third of the current habitat for threatened and endangered Pacific Northwest salmon species will no longer be suitable by the end of this century as key temperature thresholds are exceeded.[38] Warmer water temperature also reduces habitat quality by increasing primary productivity in aquatic systems, leading to increased prevalence of algal blooms and related anoxic conditions.[39]
- *Increasing thermal barriers.* Water temperatures that exceed the thermal tolerances of cold-water fish act as a thermal barrier to movement, reducing habitat connectivity in aquatic networks, and impairing fish migrations and access to spawning areas.[40]

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[33] Glick, Patty, Jonathan Clough, and Brad Nunley. "Sea-level rise and coastal habitats in the Pacific northwest." (2007).
[34] Smith, Collin D., et al. "Modeling the potential effects of sea-level rise on the spawning habitat of Salish Sea forage fish." (2010).
[35] Nelson, Joanna L., and Erika S. Zavaleta. "Salt marsh as a coastal filter for the oceans: changes in function with experimental increases in nitrogen loading and sea-level rise." PLoS One 7.8 (2012).
[36] Sharma, S., Vander Zanden, M. J., Magnuson, J. J., & Lyons, J. (2011). Comparing climate change and species invasions as drivers of coldwater fish population extirpations. Plos One, 6(8).
[37] Kaushal, Sujay S, Likens, Gene E, Jaworski, Norbert A, Pace, Michael L, Sides, Ashley M, Seekell, David, . . . Wingate, Rebecca L. (2010). Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment., 8*(9), 461-466.
[38] Littell, J.S., M. McGuire Elsner, L.C. Whitely Binder, and A.K. Snover (eds). 2009. *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*, (PDF 14.1 MB) Climate Impacts Group, University of Washington, Seattle, Washington.
[39] Paul, V. J. (2008). Global warming and cyanobacterial harmful algal blooms. Cyanobacterial harmful algal blooms: state of the science and research needs, 239-257.
[40] Whitney, James E, Al-Chokhachy, Robert, Bunnell, David B, Caldwell, Colleen A, Cooke, Steven J, Eliason, Erika J, . . . Paukert, Craig P. (2016). Physiological Basis of Climate Change Impacts on North American Inland Fishes. *Fisheries., 41*(7), 332-345.

- *Increasing prevalence of invasive species and pathogens.* Increasing water temperatures facilitate the range expansion of non-native warm-water fish species (e.g., bass, walleye and pike) and other aquatic species (e.g., zebra mussel, *Dreissena polymorpha*) that are competitors with and predators of native species.[41] Fish pathogens can also become more virulent in warmer water, and the thermal stress associated with warmer water can increase fish species' susceptibility to pathogens. Dense concentrations of fish seeking thermal relief in cold-water pools or being raised in hatchery environments are at risk of disease transmission.[42]

Altered hydrology is affecting habitat quality and connectivity, and the phenology of native aquatic and riparian species.

- *Declining summer streamflow.* Reduced snowpack (particularly in mid-elevation basins) and increasingly common summer drought conditions are expected to reduce summer streamflows in about 80% of watersheds across Washington State. Low summer flow conditions can reduce egg and juvenile fish survival and act as a movement barrier to migrating fish.[43]
- *Increasing flood impacts.* Heavy rainfall events are projected to become more intense by mid-century, increasing flood risk, scouring stream beds and reducing salmon egg-to-fry survival, particularly in rain-dominated and mixed rain and snow watersheds. Extreme flooding events can destroy riparian vegetation, cause erosion and increase suspended sediment loads, reducing water quality and impairing fish habitat.[44] [45] As more winter precipitation falls as rain rather than snow, higher winter stream flows can scour streambeds, damaging salmon spawning nests and washing away incubating eggs.[46]
- *Altered life-cycles.* Altered timing of peak flow (shifting earlier in mixed rain and snow and snow-dominated basins) and low flow in streams affects the timing of migratory and anadromous game fish species like salmonids, sturgeon, eulachon and lamprey. This altered timing could create mismatches with when prey are available to fish at various life stages.[47] Earlier peak streamflows can also flush young salmon from rivers to estuaries before they are physically mature enough for transition, increasing a variety of stressors including the risk of predation.

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[41] Britton, J R, Cucherousset, J, Davies, G D, Godard, M J, & Copp, G H. (2010). Non-native fishes and climate change: Predicting species responses to warming temperatures in a temperate region. *Freshwater Biology., 55*(5), 1130-1141.
[42] McCullough, D. A. (1999). A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon (pp. 1-291). US Environmental Protection Agency, Region 10.
[43] Mantua, N., Tohver, I., & Hamlet, A. (2009). Impacts of climate change on key aspects of freshwater salmon habitat in Washington State.
[44] Mantua, Nathan, Tohver, Ingrid, & Hamlet, Alan. (2010). Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change, 102*(1), 187-223.
[45] Arora, Vivek K, & Boer, George J. (2001). Effects of simulated climate change on the hydrology of major river basins. *Journal of Geophysical Research., 106*(D4), 3335-3348.
[46] Goode, Jaime R., et al. "Potential effects of climate change on streambed scour and risks to salmonid survival in snow-dominated mountain basins." Hydrological Processes 27.5 (2013): 750-765.
[47] Crozier, L. G., Lawson, P. W., Quinn, T. P., Hendry, A. P., Battin, J., Mantua, N. J., ... & Shaw, R. G. (2008). Evolutionary responses to climate change for organisms with complex life histories: Columbia River salmon as a case in point. Evol Appl, 1(1), 252-270.

Increasing natural disturbances in riparian areas are reducing habitat quality and availability for riparian-associated species and impairing water quality for aquatic species.

- *Increasing riparian disturbances.* Increased occurrence of wildfire, flooding, and other natural disturbances is driving losses in riparian forests and other riparian vegetation, negatively impacting this Priority Habitat and associated mammals like beaver (*Castor canadensis*), mink (*Neovison vison*) and spotted skunk (*Spilogale gracilis*) as well as birds (e.g., cavity nesting ducks), amphibians and arthropods, a number of which appear on the PHS list. [48] [49]
- *Impacts of riparian vegetation loss.* The loss of riparian vegetation can cause increases in stream temperatures as well as increased erosion and suspended sediment loads, negatively impacting water quality for native species that require clear, cool water. [50] [51]

Declining precipitation and higher temperatures in summer are expected to lead to more frequent and severe summer droughts, reducing water availability in soils, seeps, ponds and streams, impairing habitat for wetland-associated species.

- *Loss of montane wetlands.* Montane wetlands that persist into the summer due to water stored in the snowpack are particularly at risk in watersheds that will shift from snow-dominated to rain-dominated. The loss of these montane wetlands would reduce the area of habitat available for montane wetland-associated species, including several PHS-listed amphibians like western toad (*Anaxyrus boreas*) and Columbia spotted frog (*Rana luteiventris*), mammals such as moose (*Alces alces*) and several PHS-listed arthropods.[52]
- *Loss of lowland wetlands.* Lowland wetlands that are fed by precipitation rather than groundwater (e.g., vernal pools) are also vulnerable to increasing summer drought conditions. As a result, lowland wetland-associated species are also at risk of habitat loss, including several PHS-listed species of birds such as sandhill crane (*Antigone canadensis*), black-crowned night heron (*Nycticorax nycticorax*), and great blue heron (*Ardea herodias*), amphibians such as tiger salamander (*Ambystoma*

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[48] Capon, Samantha J, Chambers, Lynda E, Mac Nally, Ralph, Naiman, Robert J, Davies, Peter, Marshall, Nadine, . . . Williams, Stephen E. (2013). Riparian Ecosystems in the 21st Century: Hotspots for Climate Change Adaptation? *Ecosystems, 16*(3), 359-381.
[49] Raymond, C. L., Peterson, D. L., & Rochefort, R. M. (2014). Climate change vulnerability and adaptation in the North Cascades region, Washington. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 279 p. 892.
[50] From logging increase stream temp citation: Johnson, Sherri L, & Jones, Julia A. (2000). Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences, 57*(S2), 30-39.
[51] Vegetation and erosion citation: Zhang, Xia, Yu, Guo Qiang, Li, Zhan Bin, & Li, Peng. (2014). Experimental Study on Slope Runoff, Erosion and Sediment under Different Vegetation Types. Water Resources Management., 28(9), 2415-2433.
[52] Lee, Se-Yeun, Ryan, Maureen E, Hamlet, Alan F, Palen, Wendy J, Lawler, Joshua J, Halabisky, Meghan, & Richardson, Curtis J. (2015). Projecting the Hydrologic Impacts of Climate Change on Montane Wetlands. PloS One., 10(9), E0136385.

tigrinum), and several species of arthropods.[53]

- *Altered floodplains.* Floodplain wetlands are sensitive to changes in the timing of peak flows, affecting which species and life stages can access and use floodplain habitat for rearing.[54]

The cumulative impacts of increased water temperature, altered hydrologic cycles and increasing natural disturbances in riparian areas are altering the abundance and distributions of freshwater aquatic, wetland and riparian-associated species.

- *Population-level impacts.* Increased mortality, reduced reproductive success (e.g., from poor body condition due to reduced prey/forage availability), and habitat fragmentation in aquatic networks are driving deleterious shifts in the age composition, population size and genetic diversity of coldwater fish populations. [55] [56] [57]

- *Range contractions.* Wetland and riparian-associated species are experiencing range contractions in some watersheds due to increasing rates of natural disturbance in riparian vegetation and drier conditions (e.g., from drought and reduced water storage in snowpack) that limit the amount of water available to feed precipitation-dependent wetlands.[58] In addition, impaired water quality and altered hydrology combined with movement barriers (e.g., thermal barriers and low-flow barriers) are driving range contractions in native cold-water fish species, including many PHS-listed species and game fish species.[59] [60]

- *Extirpation.* Local extirpation of native cold-water fish species driven by a variety of stressors is resulting in local declines in the diversity of fish species.[61] [62]

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53 Pyke, C. (2005). Assessing Climate Change Impacts on Vernal Pool Ecosystems and Endemic Branchiopods. Ecosystems., 8(1), 95-105.
54 Tockner, K., & Stanford, J. A. (2002). Riverine flood plains: present state and future trends. Environmental conservation, 308-330.
55 Macdonald, J. (2000). Mortality during the migration of Fraser River sockeye salmon (Oncorhynchus nerka): A study of the effects of ocean and river environmental conditions in 1997. Race Rocks Pilot Marine Protected Area : An Ecological Overview /, 12, 2315.
56 Rand, P S, Hinch, S G, Morrison, J, Foreman, M G G, MacNutt, M J, Macdonald, J S, . . . Higgs, D A. (2006). Effects of River Discharge, Temperature, and Future Climates on Energetics and Mortality of Adult Migrating Fraser River Sockeye Salmon. Transactions of the American Fisheries Society., 135(3), 655-667.
57 Pankhurst, Ned W, & Munday, Philip L. (2011). Effects of climate change on fish reproduction and early life history stages. Marine & Freshwater Research., 62(9), 1015.
58 Martínez-Fernández, Vanesa, Van Oorschot, Mijke, De Smit, Jaco, González del Tánago, Marta, & Buijse, Anthonie D. (2018). Modelling feedbacks between geomorphological and riparian vegetation responses under climate change in a Mediterranean context. Earth Surface Processes and Landforms : The Journal of the British Geomorphological Research Group., 43(9), 1825-1835.
59 Santiago, José María, Muñoz-Mas, Rafael, Solana-Gutiérrez, Joaquín, García de Jalón, Diego, Alonso, Carlos, Martínez-Capel, Francisco, . . . Ribalaygua, Jaime. (2017). Waning habitats due to climate change: The effects of changes in streamflow and temperature at the rear edge of the distribution of a cold-water fish. Hydrology and Earth System Sciences., 21(8), 4073-4101.
60 Jacobson, P. C., Hansen, G. J., Olmanson, L. G., Wehrly, K. E., Hein, C. L., & Johnson, L. B. (2019). Loss of coldwater fish habitat in glaciated lakes of the midwestern United States after a century of land use and climate change. Advances in Understanding Landscape Influences on Freshwater Habitats and Biological Assemblages, eds RM Hughes, D. Infante, L. Wang, K. Chen, and B. F. de Terra (Bethesda, MD: American Fisheries Society), 141-158.
61 Daufresne, M., & Boet, P. (2007). Climate change impacts on structure and diversity of fish communities in rivers. Global Change Biology, 13(12), 2467-2478.
62 Kingsolver, J. (2009). The Well-Temperatured Biologist. The American Naturalist., 174(6), 755-768.

1.4 Impacts on Forest Habitats

Higher temperatures and increasing summer drought conditions are affecting tree phenology and driving increases in natural disturbances affecting forest structure and composition.

- *Shifts in forest types.* Under a medium GHG scenario, the area of Washington forests that is water-limited (i.e. forests on warm and dry sites where water is more limiting to growth than energy, most often occurring east of the Cascade crest at mid to low elevations) is projected to increase by 32% in the 2020s, with an additional 12% increase in both the 2040s and 2080s, relative to 1970-1999. Severely water-limited forests are projected to occur on the east side of the Cascade Range and in the northeastern part of the state. Increasing drought stress in water-limited forests is likely to lower forest productivity and result in forest loss in some areas, while also increasing vulnerability to disturbance (e.g., fire, insects, pathogens).[63]
- *Increasing wildfire frequency and area burned*. More frequent and intense summer drought conditions reduce fuel and soil moisture, increasing the annual area burned by forest fires. One study estimates the area of Northwest forests burned annually will increase by 76% to 310% by 2070-2099 under a high GHG scenario relative to a 1971-2000 baseline. Increases in area burned are projected to vary across the region, with most of the increase occurring in drier, east-side forests. However, increasing summer drought conditions could result in more area burned in western Washington forests that have not traditionally been considered fire-prone.[21]
- *Increasing prevalence of forest pathogens and insect outbreaks.* Milder winter temperatures and drought stress are driving increases in forest disease and insect outbreaks, contributing to increased tree mortality. Over the past 30 years, tree mortality caused by bark beetles in the western United States has exceeded mortality caused by wildfire.[64] Insect outbreaks are likely to become more common and widespread as drought stress weakens tree defenses and milder winters reduce insect mortality. As a result, the area susceptible to mountain pine beetle (*Dendroctonus ponderosae*) outbreak is projected to increase by 27% from 2001-2030 compared to 1961-1990 across the western United States. However, by the end of the century (2071-2100), temperatures are likely to exceed the beetle's thermal optimum, resulting in a decline of area susceptible by 49-58%. Ranges of other bark beetles such as the pine engraver beetle (*Ips pini*) may also decrease by

[63] Holden, Z., Swanson, A., Luce, C., Jolly, W., Maneta, M., Oyler, J., . . . Affleck, D. (2018). Decreasing fire season precipitation increased recent western US forest wildfire activity. *Proceedings of the National Academy of Sciences of the United States of America., 115*(36).
[64] Hicke, J. A., A. J. H. Meddens, and C. A. Kolden, 2016: Recent tree mortality in the western United States from bark beetles and forest fires. Forest Science, 62 (2), 141–153.

the end of the century.[65]

- *Altered phenology.* For high elevation tree species, warming is expected to favor earlier growth initiation (due to less time required to meet the warming requirement). At lower elevations, warming is expected to favor delayed growth-initiation (due to more time required to meet the chilling requirement). Other phenological shifts affecting the timing of growth-initiation, budding and flowering are broadly expected across many plant taxa, with cascading effects across trophic levels throughout the forest food web. For example, huckleberry fruiting is projected to shift 24-52 days earlier by the end of the century under a high GHG scenario, shifting the seasonality of an important food resource for game species like black bear (*Ursus americanus*). Phenological mismatches may become more common in the future (e.g., as warming shifts the timing of plant flowering earlier relative to their pollinators' emergence in the spring or as the timing of pollen release and female flower receptivity become decoupled).[66]

The cumulative impacts of warming, altered hydrology, and increasing natural disturbances are driving range shifts in tree species, forest-associated animals and invasive species, resulting in altered forest community composition.

- *Declines in late-seral forests and associated species.* Increasing frequency and severity of natural disturbances (e.g., fire, forest disease, insect outbreaks) are reducing habitat and driving range contractions for species that depend on late-seral forests (a PHS priority habitat), including PHS-listed species such as the marbled murrelet (*Brachyramphus marmoratus*), northern spotted owl (*Strix occidentalis caurina*), pileated woodpecker (*Dryocopus pileatus*), American marten (*Martes americana*) and Pacific fisher (*Pekania pennanti*).[67] [68]
- *Increases in early-seral forests and associated species.* The increasing prevalence of forest disturbances is driving increases in habitat for early-seral species that thrive in open-canopy forests and forest openings with abundant grasses, forbes and shrubs. Animal species that benefit from increasing early seral and post-disturbance forest landscapes include game animals like deer, elk and black bear as well many bird species, including the PHS-listed black-backed (*Picoides arcticus*) and white-headed woodpeckers (*Leuconotopicus albolarvatus*).[69]
- *Spread of invasive species.* Higher temperatures, altered precipitation regimes and

65 Barbara J. Bentz, Jacques Régnière, Christopher J Fettig, E. Matthew Hansen, Jane L. Hayes, Jeffrey A. Hicke, Rick G. Kelsey, Jose F. Negrón, Steven J. Seybold, Climate Change and Bark Beetles of the Western United States and Canada: Direct and Indirect Effects, BioScience, Volume 60, Issue 8, September 2010, Pages 602–613.
66 Ford, Kevin R, Harrington, Constance A, Bansal, Sheel, Gould, Peter J, & St Clair, J Bradley. (2016). Will changes in phenology track climate change? A study of growth initiation timing in coast Douglas-fir. Global Change Biology., 22(11), 3712-3723.
67 Thom, Dominik, Golivets, Marina, Edling, Laura, Meigs, Garrett W, Gourevitch, Jesse D, Sonter, Laura J, . . . Keeton, William S. (2019). The climate sensitivity of carbon, timber, and species richness covaries with forest age in boreal–temperate North America. Global Change Biology, 25(7), 2446-2458.
68 Halofsky, Joshua S, Conklin, David R, Donato, Daniel C, Halofsky, Jessica E, Kim, John B, & Carcaillet, Christopher. (2018). Climate change, wildfire, and vegetation shifts in a high-inertia forest landscape: Western Washington, U.S.A. PloS One, 13(12).
69 Swanson, Mark E, Studevant, Nichole M, Campbell, John L, & Donato, Daniel C. (2014). Biological associates of early-seral pre-forest in the Pacific Northwest. Forest Ecology and Management, 324, 160-171.

increasing rates of forest disturbance are expected to facilitate the range expansion of some non-native plant species (e.g., knapweeds, Scotch broom, and English ivy) and in forest ecosystems, driving declines of native plant species that compete with non-native plants.[70]

- *Changes in tree species distributions.* The spatial distribution of suitable climate for many tree and forest understory species in Washington may change considerably by the end of the 21st century. Some vegetation types, such as subalpine forests, may become very limited in their ranges. Areas of climatic suitability may also decline for high-elevation populations of whitebark pine (*Pinus albicaulis*), Engelmann spruce (*Picea engelmannii*), yellow cedar (*Cupressus nootkatensis*) and subalpine fir (*Abies lasiocarpa*).[68] [71]
- *Changes in distributions of forest animals.* Warming temperatures and altered hydrology are driving increased rates of forest disturbance and shifting the species composition and distribution of forest ecosystems. Some forest-associated species, particularly those that favor early seral and post-disturbance landscapes (e.g. elk, deer, and moose) may expand their ranges. Other species that favor late-seral forests and are more sensitive to climate will be challenged to track suitable forest conditions over time given the rapid pace of change and prevalence of disturbance. The following examples are of PHS-listed species that may experience changes in distributions under future conditions:
    - Western gray squirrels (*Sciurus griseus*) and their oak woodland habitats (both appear on the PHS list) are susceptible to altered fire regimes that degrade forest quality for extended periods of time. However, one recent study has projected that some forest types used by this species will expand under warmer, drier conditions.[72] [73]
    - Warming winter temperatures are expected to reduce snowpack and favor wetter snow conditions (i.e., the snow temperature is closer to the freezing point and therefore wetter) in Canada lynx (*Lynx canadensis*) habitat, placing this PHS-listed species at a competitive disadvantage compared to other predators. Increasingly variable timing of the arrival and melting periods of snowpack may lead to local extirpations of snowshoe hare (*Lepus americanus*), likely affecting lynx survival and recruitment. Lynx also require a variety of forest age classes for denning and foraging, and are thus susceptible to large, stand-replacing fires that create uniform forest age structures and favor early-

[70] Stevens, Jens T, & Latimer, Andrew M. (2015). Snowpack, fire, and forest disturbance: Interactions affect montane invasions by non-native shrubs. *Global Change Biology., 21*(6), 2379-2393.
[71] Sheehan, T, Bachelet, D, & Ferschweiler, K. (2015). Projected major fire and vegetation changes in the Pacific Northwest of the conterminous United States under selected CMIP5 climate futures. *Ecological Modelling., 317*, 16-29.
[72] Ryan, L. A., & Carey, A. B. (1995). Biology and management of the western gray squirrel and oregon white oak woodlands: with emphasis on the Puget Trough. *Gen. Tech. Rep. PNW-GTR-348. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 36 p*, *348*.
[73] Mazzamuto, M. V., Mazzella, M. N., Merrick, M. J., & Koprowski, J. L. (2020). Fire impacts on a forest obligate: western gray squirrel response to burn severity. *Mammalian Biology*, *100*(3), 295-303.

seral forests that lack suitable trees for denning.[74]

1.5 Impacts on Alpine Habitats

Warmer temperatures are increasing thermal stress and reducing snowpack, leading to habitat loss for cold-adapted, snow-dependent species, many of which appear on the PHS list.

- *Increasing thermal stress.* Many cold-adapted species like the American pika (*Ochotona princeps*) are sensitive to thermal stress. Future warming may shrink the ranges of cold-adapted species or force behavioral shifts such as limiting daytime activity during warm temperatures and seeking cooler microclimates.[75]
- *Changing snow conditions.* As snow becomes more dense and less abundant, Canada lynx will increasingly experience a competitive disadvantage with other predators like bobcat (*Lynx rufus*) and coyote (*Canis latrans*).[76] Earlier snowmelt and reduced spring snowpack in mixed rain and snow basins will reduce available denning habitat for wolverines (*Gulo gulo*). Where available, denning may shift to higher elevation, snow-dominated basins where snowpack may actually increase during winter and still persist into the spring denning season. However, the area available at these highest elevations is small compared to the historical distribution of suitable denning habitat.[77] [78] A less persistent snowpack will also negatively impact habitat for species that require snowpack for insulation and cover and are active in the subnivean (i.e., beneath the snowpack) environment during winter (e.g., American marten and pika).[79] [80]
- *Changes in species distributions.* Warmer temperatures and reduced snowpack in mid-elevation basins are likely to drive range shifts of cold-adapted and snow-dependent species upwards in elevation and latitude, to cooler microclimates and to topographic features (e.g., north-facing, leeward slopes) that retain snow. Because the area of habitat available decreases and the fragmentation of habitat increases near summits and ridges, range contractions are likely for alpine species driven upwards in elevation by climate change.[81]

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[74] King, Travis W, Vynne, Carly, Miller, David, Fisher, Scott, Fitkin, Scott, Rohrer, John, . . . Thornton, Daniel. (2020). Will Lynx Lose Their Edge? Canada Lynx Occupancy in Washington. *The Journal of Wildlife Management., 84*(4), 705-725.
[75] Erb, Liesl P, Ray, Chris, & Guralnick, Robert. (2011). On the generality of a climate-mediated shift in the distribution of the American pika (Ochotona princeps). *Ecology, 92*(9), 1730-1735.
[76] Peers, Michael J L, Majchrzak, Yasmine N, Menzies, Allyson K, Studd, Emily K, Bastille-Rousseau, Guillaume, Boonstra, Rudy, . . . Boutin, Stan. (2020). Climate change increases predation risk for a keystone species of the boreal forest. *Nature Climate Change., 10*(12), 1149-1153.
[77] Barsugli, Joseph J, Ray, Andrea J, Livneh, Ben, Dewes, Candida F, Heldmyer, Aaron, Rangwala, Imtiaz, . . . Torbit, Stephen. (2020). Projections of Mountain Snowpack Loss for Wolverine Denning Elevations in the Rocky Mountains. *Earth's Future, 8*(10).
[78] Copeland, J. P., McKelvey, K. S., Aubry, K. B., Landa, A., Persson, J., Inman, R. M., ... & May, R. (2010). The bioclimatic envelope of the wolverine (Gulo gulo): do climatic constraints limit its geographic distribution? *Canadian Journal of Zoology*, *88*(3), 233-246.
[79] Zielinski, W. J., Tucker, J. M., & Rennie, K. M. (2017). Niche overlap of competing carnivores across climatic gradients and the conservation implications of climate change at geographic range margins. *Biological Conservation*, 209, 533-545.
[80] Pauli, Jonathan N, Zuckerberg, Benjamin, Whiteman, John P, & Porter, Warren. (2013). The subnivium: A deteriorating seasonal refugium. *Frontiers in Ecology and the Environment., 11*(5), 260-267.
[81] Galbreath, Kurt E, Hafner, David J, & Zamudio, Kelly R. (2009). When Cold Is Better: Climate-driven Elevation Shifts Yield Complex Patterns Of Diversification And Demography In An Alpine Specialist (American Pika, Ochotona Princeps. *Evolution : International Journal of Organic Evolution., 63*(11), 2848-2863.

Warming temperatures and altered precipitation and disturbance regimes are driving shifts in high-elevation plant and animal communities,

- *Tree encroachment in low-disturbance areas.* In some basins (particularly the west-side of the Cascades and Olympics) where future warming and earlier snowmelt will increase the growing season but not coincide with greater rates of natural disturbances, trees may encroach on alpine meadows, avalanche chutes, and high elevation huckleberry patches. This will negatively impact habitat for meadow-dependent species, including PHS-listed species like the hoary marmot (*Marmota caligata*), Olympic marmot (*Marmota olympus*), mountain goat (*Oreamnos americanus*) and Cascade red fox (*Vulpes vulpes cascadensis*), as well as game species like black-tailed and mule deer (*Odocoileus hemionus*), elk and black bear. Conversely, parkland and alpine forest-associated species (e.g., American marten) may benefit from greater forest cover in alpine areas.[82]
- *Alpine meadow and parkland expansion into high disturbance areas.* In other basins (particularly on the east-side of the Cascades), warmer temperatures, reduced snowpack and drier summer conditions will increase the risk of fire, insect outbreaks and forest pathogens, favoring expansion of alpine meadows and loss of alpine forest habitat. The loss of high-elevation forests will negatively impact high-elevation species that depend on these habitats, including PHS-listed species like the Canada lynx.[20]
- *Tree encroachment in avalanche chutes.* Shifts to rain-dominated winter precipitation in many mixed rain and snow basins will reduce the frequency of avalanches, which are an important disturbance agent in alpine ecosystems. Without avalanches, forests may encroach upon the lush shrub and meadow habitats of avalanche chutes, an important foraging area for many alpine animals, including PHS-listed species like grizzly bear (*Ursus arctos horribilis*) as well as big game species like deer and elk.[83]
- *Changing distributions of alpine tree species.* Increasing occurrence of fire in alpine systems will favor fire-adapted tree species like lodgepole pine relative to slow-growing species that are sensitive to wildfire (e.g., subalpine fir and Engelmann spruce).[84] Though mid-elevation montane tree species such as silver fir and lodgepole pine may readily colonize higher elevations, the highest elevation tree species (e.g., subalpine fir, Engelmann spruce, mountain hemlock, whitebark pine) are less able to shift their ranges higher due to lack of soil and nutrients above the current treeline. The area of habitat available is

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[82] Franklin, J. (1971). Invasion of subalpine meadows by trees in the Cascade Range, Washington and Oregon. *Arctic, Antarctic, and Alpine Research., 3*(3), 215.
[83] Martin, Eric, Giraud, Gérald, Lejeune, Yves, & Boudart, Géraldine. (2001). Impact of a climate change on avalanche hazard. *Annals of Glaciology, 32*, 163-167.
[84] Buma, B., Brown, C. D., Donato, D. C., Fontaine, J. B., & Johnstone, J. F. (2013). The impacts of changing disturbance regimes on serotinous plant populations and communities. *BioScience*, *63*(11), 866-876.

also smaller as ranges shift upwards towards mountain summits and ridge crests, leading not only to habitat loss but also increased habitat fragmentation in high-elevation plant species.[85]

1.6 Impacts on Shrubsteppe and Grassland Habitats

Warmer temperatures and reduced summer precipitation are increasing the frequency and extent of fire and drought conditions, driving shifts in shrubsteppe and grassland plant and animal community composition and expansion of non-native species.

- *Expansion of grasslands.* Grasslands may expand because they are adapted to warmer, drier conditions and predominate in areas with frequent fires that limit regrowth of shrubs and forest encroachment. More frequent fire also favors increased herbaceous ground cover relative to woody biomass.[86] In many areas, non-native grasses are occupying these expanding grasslands.
- *Reduced vegetation and productivity.* Reduced soil moisture during summer droughts could reduce vegetative cover and productivity of these systems.[87] [88] Increasing prevalence of wildfire is also degrading the cryptobiotic crust (living soils that play an important role in retaining soil moisture in shrubsteppe ecosystems), allowing for greater moisture loss during warm periods.
- *Increasing runoff and erosion.* Extreme precipitation events coupled with increased drought frequency may exacerbate impacts from excessive grazing by increasing runoff and erosion and further degrading the condition of the biological soil crust, affecting plant communities and soil communities that depend on an intact crust.[89]
- *Shifting distributions of native and invasive species.* Drought-tolerant species are likely to become more dominant within plant communities in both grassland and shrubsteppe habitats.[90] [91] Washington is at the upper end of the precipitation range for low sagebrush (*Artemisia arbuscula*); Washington low sagebrush may thus be more intolerant of increased winter precipitation than summer drought. Increasing fire disturbance creates opportunities for the expansion of non-native annual grasses and other invasive species. Annual

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[85] Michael J, & Lawler, Joshua J. (2016). Relative vulnerability to climate change of trees in western North America. *Climatic Change, 136*(2), 367-379.

[86] Lenihan, James M, Bachelet, Dominique, Neilson, Ronald P, & Drapek, Raymond. (2008). Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California. *Climatic Change, 87*(1), 215-230.

[87] Vicente-Serrano, S., Gouveia, C., Camarero, J., Beguería, S., Trigo, R., López-Moreno, J., . . . Sanchez-Lorenzo, A. (n.d.). Response of vegetation to drought time-scales across global land biomes. *Proceedings of the National Academy of Sciences of the United States of America., 110*(1), 52-57.

[88] Palmquist, Kyle A, Schlaepfer, Daniel R, Bradford, John B, & Lauenroth, William K. (2016). Mid-latitude shrub steppe plant communities: Climate change consequences for soil water resources. Ecology., 97(9), 2342-2354.

[89] Li, Zhiying, & Fang, Haiyan. (2016). Impacts of climate change on water erosion: A review. *Earth-science Reviews., 163*, 94-117.

[90] Cartwright, Jennifer M, Littlefield, Caitlin E, Michalak, Julia L, Lawler, Joshua J, & Dobrowski, Solomon Z. (2020). Topographic, soil, and climate drivers of drought sensitivity in forests and shrublands of the Pacific Northwest, USA. *Scientific Reports., 10*(1), 1.

[91] Craine, Joseph M, Ocheltree, Troy W, Nippert, Jesse B, Towne, E Gene, Skibbe, Adam M, Kembel, Steven W, & Fargione, Joseph E. (2013). Global diversity of drought tolerance and grassland climate-change resilience. *Nature Climate Change., 3*(1), 63-67.

grasses like cheatgrass (*Bromus tectorum*) form a continuous herbaceous cover (unlike bunchgrasses), allowing fire to spread further and creating a feedback that perpetuates its spread.[92] [93]

Warmer temperatures and altered hydrology is driving shifts in phenology in plant and animal populations.

- *Failed germination.* Warmer winters could result in failed germination for sagebrush and other species (e.g., showy milkweed, an important forage plant for monarch butterflies) due to insufficient cold stratification required for germination.[94]
- *Reduced juvenile survival.* Reproductive success in Greater Sage-grouse (*Centrocercus urophasianus*) is associated with forb and invertebrate availability; sage grouse maximize chick survival by timing their hatching with peak of season (i.e., end of frost and abundance of forbs and arthropods) which can shift with climate change, creating a phenological mismatch.[95]
- *Maladapted bird migrations.* Across North America, climate change is shifting the timing of spring greenup, and migratory birds are responding in complex ways that vary by species and region. Of the 48 species assessed in one study, 9 were not adjusting their arrival times to keep pace with the changing climate, a mismatch likely to result in reduced fitness.[96]

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[92] Bradley, Bethany A, Curtis, Caroline A, Fusco, Emily J, Abatzoglou, John T, Balch, Jennifer K, Dadashi, Sepideh, & Tuanmu, Mao-Ning. (2018). Cheatgrass (Bromus tectorum) distribution in the intermountain Western United States and its relationship to fire frequency, seasonality, and ignitions. *Biological Invasions., 20*(6), 1493-1506.

[93] Hunter, Molly E., Omi Philip N., Martinson Erik J., Chong Geneva W. (2006) Establishment of non-native plant species after wildfires: effects of fuel treatments, abiotic and biotic factors, and post-fire grass seeding treatments. International Journal of Wildland Fire 15, 271-281.

[94] Still, Shannon M., and Bryce A. Richardson. "Projections of contemporary and future climate niche for Wyoming big sagebrush (Artemisia tridentata subsp. wyomingensis): a guide for restoration." Natural Areas Journal 35.1 (2015): 30-43.

[95] Blomberg, Erik J, Sedinger, James S, Atamian, Michael T, & Nonne, Daniel V. (2012). Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. *Ecosphere., 3*(6), Art55.

[96] Mayor SJ, Guralnick RP, Tingley MW, et al. Increasing phenological asynchrony between spring green-up and arrival of migratory birds. *Sci Rep*. 2017;7(1):1902.

SECTION 2 – OVERARCHING AGENCY VULNERABILITIES

A changing climate is already affecting many of WDFW's operations. Increasing stream temperatures and low summer flows have resulted in fish die-offs and fishing closures along rivers. Declines in snowpack and intensified wildfires have damaged critical habitat and pose significant management challenges for many listed species. Continuing climate change trends are expected to exacerbate these and other climate-related impacts, further challenging the agency's ability to fulfill its mission to "*preserve, protect and perpetuate fish, wildlife and ecosystems while providing sustainable fish and wildlife recreational and commercial opportunities.*"

Drawing on results from internal agency workshops conducted in 2020, this section highlights climate-related vulnerabilities that were most commonly identified by WDFW staff across the Fish Program, Wildlife Program, Habitat Program and the CAMP program. While each of these programs will experience the impacts of climate change uniquely, four aspects of the agency's mission were broadly considered most vulnerable to climate-related impacts. In the subsections below, we summarize these four overarching concerns, which include: (1) Risks to Harvest and Recreation; (2) Risks to Species Conservation and Recovery; (3) Risks to Providing Effective Technical Assistance, Permitting, Research and Planning; and (4) Risks to WDFW Lands and Infrastructure.

***Table 2**. Summary of key climate impacts and adaptation actions for each overarching WDFW vulnerability. If viewing the online PDF, click on the underlined text to be taken to the relevant report section.*

	Species Recovery				Harvest & Recreation					Technical Assistance			Lands & Infrastructure				
Climate Impact	Species Recovery Goals	Listed Species Management	Species Monitoring	Habitat Investment	Freshwater Fisheries	Marine Fisheries	Shell-fishing	Land-based Recreation	Hunting & Harvest	Permitting / Design Guidance	Habitat Guidance	Restoration Guidance	Hatcheries	Culverts	Roads	Signs/Kiosks	Trail Damage
Increasing stream temperatures					X						X						
Decreasing summer streamflows					X					X	X						
Decreasing snowpack depth and duration		X	X	X					X		X						
Increasing winter precipitation										X	X		X	X	X		X
Changes in invasive species					X							X					
Changes in disease spread and prevalence		X			X												
Ocean acidification							X										
Harmful algal blooms						X	X										
Increasing food web disruptions						X											
Increasing risk of wildfire		X						X			X				X	X	X
Riverine flooding				X				X		X	X		X	X	X		X
Coastal flooding / sea level rise								X						X	X		X
Changes in vegetation												X					
Geographic shifts in species ranges	X		X						X			X					
Changes in phenology			X														

2.1 Risks to Species Conservation and Recovery

With dozens of species classified as state-endangered, -threatened, or -sensitive, the Washington Department of Fish and Wildlife is tasked with guiding recovery efforts for many at-risk fish and wildlife species. The historical drivers that have led to species becoming at-risk were often not climate-related, but rather reflect the legacy of post-colonization human activities and land-use. These include conversion of native habitats (e.g., to agriculture, urban and industrial areas), overharvest, natural resource extraction (e.g., timber harvest), pollution, introduction of exotic species and pathogens, and habitat fragmentation (e.g., due to highways and urbanization). Increasingly, climate change is becoming an additional stressor that is raising the extinction risk for many species. For climate-sensitive species (i.e., species that are adapted to a relatively narrow range of climatic conditions and therefore vulnerable to changing climate) that are already at-risk, this will make meeting recovery goals even more difficult and costly. In addition, the added stressors of climate change will likely add new climate-sensitive species to the list of threatened species requiring management interventions.

The rapid pace of climate change poses challenges to many climate-sensitive species as they seek to adapt in-place or shift their ranges to track suitable conditions. These challenges are in addition to other stressors related to our expanding human population, extractive industries like timber harvest and agriculture and a legacy of past practices such as overexploitation and eradication of predators. These threats are increasing extinction risks for many species and making it more difficult for WDFW to achieve its mission to protect species and recover at-risk species. Examples include:

- *Migration barriers*. Climate-driven range shifts are made more difficult by anthropogenic movement barriers like highways and cities. Large expanses of agricultural areas and areas of intensive timber harvest can also serve as movement barriers to species that are sensitive to highly modified landscapes. Investments in wildlife crossing structures may increasingly be required to facilitate range shifts and connect fragmented populations.
- *Increasingly isolated populations.* Populations that cannot shift their ranges (either due to movement barriers or limited dispersal abilities) to keep up with the changes in climate become isolated in 'islands' of habitat and may require intensive management interventions (e.g., assisted migration) to keep viable. As our regional population grows, our expanding human footprint is reducing the size and increasing the fragmentation of these islands for many species. Projections for increasing immigration into the region in the future, driven in part by an attraction to our comparatively stable and attractive climate, could exacerbate these trends.
- *Greater need for assisted migration.* In areas of isolated habitat where remnant populations persist, translocations are often used to increase the size and

genetic diversity of the population or to help reoccupy habitat after extirpation. Translocations are also a potential tool for facilitating species range shifts during periods of rapid climate change. As populations shrink and extirpations occur more frequently, and as the climate changes, translocation may become more necessary, at significant cost to the agency and requiring access to healthy 'source' populations (which are also becoming increasingly difficult to find). For example, translocations from Oregon have helped bolster the greater sage-grouse population of Douglas County and recolonize habitat in Lincoln county where they were previously extirpated.

- *Greater need for captive breeding and rearing.* Headstarting (i.e., rearing of young animals before release into the wild) is another costly but potentially effective conservation tool to bolster small populations. Existing examples include rearing salmon in state hatcheries and raising pygmy rabbits in WDFW's captive breeding program. Headstarting may become increasingly necessary to support populations as climate change shrinks the ranges of some climate-sensitive native species.

Future shifts in our regional climate may make Washington unsuitable for some climate-sensitive state-listed species, making recovery impractical and reassessment of recovery goals and allocation of scarce resources necessary. Examples include:

- *Increasing risk to snow-dependent species.* The projected shift in many montane basins from mixed rain and snow to rain-dominated and projections of wetter, more dense snow are predicted to decrease the area of suitable habitat and the competitive advantage of snow-dependent species such as lynx. In addition, the increasing frequency and severity of wildfire is causing widespread losses in forests suitable for lynx and their primary prey, snowshoe hare. Together, these dual threats pose a considerable challenge to successfully meeting the goals of WDFW's lynx recovery plan.
- *Loss of snow-denning habitat.* Wolverines are dependent on persistent, deep spring snowpack for denning, so widespread loss of snowpack is a considerable threat to their recovery.

Disease control measures may become increasingly necessary as climate change creates more favorable conditions for outbreaks of some diseases and parasites, further threatening listed species. Examples include:

- *More frequent outbreaks of avian cholera.* Milder winters create favorable conditions for avian cholera outbreaks, affecting many bird species including ducks, geese and seabirds. In 2015, a year of anomalously warm temperatures region-wide, an avian cholera outbreak killed 2,500 birds in south-central Washington in a single week.

- *Increasing frequency of bluetongue.* Drought can concentrate animals (e.g., deer, moose, birds) around water sources, increasing the transmission of disease and compounding the effects of outbreaks. In the summer drought of 2015, hundreds of white-tailed deer were killed by an outbreak of bluetongue (a viral disease transmitted by gnats or midges) spread by deer congregating near wetlands and lakes that retained surface water during the drought.
- *Increasing parasite loads.* Warmer winters and a longer warm season are driving increases in the prevalence of ticks, resulting in greater parasite burdens on animal hosts of ticks. In species like moose that are particularly susceptible to ticks, high tick loads can weaken animals (particularly young animals) and make them vulnerable to predation.[97] This has been linked to moose declines in Idaho.
- *Increasing prevalence of disease in hatcheries.* In aquatic environments, warming waters are increasing risks of disease outbreaks in fish populations in streams and lakes as well as in hatcheries. For example, in 2020, warm temperatures in a rearing pond at the Ringold Springs Hatchery were linked to an outbreak of the parasite *Ichthyophthirius multifilis*, resulting in the loss of nearly 150,000 steelhead.

Monitoring is often a key element of recovery plans. Some impacts of climate change may make monitoring more difficult and costly. Examples include:

- *Challenges to snow track surveys.* Winter snow track surveys are a frequently used monitoring tool for many threatened species (e.g., wolves, lynx, woodland caribou), and the loss of winter snowpack in many basins will require more difficult and costly alternative survey methods.
- *Seasonal shifts and climate variability.* Climate-driven changes in phenology and seasonality of species occurrence create uncertainty for planning field seasons. More variable conditions can lead to missed opportunities for surveys, requiring longer survey periods (and therefore greater cost) to achieve the same level of sampling.
- *Range shifts*. Populations may shift their geographic distributions relative to traditional survey areas, affecting the continuity of long-term monitoring efforts and datasets and requiring changes in the area monitored.
- *Declining species abundance*. For species that become rare in future climates, inventory and monitoring are likely to become more difficult and expensive.

Investments in habitat restoration, land acquisition, reintroductions and habitat protection for threatened species may lose value due to natural disturbances and species shifting their ranges or becoming extirpated. Examples include:

[97] Weiskopf, Sarah R., Olivia E. Ledee, and Laura M. Thompson. "Climate change effects on deer and moose in the Midwest." The Journal of Wildlife Management 83.4 (2019): 769-781.

- *Increasing risks to pygmy rabbits*. Since 2001, WDFW has invested in a captive breeding program to recover pygmy rabbits in eastern Washington. In 2011, populations were reintroduced into the wild at three locations. In 2020, the Cold Springs and Pearl Hill fires killed off the largest and most robust of the three populations (Jameson Lake), reducing the statewide population of pygmy rabbits by about half. Future projections of increasing fire frequency and severity in the sagebrush ecosystem place the agency's investments in pygmy rabbit recovery further at risk.
- *Increasing risks to greater sage-grouse.* To bolster declining populations and expand the range of greater sage-grouse, WDFW has translocated birds from out-of-state into occupied habitat and reintroduced birds into areas where they were formerly extirpated. Recent wildfires in the sagebrush ecosystem have destroyed sage-grouse habitat, resulting in loss of leks and local breeding populations. Future projections of increasing fire in the sagebrush ecosystem put these investments in sage-grouse recovery at risk.
- *Increasing risks to lynx and wolverine.* WDFW has invested resources in habitat management for montane, snow-dependent species like Canada lynx and wolverine. The projected loss of snowpack in most mixed rain and snow basins of the Cascades may drive a range contraction for such species that sees their extirpation from the lower elevations and latitudes of their distributions, resulting in their disappearance from Washington despite investments to retain them in the state.
- *Increasing risks to cold-water fish.* WDFW has invested significant resources into stream restoration projects (e.g., increasing riparian vegetation and canopy cover, increasing the complexity of stream channels) and fish passage infrastructure (e.g., larger culverts, fish ladders) to help support salmon and other cold-water fish. Reduced summer flows and warming stream temperatures put those investments at risk, threatening the extirpation of cold-water species and favoring warm-water invasive species.

Expanding populations of invasive species negatively influence the agency's ability to achieve species recovery objectives. Examples include:

- *Expanding cheatgrass.* Sagebrush steppe habitat is vulnerable to invasion by brome grasses, including cheatgrass (*Bromus tectorum*), which establish readily following disturbance events (e.g., wildfire or improper grazing practices) and can form in dense stands across the landscape. These structural changes can negatively influence species that inhabit the sagebrush steppe ecosystem. For example, the pygmy rabbit relies on sagebrush steppe habitat year round for food and shelter. Cheatgrass produces dense root matts which can prevent pygmy rabbit burrow formation. Since 2011, thousands of rabbits have been released into the Sagebrush Flat Wildlife Area in Douglas County as part of a robust pygmy rabbit recovery strategy. Ongoing cheatgrass control is part of the management plan for the wildlife area, however, record-breaking wildfire seasons in recent years coupled with invasive grass species have reduced the area of suitable habitat for this species, challenging this WDFW's recovery efforts.

2.2 Risks to Harvest and Recreation Opportunities

WDFW provides access for hunting, fishing and wildlife-related recreation throughout the state. These activities occur primarily across the one million acres of WDFW-owned lands and waters throughout the state.

Wildfire and smoke, warming oceans and streams, shifts in snowpack and altered hydrology, ocean acidification, sea level rise and resulting shifts in the distribution of species and the habitats that support them are likely to impact WDFW's ability to provide harvest and recreation opportunities to Washingtonians.

Climate change is likely to exacerbate existing challenges to fish hatchery management and fishing opportunities across the state via warming stream temperatures, projected declines in summer flows, increasing prevalence of disease and invasive species, as well as sea level rise. Examples include:

- *Impaired water quality and thermal barriers.* Warming stream temperatures and low summer flows are an ongoing challenge for the agency's freshwater fisheries. By the end of June 2015, more than 12 of the 83 fish hatcheries operated by WDFW were experiencing high water temperatures or low water levels as a result of the 2015 snowpack drought. For example, the Soos Creek hatchery lost half (34,000 fish) of its summer steelhead population and 18% of coho juveniles (153,000 fish) in June due to disease spread, which was exacerbated by warm water temperatures. The 2015 drought also resulted in fishing restrictions or closures in more than 30 rivers and tributaries throughout Washington state. These closures were a result of low water levels and high water temperatures, which can be lethal to fish populations.
- *Increasing prevalence of invasive species.* Increasing water temperatures and declining summer streamflows could favor the spread of warm-water invasive species which prey on native salmon species. Lake Washington sockeye salmon populations have declined over the past two decades, and there have been no Lake Washington sockeye fisheries since 2006. The primary cause of the population decline is predation of juvenile salmon by invasive, predatory fish including walleye (*Sander vitreus*) and largemouth and smallmouth bass (*Micropterus salmoides* and *Micropterus dolomieu*, respectively). Additionally, in Banks Lake, a 27-mile long reservoir in central Washington, Kokanee salmon populations have declined dramatically since the 1970s -- with Kokanee now being virtually non-existent in Banks Lake. The Kokanee population declines are largely attributed to predation by invasive warmwater fish species.

- *Sea level rise.* Sea level rise can affect nearshore habits (e.g., beaches, estuaries, and embayments) via increased inundation, impacts from waves, saltwater intrusion (i.e., increase the salinity of groundwater and porewater), and a rising of groundwater surface elevation which can cause flooding from below. These nearshore habitats are important habitats for shellfish, forage fish, and salmon.

Climate change is likely to result in more frequent closures of recreational shellfish harvest along Washington's coast due to impacts on shellfish populations and increasing incidence of harmful algal blooms. Examples include:

- *Multiple stressors affecting shellfish.* Climate change is expected to exacerbate existing stressors on shellfish populations. Recent large-scale shellfish mortality events (e.g., the 2018 die-offs in Willapa Bay, South Puget Sound, Hood Canal and other coastal harvest areas) far exceed the shellfish "summer mortality" occasionally reported by shellfish producers. While the cause of these die-offs has not been confirmed, it is likely there are multiple drivers, which may include high water temperatures, low water oxygen levels or above average concentrations of harmful algae.[98]
- *Increasing* o*cean acidification.* Acidifying oceans affect the growth, reproduction and survival of many shelled organisms (e.g., oysters, clams, mussels, crabs) in Puget Sound and Washington's outer coast.
- *Increasing frequency of harmful algal blooms.* Ocean acidification may increase the toxicity of some harmful algal blooms. For example, studies have found that the high carbon dioxide conditions that occur with ocean acidification in combination with silicate limitation increases the toxicity of the domoic acid-producing diatom *Pseudo-nitzschia fraudulenta.* While silicate is not currently a limiting resource in Washington's marine waters, observations do suggest silicate is declining in abundance relative to nitrogen concentrations. This suggests that Puget Sound conditions may shift from nitrogen- to silicate-limited in the future. In the winter of 2020, WDFW closed crab fishing between Queets River and Point Chehalis due to concentrations of domoic acid that exceeded thresholds established by the Washington Department of Health. Previous to this closure, crab fishing had not been restricted since 2015.

Cascading impacts from food web disruptions and harmful algal blooms are likely to exacerbate ongoing challenges to WDFW's management and preservation of marine species. Examples include:

- *Increasingly common marine heatwaves.* Coastal ocean surface temperatures are projected to increase and exacerbate marine food web disruptions. During the 2013-2014 winter a large area of anomalously warm water (sea surface temperatures were approximately 2°F to 7°F above average) developed off the west coast from Alaska to California. This marine heatwave event, known as

[98] https://wdfw.medium.com/whats-been-causing-mass-shellfish-die-offs-around-puget-sound-1ada7071a242

"the Blob," persisted through 2015 and resulted in numerous changes to marine and coastal ecosystems, including harmful algal blooms and changes in the geographical range and diet of marine mammals and fish.

- *Disruptions to marine food webs.* 'The Blob' also caused significant disruptions in forage fish and zooplankton abundance and distribution, leading to cascading impacts on marine mammals and seabirds further up the food chain. For example, in the fall of 2014, tens of thousands of Cassin's auklet (*Ptychoramphus aleuticus*) carcasses were discovered on beaches from California to Washington. These birds starved to death due to low abundance of krill and copepods, the species' primary food source. Game fish like salmon were also widely affected. One study observed marked declines in juvenile coho and chinook salmon during the 2015 marine heat wave and extending for several years afterwards. The reduced abundance of juvenile salmon is expected to lead to cascading declines in abundance of adult fish.[99]

Visitation rates to WDFW lands are growing as people continue to move to our region, but wildfire, smoke, and flooding are increasingly disrupting access. Examples include:

- *Increasingly common wildfire closures.* Wildfires have forced WDFW to temporarily close public access to wildlife areas to help ensure public safety during these events. For example, in 2019, a wildfire in Yakima County resulted in a WDFW closure of 50,000 acres in the Wenas Wildlife Area to help protect firefighters and the public.[100] This same wildfire event also resulted in the closure of 5,000 acres of the Oak Creek Wildlife Area.[101] In 2018, WDFW closed the Methow Wildlife Area shooting range to reduce the risk of wildfire.[6] This closure was motivated by extremely dry conditions in the Methow Valley, where the shooting range provided ample opportunity for a human-caused wildfire ignition. Wildfire closures are even occurring in west-side forests. In 2017, the south unit of the Scatter Creek Wildlife Area experienced a 494 acre wildfire that burned a historic barn and a previously restored native prairie. Access to this unit was closed or limited for two years post-fire. Climate change is accelerating the risk of wildfires throughout Washington state, which is likely to result in more wildfire-related closures on WDFW lands.
- *Increasingly common flood closures.* In May of 2018, flooding forced the closure of several roads at campgrounds at three wildlife areas and numerous water access sites in Okanogan County. This flooding was caused by above average temperatures which rapidly melted heavy snowpack, flooding north central

[99] Morgan, C.A., Beckman, B.R., Weitkamp, L.A. and Fresh, K.L. (2019), Recent Ecosystem Disturbance in the Northern California Current. Fisheries, 44: 465-474
[100] https://wdfw.wa.gov/news/wildfire-closes-50000-acres-wenas-wildlife-area
[101] https://wdfw.wa.gov/news/left-hand-fire-closes-5000-acres-oak-creek-wildlife-area

Washington's rivers and streams. Increasing future flood risks in coastal areas and along rivers is likely to make closures like this more common.

Climate change may also lead to hunting permit constraints for species declining due to climate impacts. Examples include:

- *Declining moose population.* Climate change may exacerbate challenges to hunted species that are already experiencing population declines. For example, moose (*Alces alces*) populations are declining in Washington. There are a variety of contributing factors to this decline including predation by wolves, parasites and starvation; climate change is likely to exacerbate this decline.[102] This may limit the number of moose permits available per season.
- *Declining geese populations.* In the winter of 2019, WDFW had to restrict the hunting season for brant geese to three days (from its typical eight-day length) due to low population numbers. The low species counts required the agency to prioritize conservation responsibilities, while providing harvest opportunities when appropriate.[103] Brants breed in the arctic and stop over in Washington during their winter migration south. Increasing temperatures are projected to result in range contractions of the species breeding habitat in the arctic regions.[104]

Sustained high levels of people migrating to Washington, potentially driven, in part, by the relative stability and attractiveness of our Pacific Northwest climate, may challenge WDFW to provide adequate harvest and recreation opportunities in the future, particularly if recent increases in the popularity of outdoor recreation, hunting, and fishing persist.

- *Future immigration.* The long-term migration rate into Washington has averaged about 48,700 people per year since 1990, and the state forecasts that will continue through 2040. As the climate in other regions (e.g. the southern United States) becomes less suitable for human health and well-being, the increasingly suitable Pacific Northwest climate may drive higher rates of climate migrations to our region.[105] A large influx of potential new hunters and anglers at a time when climate change is posing challenges to sustaining viable populations of game species could put at risk the ability of WDFW to provide these opportunities in the future.
- *Rising popularity of outdoor recreation.* The number of people engaging in outdoor recreation, including fishing and hunting, increased markedly during the 2020-2021 coronavirus pandemic. In 2020, WDFW sold 45,000 more fishing licenses and 12,000 more hunting licenses compared to 2019. That represents a

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[102] https://crosscut.com/2018/10/washingtons-first-ever-moose-census
[103] https://wdfw.wa.gov/news/brant-seasons-restrict-hunting-skagit-provide-opportunities-other-counties
[104] https://www.audubon.org/field-guide/bird/brant
[105] Future of the human climate niche Chi Xu, Timothy A. Kohler, Timothy M. Lenton, Jens-Christian Svenning, Marten Scheffer. Proceedings of the National Academy of Sciences May 2020, 117 (21)

16% increase in fishing license sales and a 40% increase in hunting license sales. Sales of Discover Passes for access to state lands increased 19%. Hunter education class enrollment more than doubled in 2020 compared to 2019.[106] These increases at least temporarily reversed a long-term trend of declining rates of hunting and fishing in the state. It is uncertain whether the recent increases in these activities will be sustained. If these activities remain popular and our population continues to grow, it could become more challenging for WDFW to provide harvest and recreation opportunities in the future.

2.3 Risks to Providing Effective Technical Assistance, Permitting, Research and Planning

WDFW provides technical assistance, permitting, research and planning support to a broad array of stakeholders across the state, with the goal of ensuring industry, infrastructure, recreation, agriculture, forestry and other human activities are compatible with healthy fish and wildlife populations. This includes guidance for managing our state's infrastructure, lands and waters to protect fish and wildlife habitat, restoring habitat, as well as research and planning to support management of game species and recovery of at-risk species.

Many of WDFW's technical assistance, permitting, research and planning activities are based on best practices derived from many decades of past experience. However, those practices were developed in an historical climate that is now changing rapidly. These shifting baselines and the high uncertainty around future conditions are making it increasingly challenging to provide effective guidance to stakeholders.

Climate change is impacting WDFW's ability to provide effective permitting, design and mitigation guidance related to infrastructure projects for energy production, flood management, fish passage and water storage. Climate change is shifting conditions from past baselines, requiring new recommendations that anticipate future conditions while addressing the uncertainty in future projections. Examples include:

- *Wind and solar power impacts to wildlife.* Wind power currently generates 8,326 GWh of electricity in Washington, comprising about 7.3% of total power generation in the state. Wind turbines have been linked to high mortality rates among raptors and bats. The sight and sound of wind turbines has also been linked to behavioral avoidance by wildlife, causing habitat loss and fragmentation. New solar power projects planned for Washington, most of which are proposed to be sited in shrubsteppe and grassland communities, also have the potential to degrade and fragment habitat. Permitting and guidance on the siting and construction of new wind and solar farms as climate mitigation efforts accelerate will require knowledge of their potential impacts on populations now and in the future given shifting species ranges.

[106] www.chronline.com/stories/pandemic-brings-record-hunting-and-fishing-license-revenues-for-washington,260081

- *Culvert and bridge design.* Most culverts and bridges are designed to last 50 to 100 years under current stream conditions. Designing structures to be resilient to future changes in stream conditions can reduce the risks of culverts and bridges failing and blocking fish passage. Hydraulic Permit Approvals based on past streamflow baselines may not provide adequate protection for fish over the projected life of the structure.

Climate change is impacting WDFW's ability to provide effective research, technical assistance and planning to protect habitat for fish and wildlife. Recommendations related to forest practices, wildlife conflict, water rights, water access management, invasive species control, disease control and agricultural leases based on the historical climate may become less relevant and effective under future climatic conditions. Examples include:

- *Guidance and recommendations based on past conditions.* Recommendations based on past norms may not be adequate to protect species in the future and are at risk of becoming obsolete or irrelevant. For example, current forest practices guidance for sizing riparian management zones may have reduced effectiveness due to future changes in streamflow and morphology.
- *Competing goals.* Guidance for different management concerns may be increasingly at odds under climate change. For example, recommendations for fuels reductions to reduce fire risk around homes near streams and lakes goes against recommendations for restoring riparian vegetation that supports salmon habitat.
- *Outdated models for informing wildlife management decisions.* A number of modeling exercises have been conducted over the past 20 years to map potential habitat and connectivity areas for a range of species across the state. However, the base data that was used in those models is now up to 20 years or more out-of-date. Wildfire, timber harvest, urban growth, and other impacts have dramatically changed regional ecosystems over recent decades. In highly dynamic landscapes, habitat and connectivity models become rapidly out-of-date and therefore less valuable for guiding habitat management decisions. Also, many of the existing habitat and connectivity models for our region do not project and account for the future impacts of climate change, so management decisions based on those models do not anticipate future risks.

Climate change is affecting WDFW's ability to provide effective research and technical assistance for restoring habitat for fish and wildlife. In a rapidly changing climate, restoration approaches that were effective in the past may not be effective in the future. Examples include:

- *Adaptations to future climate.* Commonly recommended species of trees, shrubs, grasses and forbs to plant for riparian restoration projects may not be adapted to future climates or may be outcompeted by expanding populations of invasive species.

- *Sea level rise impacts and nearshore restoration.* Failure to consider sea level rise in technical assistance to support restoration of nearshore habitats may result in wasted investments if future coastal flooding impacts restored sites.
- *Future flood risk and in-stream restoration.* Guidance for in-stream restoration that does not anticipate future streamflows and morphology could be ineffective for streams where future flood risk increases or summer flows decline.

Climate change is affecting WDFW's ability to provide effective research, technical assistance and planning to enable WDFW and other organizations to achieve their conservation mandates. Assessing the status of threatened species, making decisions on listing species, managing and prioritizing habitat for recovery goals, State Environmental Policy Act review, and species recovery plans are all made more difficult due to future uncertainties around climate and land-use change as well as complex species responses to these stressors. Examples include:

- *Species recovery planning.* Recovery planning for lynx, wolverine and other climate-sensitive, at-risk species requires strategies that account for the present and future needs of species to have sufficient area of high quality habitat (e.g., to support stable breeding populations) and sufficient habitat connectivity (e.g., to facilitate range shifts, support viable demographics and maintain gene flow). Habitat and connectivity are difficult to project into an uncertain future, making it challenging for WDFW to devise effective recovery plans that meet recovery goals under future climates.
- *Siting of wildlife crossing structures.* Recent and continued investments in wildlife crossing structures over major state highways and interstate highways require careful planning to ensure they align with potential movement corridors of target species. Shifts in species ranges and migration routes may make it more challenging to optimally locate wildlife crossing structures.

2.4 Risks to WDFW Lands and Infrastructure

Climate change not only poses risks to WDFW operations, but also to the more than one million acres of WDFW-owned lands and supporting infrastructure the agency relies on to achieve its mission. Projected increases in flood risk, wildfire risk, sea level rise, expanding populations of invasive species and pathogens, and shifting vegetation and disturbance regimes have the potential to cause closures and diminish the value of WDFW-owned lands and put agency infrastructure at risk.

Riverine flooding due to increases in winter precipitation, declining snowpack and projected increases in the intensity of extreme precipitation events threatens WDFW infrastructure and lands. Examples include:

- *Flood damage to infrastructure.* More frequent and intense extreme precipitation events are likely to cause flood damage to WDFW infrastructure. For example, in 2006, record rainfall during an atmospheric river event caused an estimated one million dollars in damages to WDFW fish hatcheries and other facilities in 13 western Washington counties. Runoff debris clogged hatchery intake pipes, increased sediment loads clogged water filters and flooded creeks transported downed logs which damaged dams and fish ladders. A flood on the Tucannon River and subsequent debris flows caused significant damage to infrastructure in the W.T. Wooten Wildlife Area. Damages from this event included a road washout, footbridge damage, a flooded campground, and damage to a dam, roadways and trails. During the February 2020 flood event the Tucannon River was flowing into Deer Lake, causing the lake to overfill and water to run over the dam around the north and west sides of the lake. This caused spots in the dam to weaken and water to continue to run through the dam at high lake levels. This event is likely to result in the construction of a new lake just south of the existing Deer Lake.
- *Increased future flood risk.* As watersheds become increasingly rain dominant with warming, winter streamflow is projected to increase across Washington. This is likely to exacerbate incidence of damage to agency lands and infrastructure during flood events.

Increasing rates of erosion and sediment transport in winter and spring are likely to exacerbate ongoing challenges related to sediment deposition and water-quality issues. Examples include:

- *Increasing sediment accumulation at dams.* WDFW owns and manages 44 dams throughout the state and provides permitting and management guidance to dam operators state-wide. Increasing sediment loads due to flooding will require increased maintenance (e.g., sediment removal). For example, Roza Dam (owned and operated by the US Bureau of Reclamation) forms an impoundment, Roza Pool, where fine sediment material accumulates on the upstream side of the dam and has occasionally cut off water flow to a low-flow fish ladder intake. In addition to the staff capacity and funds required to remove the sediment, the reductions in flow for the low-flow fish ladder can cause migration delays for salmon, steelhead and trout.

- *More common sediment burial of boat ramps.* Winter flood events in 2006 and 2007 resulted in sediment deposition on boat launches, which prevented access and use of these ramps. Approximately 10 cubic yards of sediment was removed from the emergency access boat ramp located 10 yards upstream of the SolDuc Hatchery. Future increases in flood risk will require greater investments to clear boat ramps after flood events.
- *Increasing risk of mudslides and landslides.* Future increases in risk of mudslides and landslides will require increasing investment to maintain roads and other agency infrastructure. During a flood event in February 2020, several mudslides occurred on WDFW managed lands in southeastern Washington. Slides were observed at Deer Lake, south of Little Tucannon River and at the access road to a campground in the Wooten Wildlife Area. While they did not directly damage any infrastructure, these events all required clean-up efforts as many of the slides were blocking or partially obstructing road access. Projected changes in rainfall, snowpack and streamflow may lead to an increase in landslide risk in fall, winter and spring, while reducing such risk in summer.

Increasing area and frequency of wildfire is increasing the risk of damage to infrastructure, diminishing the habitat value of agency lands and reducing access to lands during closures.

- *Increasing wildfire impacts.* In the 2015 fire season alone, 30,000 acres of WDFW lands burned. The impacts from this catastrophic wildfire season were widespread across the agency, including timber loss, more than 90 miles of fence burned, impacts to grazing lessees, infrastructure and trail damage, and destruction of signs and kiosks. Many of the affected wildlife areas across the state are still working on fence replacement, habitat restoration efforts including dozer lines, reseeding and erosion management. WDFW is also focusing efforts on hazard tree removal and timber restoration and management in response to these burn events - all of which require staff time. Warming is projected to result in larger and more frequent wildfires on both sides of the Cascades in Washington, likely resulting in additional damage to agency-managed lands and agency-owned infrastructure.
- *Increasingly common post-fire debris flows.* Fast-moving debris flows initiated by heavy precipitation events can be extremely destructive post-wildfire events. Wildfires burn through vegetation and expose soil on the landscape, which can mobilize quickly during a heavy rainfall event. These debris flows or mudslides can occur quickly and may destroy existing vegetation, block drainage or roads, fill and block culverts and damage infrastructure. Increasing frequency of wildfire and storm events will exacerbate these risks in the future.

Box 2. WDFW Adapts by Altering Fence Construction Materials

One of the most costly impacts stemming from weather and climate-related events to WDFW is replacing miles of fencing after wildfires burn the wood posts. Since 2009, the agency has altered its fence construction materials, using 2-inch steel pipe that is able to withstand wildfire events. While the steel posts are a higher upfront cost, the agency is ultimately saving money on both materials costs and staff time, because the steel posts are much less likely to need replacement.

Box 2 Figure. Burned fence posts in the Swanson Lake Wildlife Area following a wildfire in 2020.

SECTION 3 – OPPORTUNITIES FOR ACTION

Mitigating the climate risks described in Section 2 will require new policies, regulations, guidance and management plans to proactively address threats before increasingly severe impacts limit options and raise costs. Managing these climate risks will require new investments in research, monitoring, tools and data management to track and assess changing conditions and to inform adaptive policy and management. This risk management will require more staff capacity, training and coordination, and it will require greater outreach, communication, collaboration and partnerships to link agency actions to external partners and stakeholders. Some of these changes are already underway and can be expanded upon; others will take more time and capacity to implement.

In this section, we summarize potential opportunities for actions, based on results from internal agency workshops conducted in 2020. Many of these actions are already underway within WDFW and/or partner organizations. Here we do not distinguish between actions that can be undertaken by WDFW alone and those that will require partnerships, new authorities, or other concerns. Also, this list is not an exhaustive inventory of all possible actions, nor does it represent a formal strategy. Rather, it is a starting point intended to inspire development and ongoing review of a comprehensive and rigorous agency climate adaptation strategy. The sub-sections below describe major themes emerging from this list, with bold statements describing relevant actions and bulleted statements highlighting specific examples.

3.1 Policy, Regulations, Guidance and Management Plans

Current WDFW policy, regulations, guidance and management plans generally reflect practices of the past, which tend to follow rigid planning cycles that are inflexible to rapidly changing conditions. However, the recent agency response to COVID-19 - a rapid, sweeping and broadly successful re-imagining of virtually every element of daily operations - demonstrates WDFW's capacity to experiment, adapt and thrive in the face of unexpected challenges. Efforts to make WDFW more nimble and responsive to our rapidly changing world and more capable of anticipating and acting on future risks will help make our agency more effective in achieving its mission and more resilient to the impacts of climate change.

Employing more nimble and responsive adaptive management strategies will help WDFW maintain operations and achieve the agency's mission despite rapidly changing conditions. Examples include:

- *Adaptive fisheries management*. Decision-support tools could be devised that tie fisheries management to current and forecasted conditions, so that harvest planning is responsive to changing climate risks and environmental conditions (e.g., marine heat waves). With sufficient monitoring, closures could be selective and limited only to affected species. For example, when an intense marine heatwave affected the eastern Pacific in 2015, WDFW closed many fisheries without linking the closures to observational data. A data-driven approach based on key indicators (similar to the Pacific Fisheries Management Council's ecosystem management approach) would allow the agency to be more precise in deciding how to manage fisheries while also being more effective in achieving long-term goals.
- *Adaptive water quality management.* Water quality regulatory agreements and permits (e.g., Hydraulic Permit Approvals, Clean Water Act discharge permits) could be made more flexible and responsive to changing conditions to maintain healthy fish habitat, for example by linking them to the current status and forecasts of relevant indicators.
- *Adaptive dam and reservoir management.* WDFW actively works to support and advise the setting of environmental flows to maintain adequate streamflow levels. Additional work could be done to research how environmental flows can be improved to maintain key ecological processes including channel forming process flows and streamflow during critical low flow periods. Operational adjustments to provide adequate flow and thermal environments for fish could help mitigate the impacts of summer drought and warming temperatures. This could be done in an adaptive manner based on current and forecasted levels of relevant indicators. WDFW could also provide more technical support to the Washington Department of Ecology and dam operators to better incorporate fish impacts into water quality management plans. Further, a policy on cold water refugia could be developed that helps manage habitat for cold-water

species on the Columbia and other rivers impacted by dam operations. Federal Energy Regulatory Commission license renewals could be tied to such policies.

- *Adaptive hatchery management.* Hatchery and Genetic Management plans could be revised to better consider climate impacts, including adapting hatchery broodstocks, feeding, rearing and release strategies to shifting river conditions. Hatchery management downstream of dams could be more adaptively linked to dam management, so that water levels and temperatures are better controlled during periods of low flow and high temperature. Testing a range of hatchery management strategies and matching them to changing conditions will be important. This may require that hatcheries operate, in part, as research sites in addition to being production facilities.
- *Adaptive harvest limits for game species.* Harvest limits for game species could be more adaptively linked to survey data and future projections given climate change scenarios to better sustain hunting opportunities long-term. This could be done per game management unit but based on a regional-scale adaptive management plan to sustain harvest opportunities over time.
- *Adaptive species recovery management.* Species recovery plans could be more adaptively linked to habitat management so that as conditions on the ground change (e.g., as wildfire and timber harvest affect forest structure, pattern and connectivity), recovery plans for forest-dependent species like lynx and fisher could be modified to be responsive. Mitigation agreements could similarly be adaptive and responsive to current conditions.

Updating regulations, stakeholder guidance and management plans relating to infrastructure to better address climate risks will help protect infrastructure from costly damage and improve resilience of affected species (e.g., fish passage affected by culvert design, fish survival affected by reservoir management). Examples include:

- *Climate-smart culvert designs*. It could be made mandatory to design new culverts for projected future flows and also provide fish passage in future code revisions. Code revisions related to Hydraulic Project Approvals for culverts could require the use of the climate adapted culverts tool.

Box 3. Climate Adapted Culverts

Many culverts across the state are currently inadequate for fish passage and unable to withstand higher future peak streamflows. WDFW has studied the required culvert widths to accommodate projected future streamflow and fish passage. That information is being used as the basis for the climate adapted culverts tool being developed by WDFW and the University of Washington Climate Impacts Group. This tool estimates the likelihood that a particular culvert size will fail as a result of projected future flows over a user-specified design lifetime. Using this tool and other information to design and construct more climate-adapted culverts can help these critical elements of our infrastructure function under future conditions and also improve habitat connectivity for fish.

Box 3 Figure. A culvert replacement project in Potlatch State Park..

- *Climate-smart coastal infrastructure.* Sea level rise projections could be incorporated into engineering designs for coastal infrastructure. For example, WDFW is already a participating member of the Washington Coastal Hazards Resilience Network, which seeks to improve regional coordination and collaboration in efforts that address the impacts of coastal hazards and climate change while increasing the resilience of Washington's shorelines. New tools for visualizing sea level rise projections and assessing risks are also available. Growth Management Act revisions could help avoid new construction in areas at risk of coastal flooding due to sea level rise. Woody debris and other measures to reduce erosion and buffer against coastal flooding can also improve coastal resilience.
- *Climate-smart floodplain infrastructure.* The siting and design of trails, trailheads, campsites, hatcheries and other WDFW infrastructure could better incorporate projected future streamflows and flood risk to reduce vulnerability to flooding and debris flows.

Recommending (externally to stakeholders) and adopting (internally) policies and plans that improve habitat connectivity for terrestrial and freshwater aquatic species will help facilitate species range shifts and improve population demographics. Examples include:

- *Map and protect fish and wildlife corridors.* Management strategies could be created that prioritize mapping (at a broad regional scale) and protecting fish and wildlife corridors to help facilitate species range shifts. Revising the criteria by which we define priority habitats to include connectivity value could be one mechanism for increasing protection of connectivity areas.
- *Mitigate migration barriers in terrestrial habitats and streams.* Where migration barriers have been identified that may impede species range shifts, barrier mitigation actions (e.g., wildlife crossing structures or access management) could be implemented. The I-90 Snoqualmie Pass East Project is an example of a barrier mitigation projection designed to increase connectivity for wildlife in the central Cascades, likely improving the climate-resilience of many montane and alpine species in the region. In freshwater streams, improving fish passage with new climate-adapted culvert designs is an example of a barrier mitigation strategy already being implemented on WDFW lands and being advised to stakeholders.
- *Transboundary collaboration.* The challenge of facilitating species range shifts under climate change extends to regional scales and requires coordinated transboundary management of habitat connectivity. Increasing transboundary collaboration around connectivity conservation would help align efforts across the region to support species resilience.

Modifying forest practices and shrub-steppe management plans to improve resilience to wildfire will help support fire-sensitive species and habitats and also help protect property and infrastructure. Examples include:

- *Climate-smart forest practices*. Historical fire suppression and exclusion in fire-adapted forests has resulted in denser forests at higher risk of catastrophic fire. WDFW could more actively support habitat-friendly fire risk reduction (e.g., thinning forests and applying prescribed burns to help mimic natural forest conditions before the era of fire suppression) on non-agency lands. Retaining riparian vegetation and late-seral forests is an important consideration when taking action to reduce fire risks.
- *Climate-smart shrub-steppe management.* Recent fires in Washington's sagebrush habitats have further imperiled and set back recovery of the state's greater sage-grouse, Columbian sharp-tailed grouse, and Columbia Basin pygmy rabbit populations, as well as other sagebrush-obligate species. Proactive habitat management planning and implementation on WDFW lands and across the shrubsteppe landscape with partners and landowners may help to improve recovery and resiliency of these habitats to future fires and possibly help reduce their extent. Actions could include restoration planting (both pre- and post-fire) in key areas, managing strategic fire-breaks, and advanced planning for equipment and resource staging. Adaptively managing fire in this system will be important to maintain a functioning mosaic of shrubland and grassland habitats that supports regional shrubsteppe species.

Modifying water management policy and regulations to support water conservation and improve water storage and recharge would help maintain summer streamflow for fish. Examples include:

- *Improved surface water management.* To help maintain stream levels, particularly in summer, WDFW could advocate for additional instream protections and the use of in-kind (i.e., water-for-water) mitigation.
- *Improved groundwater management.* Expanding issuance of HPAs for projects specifically designed to improve streamflows could present opportunities for WDFW to require climate considerations during project development. WDFW could also advocate for research and refinement of active and passive groundwater recharge projects to increase streamflow in reaches affected by low summer flows and conduct research to improve statewide mapping of reaches affected by low flows and high temperatures. For example, research on the effectiveness of off-channel impoundments could be conducted to inform strategies to slow stormwater runoff, increase infiltration and improve return flow to aquifers and streams. Findings could be used to develop science-based restoration guidance and set restoration priorities.

- *Expanded beaver management policy.* Beavers could be reintroduced to areas where they were previously extirpated as a natural solution to holding more water in watersheds and helping to provide sustained flows and lower stream temperatures during summer. Alternatively, beaver dam analogues or similar process-based strategies could be constructed to improve streamflow processes..

Managing wildlife areas with greater anticipation of future conditions will help WDFW lands contribute to ecosystem resilience in Washington. Examples include:

- *Manage for adaptive species assemblages.* Wildlife Area Plans could be adapted to reflect changing ecosystems. Rather than focus on retaining current species assemblages, plans could focus on supporting potentially novel communities of species that can adapt to changing conditions.
- *Increased use of assisted migration and assisted gene flow*. Species that are present at a site but maladapted to future conditions could be augmented (or replaced after disturbance) with species in nearby climates that are better adapted to future site conditions (i.e., assisted migration). Similarly - and likely with lower potential risk (e.g., of invasion) - native species already at a site could be augmented by individuals from populations at sites that may be closer in climate to anticipated future conditions (i.e., assisted gene flow). Tools like the seedlot selection tool can help inform choice of future climate-adapted species to plant.
- *Incorporate future risks into planning.* Current agency plans for managing Wildlife Areas, species and habitats tend to be focused on current conditions and near-term risks and opportunities. Incorporating future risks into planning and implementing risk mitigation actions now could help avoid more costly impacts later, including additional extinctions, extirpations, range contractions, reduced harvest and recreation opportunities, and damage to agency lands and infrastructure.

3.2 Research, Monitoring, Tools, and Data Management

New investments will be required in research, monitoring, tools and data management to keep managers informed about impacts to ecosystems and natural resources as they occur, and help guide more effective management responses to mitigate the impacts of climate change.

Increased monitoring is required to better track how species and habitats are responding to climate change, adjust management plans accordingly, and assess the effectiveness of agency actions and policy. *Examples include:*

- *Increased monitoring of native fish and shellfish*. Regular monitoring is needed to track trends in ocean and freshwater environmental indicators and the abundance and distribution of native fish and shellfish species that are becoming less abundant. This will help inform management responses to stressors such as ocean acidification, marine heat waves and hypoxia. More comprehensive monitoring plans are also needed to help identify which native fish and shellfish species are becoming more prevalent and of interest to recreational and commercial stakeholders (e.g., warm-water species like jellyfish, shrimp and anchovy). Increased monitoring of freshwater conditions and freshwater fish and shellfish species distributions and abundance is also needed to understand the impacts of shifting thermal and hydrological regimes so that more effective management responses can be devised. eDNA monitoring technologies hold great promise in efficiently monitoring freshwater species.

- *Increased monitoring of invasive fish and shellfish*. Additional monitoring is needed to identify trends in non-native fish and shellfish species to inform management responses and areas where treatments are necessary.
- *Adapt survey and monitoring methods to future conditions*. As species' ranges shift due to climate change, survey areas will need to be adjusted to track shifting distributions. Survey methods may also need to be modified. For example, snow tracking of moose, elk and other species will no longer be effective in the many basins expected to transition to rain-dominated systems under future warming.
- *Expanded monitoring to include additional species.* Monitoring non-game species and species that are not of greatest conservation concern is necessary to track shifting distributions (including new species arriving in Washington) and have forewarning of alarming trends that may indicate a change in conservation status for species not currently at risk.
- *Expanded monitoring of disease.* Climate change is increasing the prevalence and severity of disease across many taxa. To keep apprised of risks and track trends, additional monitoring is required. This includes monitoring of shellfish disease, forest pathogens (e.g., white pine blister rust) and insect outbreaks (e.g., mountain pine beetle) and animal pathogens (e.g., pneumonia in bighorn sheep populations).

New research is needed to understand potential impacts of climate change on species and ecosystems and translate that understanding into better technical assistance and new management strategies that increase future resilience. Examples include:

- *Predictive modeling of future conditions, species distributions and population demographics.* Anticipation of potential future risks requires new research to project future conditions and species responses. Population viability analysis could be conducted on climate-sensitive species to investigate abundances under a range of climate and management scenarios, for example. Examples of potential climate impacts that could be incorporated into population models include altered hydrology and stream temperature for cold-water fish species and future fire risk for forest species sensitive to disturbance.

- *Updated models of habitat and connectivity.* Unprecedented rates of natural and anthropogenic disturbances are driving rapid change on the landscape, with profound effects on the distribution of habitat and connectivity for terrestrial and freshwater species and ecosystems. Models of habitat and connectivity currently available to inform planning are often out-of-date relative to recent disturbances and rarely, if ever, updated. Developing new approaches to automatically and dynamically model species habitats and connectivity will provide more timely information to managers and a time series from which change can be assessed relative to management goals.
- *Adapt restoration techniques to future conditions.* Current restoration methods that have been developed for terrestrial and aquatic habitats are based on past experience and may no longer be effective under future conditions. In some cases, restoration techniques may need to be adapted to account for future site conditions. For example, this could include new species or genetic variants of plants used for restoration or new methods of stream restoration that are better adapted to future stream conditions.
- *New hatchery practices.* Hatchery operations are challenged by warming stream temperatures and reduced summer flows, conditions which increase disease risk and stress fish. New hatchery practices are needed to improve water quality and increase fish survival during warm periods and low summer flows.
- *Disease control.* In freshwater, marine and terrestrial habitats alike, stressful conditions for hosts and more permissive conditions for pathogens are increasing the prevalence and severity of disease. WDFW could partner with research organizations to develop new vaccines and other pathogen control methods to study new ways to control disease in fish and wildlife populations.
- *Better understand potential species range shifts.* Range shifts are complex ecological processes influenced by many factors and modulated by species interactions like competition and mutualisms. New research into the potential for range shifts of fish and game species, invasive species, and key prey or forage species would provide information that managers could use to better guide actions for increasing resilience.
- *Identify climatic refugia*. Climatic refugia are areas where the climate is relatively stable and likely to remain within suitable ranges for a given species. Identifying refugia for fish and game species and threatened species could help managers prioritize actions that conserve these areas and thereby increase resilience.

New tools and improved data management that enable managers to quantify and map locations of potential impacts to species, ecosystems, infrastructure and lands would offer a spatially-explicit understanding of risks and opportunities and a means to prioritize areas for actions. Examples include:

- *Scenario planning tools.* Understanding the relative advantages and disadvantages of alternative management strategies to address climate impacts is invaluable in guiding decision making. New scenario planning tools could help managers track and anticipate climate impacts (e.g., reduced snowpack, altered hydrology, wildfire, sea level rise) and adopt strategies for managing harvest, hatcheries, lands, and infrastructure in ways that mitigate future risks.
- *Dashboard of climate indicators.* Climate data and indicators available to guide adaptive management across WDFW is limited and decentralized. Investing in tracking of new indicators relevant to decision-making and making those indicators available via a centralized agency-wide dashboard would help managers easily find and track current conditions and develop adaptive responses in a timely manner.
- *Modern data repositories and databases linked across WDFW.* Our agency collects a vast amount of data on species occurrence and environmental conditions and those capabilities are likely to expand in the future given the need for additional monitoring. The agency infrastructure for storing and managing those data is currently outdated and not organized in a way that enables easy agency-wide access. Compiling WDFW data sources with other agency resources that could be useful for climate adaptation in a modern, centralized data repository would facilitate analysis of those data across the agency and serve as an agency-wide resource for environmental monitoring and research.

3.3 Staff Training, Capacity Building and Coordination

As the agency works towards prioritizing climate resilience, staff are likely to need access to information and training on projected impacts of climate change and potential adaptation options. New funding sources may also be needed to support the additional training and staff work being done to adapt to climate change.

Increasing funding to support staff allocations and create new positions will help increase the overall capacity of the agency to address climate change vulnerabilities and center resilience building efforts. Examples include:

- *Seek funding necessary to increase agency staff capacity*. Additional funding is needed to hire additional staff and to support staff time needed to appropriately implement climate resilience efforts across the agency. Agency staff are at capacity with current duties and tasks (e.g., weed control, fire suppression, etc.) and do not have the bandwidth to incorporate the most current climate science and models into agency planning and operations. Developing new positions and hiring new specialized staff (e.g., climate adaptation specialists, social scientists, statisticians, information technology personnel) can fill gaps that currently serve as barriers to climate adaptation within the agency.

Providing staff with training and education opportunities related to climate impacts and adaptation management options will enable staff to apply climate change information to program operations. Examples include:

- *Integrate climate science and climate adaptation into staff training and job descriptions.* To successfully build climate resilience across the agency, staff should be educated on potential climate impacts and adaptation options. Staff training and education on climate adaptation and emerging science should continue regularly throughout staff tenure, and should be built into existing program-specific training sessions (e.g., hatchery training). Where possible, job descriptions should explicitly include duties and responsibilities that are related to supporting climate resilience goals, and these duties should be reflected in staff allocations and budgets.
- *Connect staff with science organizations or institutions who can provide the Agency with the best available science on climate change.* These partnerships could result in a "living" curated list of sources of the best available local and regional climate science information and sources that can be used to inform agency program decisions. The list of specific climate data needs for each WDFW program should be identified and provided to staff. As necessary, programs should be provided with species- and habitat-specific climate impacts and adaptation management options. Programs should also be provided with guidelines for how to access, interpret and apply relevant climate data (e.g., using appropriate GHG scenarios, timeframes and risk tolerances).

3.4 Outreach and Communications

A strategic, agency-wide approach to building climate change into the agency's existing communication and outreach strategy will help increase public awareness of climate impacts and possible responses. In addition to outreach to the public, internal communications within the agency are also needed to facilitate dialogue s around climate-related challenges within and between teams and programs.

Improving public outreach to raise awareness of climate vulnerabilities and identify response options will be crucial in helping communities adapt to projected changes in climate. Examples include:

- *Develop agency communication and outreach strategies that integrate climate change impacts, risks and responses.* Ensure that these materials include specific messages and resources specific to each agency program to help promote consistent messaging across the agency.

- *Create and promote education and outreach opportunities in WDFW wildlife areas and hatcheries that focus on raising awareness of climate change risks.* Many Washingtonians do not fully realize the risk that climate change poses to the state's species and habitats. Education and outreach will be necessary to facilitate the adoption of actions to mitigate those risks.
- *Create new conservation opportunities for the general public.* For example, a program to educate landowners about ways they can help support beaver reintroductions would help increase the water holding capacity in streams and rivers and improve habitat for fish and wildlife.
- *Target climate-related outreach and education to passionate constituencies, including anglers and hunters.* Anglers and hunters are driving forces behind many of Washington state's conservation efforts. Outreach and communication efforts to these groups should focus on projected impacts of climate change to ecosystems and the species that inhabit them. In addition, outreach efforts can discuss observed and projected impacts of climate on agency lands and infrastructure, including flooded access roads, damaged hatcheries, and wildlife areas impacted by wildfire. This engagement provides an opportunity to explain how these impacts are likely to affect harvest opportunities and associated management decisions.

Increasing climate change-related communications capacity within the agency to produce high-quality, relevant and actionable information will help improve technical guidance to stakeholders and support them in making climate-smart decisions. Examples include:

- *Increase the agency's ability to deliver technical expertise on species and habitats that integrates climate change considerations and climate adaptation options.* Integration of projected climate change impacts and potential management options into technical guidance is needed to ensure that agency recommendations continue to be effective throughout the lifetime of a marine, terrestrial or freshwater plan or project. WDFW has an opportunity to lead in Washington by providing technical guidance that incorporates climate change considerations.

Increase communications across programs within WDFW to encourage information and data sharing and create opportunities for on-going dialogue. Examples include:

- *Host exchanges between teams and programs* to share and discuss climate-related challenges (e.g., water supply issues at hatcheries, sampling and monitoring adjustments in responses to observed changes, collaboration between science division and district biologists to share best practices for field work).

- *Create space for science-policy dialogues.* This is needed to ensure that policy adoption within the agency reflects the observed, on-going, climate-related challenges experienced by the agency. To be effective, these must be followed up with dialogues between policymakers and operations managers to ensure and facilitate implementation of those science-based policies.

3.5 Collaboration and Partnerships

WDFW needs strong partners and an integrated approach to preserve, protect and perpetuate fish, wildlife and ecosystems in the face of climate change. In order to succeed in building climate resilience across the lands, waters, species and habitats that WDFW monitors and manages, the agency must also invest in our partners' efforts to preserve, protect and manage fish and wildlife. The agency must also transition to a more integrated approach to science and management that crosses programs and integrates the social sciences.

Increasing internal WDFW collaboration across programs will be critical for providing effective climate-smart technical assistance and planning across the agency. Examples include:

- *Emphasize science-informed policy.* Shifting WDFW's focus to collaborative cross-program, cross-agency approaches, and better aligning science to policy and management needs, will improve the credibility of decision making. Strategically prioritizing, funding and delivering science products that are tied to policy and management questions will ensure that we effectively use state resources as we develop timely and effective fish and wildlife management solutions.
- *Spatial prioritization of species recovery efforts.* Cross-agency conversations can help inform the spatial prioritization of different species recovery efforts across the state of Washington. These conversations could also facilitate the translation of data into species- or habitat-specific management decisions or the identification of where species recovery funding should be directed.
- *Within-agency information and data sharing.* Data collected by agency programs likely has many applications outside of that specific program. The development of an agency-level data management system could facilitate the sharing, intake and analysis of data across programs. Ultimately, an improved data management system will provide staff with access to better science to improve agency decision-making.

Expand external partnerships to increase the capacity of WDFW to achieve its mission. Examples include:

- *Strengthen existing partnerships and promote resource pooling.* Strong partnerships are critical for WDFW's mission to preserve, protect and perpetuate fish, wildlife and ecosystems. Collaboration and strengthening partnerships - particularly with tribes and other natural resource agencies - is especially essential for building climate resilience. Partnerships can help leverage capacity and resources toward shared conservation objectives and facilitate data sharing and subsequent science-informed decision-making (e.g., monitoring datasets and research projects on vaccines and other pathogen control methods; or the state agency ocean acidification monitoring network, coordinated by the Governor's Office).

- *Increase agency credibility and relevance with partners.* Partnering with non-profit organizations and community science programs to gather important fish, wildlife and habitat data can help connect people to nature in tangible ways. Such efforts could deepen relationships and improve the Department's relevancy and credibility with residents and partners.
- *Support private landowner partnerships.* WDFW could develop a robust toolbox of incentives to encourage long- term fish, wildlife and habitat stewardship on private lands. By building partnerships with small forest landowners, the agency can better provide technical assistance for actions taken to build resilient ecosystems.

CONCLUSIONS

The risks described in Section 2 underscore the challenges climate change poses to WDFW's mission. These impacts foretell a future where many agency operations become more difficult and expensive, putting at risk the ability of WDFW to preserve, protect and perpetuate fish, wildlife and ecosystems while providing sustainable harvest, recreational and commercial opportunities. A robust plan to increase agency resilience to climate change impacts is needed to address these risks.

Increasing WDFW's climate resilience will require anticipation of future risks, careful planning for mitigation and adaptation actions to increase resilience, and an agency-wide effort to implement those actions. The pervasive nature of these risks demands a response that is distributed and integrated across all WDFW operations, rather than a centralized response from a single agency initiative. This response should be based on a shared understanding of the risks to the agency and involve strong links between science and policymakers.

Some actions (e.g., building or modifying infrastructure) may require long lead-times to complete and considerable forethought to ensure they are in place before the impact occurs, but the alternative is costly retrofits after damages have already occurred. For impacts that are too uncertain to plan for in advance, adaptive management will be required, with a strong emphasis on monitoring and adjusting plans as conditions change. This will require transitioning from what has been a relatively static and rigid management approach based on historical norms to a more nimble and flexible framework better able to respond to changing conditions.

Because the impacts of climate change occur over vast scales affecting natural and socio-economic systems alike, many aspects of WDFW resilience planning would benefit from being coordinated across management boundaries with other state and federal agencies, local governments, tribal governments, NGOs and public stakeholders. Similarly, because many of Washington's species and ecosystems extend farther north into British Columbia, coordination across the international border with federal and provincial agencies and First Nations in Canada will also be critical.

Many of the challenges described in this report are not new to the agency. However, climate change is exacerbating them and demanding greater resources and new approaches to overcome them. Already, WDFW is moving to address many of these impacts (e.g., culvert redesigns to withstand higher peak streamflow, investing in wildlife crossing structures over state highways); expanding and operationalizing WDFW's climate adaptation and mitigation efforts and, where appropriate, collaborating with other agencies, partners and stakeholders, could form the foundation of the all-hands-on-deck response demanded by the scale of the problem.

APPENDICES

Appendix A: Section 2 Tabular Summary.

If viewing the PDF, click on the underlined text to be taken to the relevant report section.

Risks to Species Recovery					
Increasing extinction risks	Recovery goals impacted	Disease increases	Monitoring more difficult and costly	Habitat investments lose value as species decline/shift	Challenges to achieving mission
Examples: Migration barriers Isolated populations Assisted migration Captive breeding and rearing	**Examples**: Snow dependent species Snow denning habitat	**Examples**: Avian cholera Bluetongue Parasites	**Examples**: Snow track surveys Seasonal shifts and climate variability Range shifts Declining abundance	**Examples:** Pygmy rabbits Greater sage-grouse Lynx and wolverine Cold water fish	**Examples**: Invasive species

Risks to harvest and recreation opportunities				
Challenges for hatchery management	**More frequent closures of shellfish harvest**	**Challenges to monitoring and management for marine species**	**Visitor access to lands limited**	**Constraints on hunting opportunity**
Examples: Impaired water quality and thermal barriers Disease Invasive species Sea level rise	Examples: Climate exacerbates existing stressors Increasing ocean acidification Harmful algal blooms increase	Examples: Marine heatwaves Marine food web	Examples: Wildfire closures Flooding impacts	Examples: Moose population declines Geese population declines

Risks to providing effective technical assistance, permitting, research and planning			
Challenges to providing permitting, design and mitigation guidance	**Research and planning focused on past conditions**	**Restoration approaches based on past conditions**	**Research and planning to achieve conservation mandate**
Examples: Wind power siting and construction Culvert and bridge design	Examples: Forest practices guidance on riparian buffers Fuels reduction versus riparian restoration Outdated models	Examples: Recommended plant species for restoration Sea level rise in nearshore restoration Instream restoration and future flows	Examples: Species recovery planning and future needs Wildlife crossing structures – track shifting ranges

Risks to WDFW Lands and Infrastructure		
Infrastructure risks from flooding and storms	**Increasing rates of erosion and sediment transport**	**Increasing area and frequency of wildfire**
Examples: Flood damage to hatcheries and WLA infrastructure Increasing future flood risk	Examples: Sediment accumulation in WDFW owned dams Sediment deposition on boat ramps Mudslide impacts on agency roads	Examples: Widespread impacts from wildfire damage Post fire debris flows

Appendix B: Section 3 Tabular Summary

If viewing the PDF, click on the underlined text to be taken to the relevant report section.

Policy, Regulations, Guidance and Management Plans					
More nimble and responsive management plans	**Updating regulations related to infrastructure**	**Adopting policies that improve habitat connectivity**	**Modify management plans to improve wildfire resilience**	**Modify policies to improve water storage and recharge**	**Manage wildlife areas for future conditions**
Examples: Fisheries Water quality Dams and discharge permits Hatchery management Harvest limits for game species Species recovery plans	Examples: Culvert sizing Coastal infrastructure Floodplain infrastructure	Examples: Map and protect wildlife corridors Mitigate migration barriers Transboundary collaboration	Examples: Forest practices Shrub steppe management	Examples: Surface water management Groundwater management Beaver management	Examples: Prepare for novel species assemblages Assisted migration and gene flow Longer planning horizons

Research, Monitoring, Tools and Data Management		
Increase monitoring	**New research to understand climate change impacts**	**New tools and data management**
Examples: Increased monitoring of native fish and shellfish Increased monitoring of invasive fish and shellfish Adapt survey and monitoring methods to future conditions Expand monitoring to include additional species Expand monitoring of disease	Examples: Predictive modeling Updated models for habitat and connectivity Adapt restoration techniques New hatchery practices Disease control Better understand potential range shifts Identify climatic refugia	Examples: Scenario planning tools Dashboard of climate indicators Modern data repositories

Staff Training, Capacity Building and Coordination	
Increasing funding for staff allocations	**Provide training and education opportunities**
Examples: Seek funding necessary to increase agency staff capacity	Examples: Integrate climate science and adaptation training into job expectations Connect staff with organizations who can provide climate science

Outreach and Communications		
Improve public outreach to raise awareness of climate vulnerabilities	**Increase climate change communication capacity within agency**	**Increase communications across programs with WDFW**
Examples: Develop agency communication strategies that integrate climate change impacts, risks, and responses Create educational opportunities on WLAs and hatcheries Create new conservation opportunities for the general public Target outreach to passionate constituencies, including anglers and hunters	Examples: Increase agency's ability to deliver technical guidance that integrates climate impacts and options	Examples: Host exchanges between teams and programs Create space for science-policy dialogues

Collaboration and Partnerships	
Increased collaboration across programs	**Expand external partnerships**
Examples: Science-informed policy Spatial prioritization of species recovery efforts Within-agency information and data sharing	Examples: Strengthen existing partnerships Increase agency credibility Support private landowner partnerships