Chapter 5: Climate Change, Fish, and Aquatic Habitat in the Blue Mountains

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Introduction

National Forest System lands in the Blue Mountains region support a diversity of important native aquatic species that will be affected by climate change. As part of the Blue Mountains Adaptation Partnership, four of these species (spring Chinook salmon (*Oncorhynchus tshawytscha* Walbaum in Artedi), bull trout (*Salvelinus confluentus* Suckley), summer steelhead (*O. mykiss* Walbaum), and interior redband trout (*O. m. gibbsi* Suckley) were selected for climate vulnerability analysis because of their important role in land management planning (e.g., grazing, timber harvest, Endangered Species Act consultations). These species occupy a broad range of aquatic habitats from small headwaters tributaries to large rivers, both within and downstream of the Malheur, Umatilla, and Wallowa-Whitman National Forests. Although habitats for the selected species overlap in places, each species uses a unique set of aquatic habitats in the Blue Mountains national forests and their associated subbasins, depending on their life stage, season of the year, and available habitat conditions. These species have a diverse array of life history strategies, including anadromy (steelhead and spring Chinook salmon), fluvial and adfluvial movements (bull trout), and residency (bull trout and redband trout).

Climate change affects the environments of these species in many ways (box 5.1). Warming air temperatures and changing precipitation patterns are resulting in warmer stream temperatures (Bartholow 2005; Isaak et al. 2010, 2012b; Petersen and Kitchell 2001), altered stream hydrology (Hamlet and Lettenmaier 2007, Luce et al. 2013), and changes in the frequency, magnitude, and extent of climate-induced events such as floods, droughts, and wildfires (Holden et al. 2012, Littell et al. 2010, Luce and Holden 2009, Rieman and Isaak 2010). Fish populations have been

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Box 5.1—Summary of climate change effects on fisheries in the Blue Mountains

Broad-scale climate change effects

- Water temperatures will increase.
- Snowpack will decrease, causing a shift of peak flows from summer to spring, and a decrease in summer flows.
- Peak flows will be flashier, likely resulting in channel scouring and increased sedimentation.
- Wildfires will increase, creating the potential for increased erosion.
- Ocean productivity may change, affecting anadromous fish species.

Species affected

- Fish species affected will differ by location. This assessment focuses on bull trout, spring Chinook salmon, and redband trout/steelhead.

Current condition and existing stressors

- Altered riparian areas (from grazing, roads, recreation, etc.) lead to elevated water temperatures.
- Reduced resiliency of stream habitat affected by removal of woody debris, roads, grazing, recreation, etc.
- Reduced summer flows—related primarily to water withdrawals.
- Invasive species—predation on spring Chinook salmon and steelhead.
- Influence of hatchery fish—spring Chinook salmon and steelhead.
- Overfishing for spring Chinook salmon.

Sensitivity to climatic variability and change

- Bull trout—Bull trout require very cold water temperatures for spawning and juvenile rearing, so their populations are already greatly constrained by the limited availability of cold habitats in the Blue Mountains. Moreover, these natal habitats are confined at their upstream extent by small stream size and channel slope, so bull trout populations are the fish world's equivalent to terrestrial species that are trapped on "mountain-top islands." Increasing temperatures will eliminate cold habitats at the downstream extent of these populations. Decreasing summer flows will make some streams too small to support fish at the upper extent, and the habitats that remain will be subject to increased environmental fluctuation associated with wildfires, debris flows, and increased winter flooding.

Box 5 (continued)

- Spring Chinook salmon—Adults require cool water for holding in fresh water prior to spawning. Juveniles could also be affected by warmer temperatures. A major impact may be changes in the size of adults and fecundity of females resulting from ocean acidification and warming. Spring Chinook salmon adults migrate upstream into low-elevation mainstem rivers and streams to spawn during the warmest months of the year. During especially warm summers, adult salmon sometimes experience direct mortality from thermal stress prior to spawning. These mortality events are exacerbated by decreases in summer flows, which confine the fish to smaller areas. Anticipated temperature increases will increase the frequency and severity of thermal stresses on spring Chinook salmon.
- Redband trout/steelhead—Most steelhead populations in the Pacific Northwest have reduced populations because they already have experienced changes in stream temperature and flow patterns as a result of land and water use practices. Both the resident and anadromous forms are important to maintain many overall populations. Both life forms have a lot of phenotypic plasticity to withstand and adapt to change, but climate change will likely increase competition between these life forms and will certainly affect populations that use lower elevations that are more susceptible to change. The loss or reduction in the larger anadromous form will mean fewer eggs, which may affect the overall population in each major population group. This species has a large adaptive capacity with a range of life histories and wide environmental tolerances, which will reduce sensitivity to the potential effects of climate change. Altered ocean conditions may affect the expression of the steelhead life history.

Expected effects of climate change

- Bull trout—Changes in water temperature will be an important determinant of persistence. Long-term climate patterns suggest both an expected decrease in the total amount of cold water stream habitat and fragmentation of some colder areas into disconnected “patches” of suitable habitat. Bull trout populations will likely increase retreat into these shrinking summer cold water refuges to avoid warming conditions. These restricted tributary populations may become more vulnerable to local extirpation. Many remaining patches will be subjected to more frequent winter peak flows that will scour the streambed and destroy redds or kill newly emerged fry. Conceivably, the combined effects of shrinking patch size and increasing frequency or magnitude of stream channel disturbance could chip away at the low resiliency of these populations, leaving them in a poorer condition to withstand the next series of disturbances, and accelerating the rate of local extirpations beyond that driven by temperature alone. Wildfire effects are less clear, although minimal empirical data suggest that wildfire will have minimal effects on bull trout.

Box 5 (continued)

- Spring Chinook salmon—Elevated temperatures can reduce the energy available for reproduction and cause mortality, particularly where there are sudden increases in water temperatures. Effects from higher winter floods will probably be minimal unless there is a very large increase. These fish are large, use large substrates for spawning, and spawn in areas where the energy of flood water can be dissipated, so the potential for increased scouring is likely to be minimal.
- Redband trout/steelhead—This species is a spring spawner and has a relatively warm thermal niche; it can move into some cold upstream areas as refugia. Because it spawns in the spring, eggs are not as susceptible to increased winter flooding as fall spawners. Shifts in the timing of peak flows will likely result in changes in outmigration timing, changes in survival, changes in distribution, and changes in the availability of spawning and rearing habitats. Increases in the temperature of cooler waters (i.e., those <9 °C currently) could improve habitat for redband trout. Further temperature increases (12 to 20 °C) could lead to greater expression of the steelhead life history. It is less clear what the tradeoff between redband trout and steelhead life histories will be at water temperatures >20 °C. Altered ocean conditions could reduce the expression of the steelhead life history, particularly in males, and reduce the size of returning adults.

Adaptive capacity

- Bull trout—This species has very limited capacity to adapt given limited current habitats and restrictive ecological tolerances.
- Spring Chinook salmon—Supporting adaptive capacity is probably compromised because of low population numbers. T. Beechie, National Oceanic and Atmospheric Administration Fisheries, Seattle, has suggested the spring Chinook salmon (stream-type life history) in Puget Sound may become fall Chinook salmon (ocean-type life history) in response to changes of climate change (warmer water and lower summer flows). This could be possible in the Columbia Basin but is not as likely as in Puget Sound. These fish may be able to adjust to altered ocean conditions by reducing the time spent in the ocean, resulting in smaller, younger fish returning to streams.
- Redband trout/steelhead—This species has high adaptive capacity for adjusting to potential effects of climate change.

Vulnerable geographic locations

- Some spring Chinook salmon stocks (e.g., Catherine Creek stock and Upper Grande Ronde stock) are already in poor shape.
- Spring Chinook salmon in Catherine Creek may lose one outmigration period owing to a shift in hydrograph and therefore lose species life history diversity.
- Fish of all species will be vulnerable to decreased summer flows in the future. Flow reductions will make some headwater streams too small to support fish. In the remainder of the network, summer flow declines will also reduce the overall amount of “living space” for fish.

Box 5 (continued)

- The nests of fall spawning fish like bull trout or spring Chinook salmon could be vulnerable to higher winter flows causing channel scour and egg mortality in channels with confined valley bottoms. This vulnerability would occur just upstream at higher elevations where winter high flows have occurred because warming will make things creep upstream.
- Places where fish distribution and abundance are currently limited by warm temperatures could experience fish declines with small amounts of additional warming. Bull trout distributions are limited at downstream sites in many streams and will have to shift upstream. Spring Chinook salmon adults have experienced heat stress, die-offs in a few streams, and are forced to cluster near cold water refuges in other streams. Additional warming will exacerbate these issues.
- Fish populations that are isolated in small headwater streams could be susceptible to local extirpations caused by more environmental variation (wildfire, debris flows, droughts, floods) as climate change progresses.

Risk assessment

Potential magnitude of climate change effects

- Bull trout—High magnitude of temperature effects by 2050 given that both species are already strongly and negatively affected by warm temperatures.
- Spring Chinook salmon—High magnitude of temperature effects by 2050 given that both species are already strongly and negatively affected by warm temperatures. The effects of altered ocean conditions may pose the greatest risk to these fish. In fresh water, elevated summer temperatures will be the greatest challenge and it is likely to increase with time. The latter can be potentially offset with restoration of riparian areas in streams throughout the stream network.
- Redband trout/steelhead—This species could be less affected by altered ocean conditions because of the ability to express life histories that are resident in fresh water. However, the steelhead component of a population may decline. Steelhead exhibit high phenotypic plasticity and may shift the timing of a life stage transition to reduce the probability of exposure to changes in stream temperature and flow, although there is a limit to how much steelhead can shift the timing of life stages.
- **Low summer flows**—Low effect on spring Chinook by 2050; moderate by 2100. Moderate effect on bull trout by 2050; high by 2100.
- **Winter flood frequency**—Low effect on spring Chinook by 2050 and 2100. Moderate effect on bull trout by 2050; high by 2100.
- **Wildfires/debris flows**—Low effect on spring Chinook by 2050 and 2100. Moderate effect on bull trout by 2050; high by 2100.
- **Invasive species**—Moderate effect on spring Chinook from smallmouth bass (*Micropterus dolomieu* Lacepède) by 2050, high effect by 2100. Low effect on bull trout from brook trout by 2050; moderate by 2100.

Box 5 (continued)

Likelihood of climate change effects

- **Temperature effects**—High likelihood by 2050.
- **Low summer flows**—Moderate likelihood by 2050, but hydrology models need to improve for this parameter. Also need more flow data from small headwater streams to calibrate hydrology models.
- **Winter flood frequency increase**—High likelihood by 2050 because it is largely controlled by temperature.
- **Wildfires/debris flows**—High likelihood by 2050.
- **Invasive species**—High likelihood by 2050 because overlap with native species is strongly controlled by temperatures.

adapting by shifting their phenology and migration dates (Crozier et al. 2008, 2011; Keefer et al. 2008), using cold water refugia during thermally stressful periods (Keefer et al. 2009; Torgersen et al. 1999, 2012), and shifting spatial distributions within river networks (Comte et al. 2013, Eby et al. 2014). These changes are adding additional stressors to many fish populations, but many populations are also likely to have sufficient resilience and habitat diversity to make the necessary adjustments.

In this chapter, we assess specific vulnerabilities of each of the four selected species to climate change in stream networks draining the Blue Mountains and Forest Service lands. Aiding this assessment are recently developed, high-resolution stream temperature and flow scenarios (Variable Infiltration Capacity [VIC] model ecological flow metrics—Wenger et al. 2010; NorWeST—Isaak et al. 2011; Hamlet et al. 2013) that translate outputs from Global Climate Models (GCMs) to reach-scale habitat factors relevant to aquatic biota. The concluding section of this chapter discusses management strategies that can be used to help species and aquatic ecosystems in the Blue Mountains better adapt to climate change. No attempt is made to provide an exhaustive review of the climate-aquatic-fisheries literature because good general reviews already exist for the Pacific Northwest (ISAB 2007, Mantua et al. 2009, 2011; Mantua and Raymond 2014; Mote et al. 2003) and other geographic regions (Ficke et al. 2007; Furniss et al. 2010, 2013; Isaak et al. 2012a, Luce et al. 2012, Poff et al. 2002, Rieman and Isaak 2010, Schindler et al. 2008).

Analysis Area

This chapter focuses on the 23 subbasins draining the Blue Mountains province, specifically the revision analysis area covered by the joint land management plan for the Malheur, Umatilla, and Wallowa-Whitman National Forests. The subbasins are distributed among four major hydrologic units or basins, referred to here as river basins (fig. 5.1): the middle Columbia River basin, which drains the west face of the Blue Mountains; the lower Snake River Basin, which drains the northern part of the Blue Mountains; the Middle Snake River basin, which drains the southeast face of the Blue Mountains; and the Oregon Closed Basins, which drains the southern Blue Mountains but has no hydrologic connections to either the Columbia or Snake Rivers.

Approximately 20 000 km of streams occur in the Blue Mountains, almost 7000 km of which are on national forest lands. The distribution of the four selected fish species differs in each subbasin depending on available habitat and unique life history characteristics. Generally speaking, redband trout are the only species in Oregon Closed Basins streams, redband trout and bull trout are the only species in the middle Snake River basin (access to this basin by anadromous steelhead and spring Chinook salmon was blocked by construction of the Hells Canyon Dam complex), and all four species occur in the lower Snake and middle Columbia River basins.

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The majority of national forest lands in the analysis area is administered by the Malheur, Umatilla, and Wallowa-Whitman National Forests, but a small portion of the Ochoco National Forest is also present and administered in conjunction with Malheur National Forest lands. For convenience, references to the southern portion of the Malheur National Forest will be assumed to also include the small portion of Ochoco National Forest lands in the analysis area. The middle Snake River basin contains portions of the Wallowa-Whitman and Malheur National Forests. The lower Snake River basin contains portions of the Umatilla and Wallowa-Whitman National Forests, and the middle Columbia River basin encompasses portions of the three main Blue Mountains national forests.

Selected Aquatic Species

Spring Chinook Salmon

Spring Chinook salmon are a fall-spawning anadromous species. They can be found in medium-sized river reaches and tributaries within and downstream of national forest boundaries. Because they are fall spawners, they move upriver to spawning grounds in mid-late summer and can experience thermal barriers to

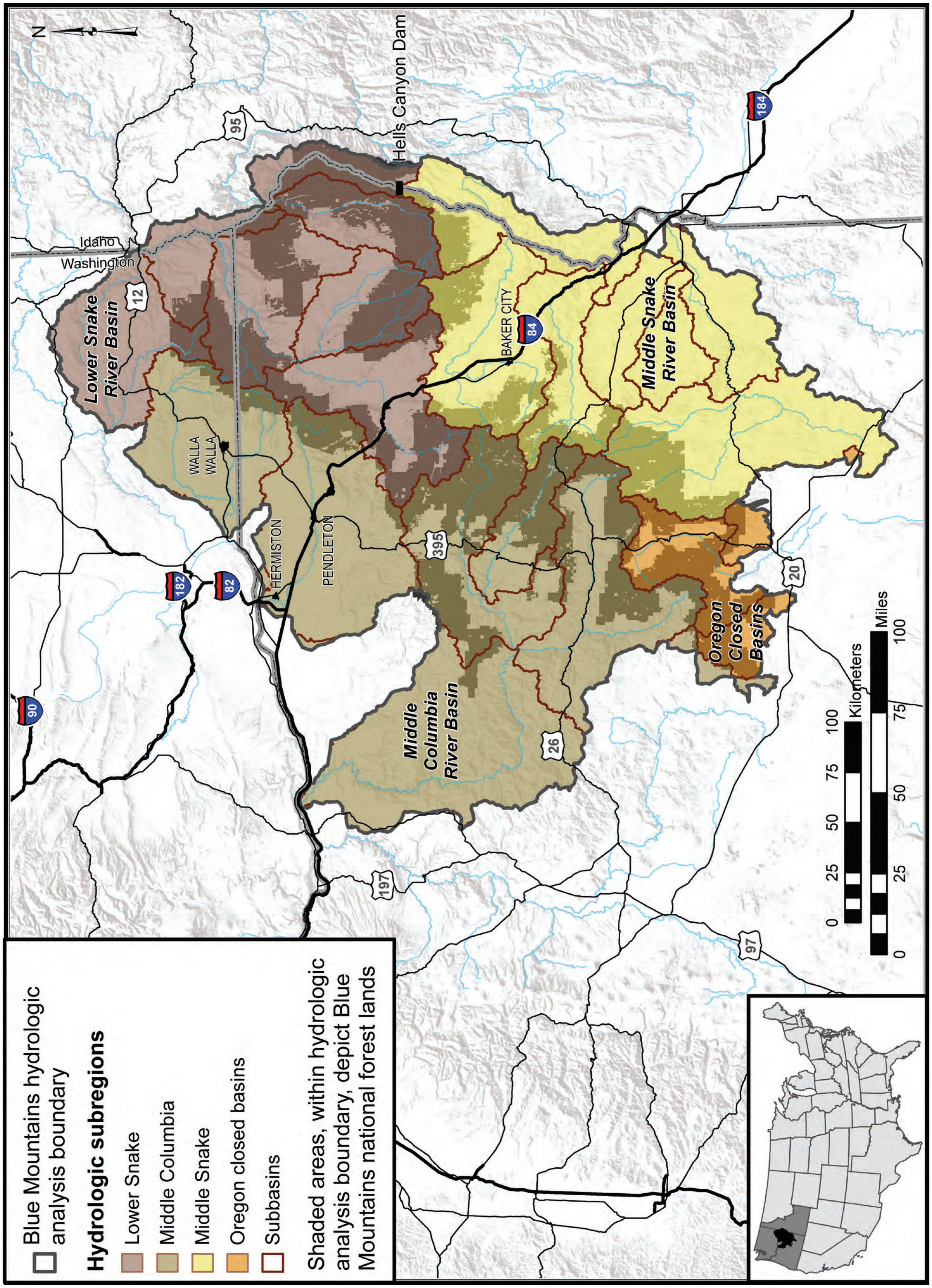

Figure 5.1—Analysis area and hydrologic subdomains for fisheries climate change assessment in the Blue Mountains.

upstream movement through migratory corridors in the analysis area caused by sudden increases in air and water temperatures at the onset of summer, known in past decades to occur more quickly than salmon can adjust to physiologically. In some instances, sudden temperature increases have caused direct mortality of salmon adults.

Native spring Chinook salmon within the analysis area belong to two different Environmentally Significant Units (ESUs): the Middle Columbia River spring Chinook salmon ESU in the Middle Columbia River Basin, and the Snake River Basin spring Chinook salmon ESU in the Lower Snake River Basin (fig. 5.1). Snake River Basin spring Chinook salmon populations spawn and rear in subbasins forming the Lower Snake River hydrologic basin: Tucannon, Grande Ronde, Wallowa, and Imnaha subbasins. Native Middle Columbia River spring Chinook salmon spawn in subbasins forming the headwater forks of the John Day River: the North, Middle, Upper John Day and South Fork subbasins draining the west face of the Blue Mountains province in the Middle Columbia River Basin. Reintroduced hatchery stocks spawn in Walla Walla and Umatilla subbasins headwater habitats within the Middle Columbia River Basin in the northern Blue Mountains. For convenience, further discussions of native Middle Columbia River spring Chinook salmon will refer to these reintroduced populations as well, unless otherwise noted.

Bull Trout

Bull trout, like spring Chinook salmon, are fall spawners with eggs that overwinter in the gravels and fry that emerge from redds in late winter and early spring. Their habitat ranges from medium-sized, high-elevation tributaries to very small headwater streams. Migratory individuals are known to winter in larger rivers and tributaries but move upriver towards headwater resident tributaries as migratory corridors begin to warm in summer and as the fish prepare to spawn. Optimum habitats for bull trout provide year-round high-quality cold water and high habitat complexity.

Bull trout in the Blue Mountains exist in a variety of life history forms, including freshwater migratory (fluvial and adfluvial) and headwater year-round resident. Migratory bull trout move between their natal streams and larger bodies of freshwater, such as lakes, reservoirs, and mainstem rivers where they can grow much larger than the year-round residents that rear and mature in small colder headwaters.

Bull trout populations are often a mix of resident and migratory individuals, an adaptation to infrequent but major natural disturbances in their high-elevation habitats. When such disturbances cause a small resident population to be eliminated, migratory individuals that were elsewhere at the time of the event can then establish a new population in the vacant habitat, although such recolonization may not occur immediately. The benefits of such disturbances are that they often deliver pulses of large wood and streambed material that provide new spawning gravels and increase habitat complexity, providing resting places and cover to shelter them from predators and reduce energy demands imposed by fast streamflow. A fresh assortment of large streambed substrate provides spaces in the streambed where juveniles can hide from predators.

Columbia River bull trout are found in all subbasins except for the Burnt River in the Middle Snake River Basin, the Oregon Closed Basins, and the South Fork Crooked River subbasin in the south end of the plan area (Ochoco National Forest lands; Middle Columbia River Basin). The migratory life history is still present in most of the populations inhabiting national forest lands in the Blue Mountains province, but some headwater resident populations in the analysis area have become isolated and are very small owing to the effects of historical land use. Connectivity among such resident populations is no longer provided by migratory individuals, and these populations are considered to be at heightened risk of long-term extirpation.

Steelhead Trout/Redband Trout

Research suggests that steelhead and redband trout are alternate life history forms of the same species, and often constitute the same populations, where they co-occur (McMillan et al 2011, Mills et al. 2012). Both steelhead and redband trout spawn at lower elevations and tolerate warmer temperatures in their spawning and rearing habitats than do fall-spawning bull trout.

Steelhead trout are a large-bodied anadromous form of *O. mykiss.* They spawn in the spring in medium rivers to headwater tributaries and rear in cool medium and small rivers, tributary and headwater streams, and upstream portions of large rivers in the analysis area, within accessible portions of the Middle Columbia River and Snake River Basins. Steelhead in the analysis area belong to two spatially discrete Distinct Population Segments (DPS): the Middle Columbia River steelhead DPS, and the Snake River Basin steelhead DPS in the Lower Snake River Basin. Snake River Basin populations spawn and rear in subbasins within the Lower Snake River Basin: Tucannon, Asotin, Upper and Lower Grande Ronde, Wallowa and Imnaha subbasins. Middle Columbia River steelhead spawn in subbasins forming the headwaters of the John Day River: the North, Middle, Upper and South Fork subbasins, as well as in the Umatilla and Walla Walla subbasins, all within the Middle Columbia River basin.

Redband trout are a much smaller bodied spring-spawning resident life form of *O. mykiss.* They represent a different range of needs both spatially and temporally than large-bodied spring Chinook salmon and steelhead. Redband trout inhabit small and medium rivers and tributary streams year round and spawn from late winter into May. They are found throughout the entire analysis area, including several subbasins where steelhead are absent, and are considered present wherever steelhead are present. They occur in subbasins of the Blue Mountains where no spring Chinook salmon, steelhead, or other native trout species are present.

The juvenile life stages of the two forms of *O. mykiss* are indistinguishable visually where they co-occur, but juvenile individuals eventually express one of two life histories: they either develop physiologically into ocean-going steelhead or remain as freshwater resident redband trout. The likelihood that a juvenile will express one or the other life history is strongly influenced by environmental and physiological factors including water temperature, food supply, gender, growth rates, and body fat development that interact to determine which individuals out-migrate as steelhead smolts and which remain to mature in freshwater (Sloat and Reeves 2014). Where they co-occur, offspring of female steelhead may mature into resident redband trout, and offspring of female redband trout may ultimately out-migrate to the ocean and return to natal streams as adult steelhead (Carmichael et al. 2005).

Current Status and Trend

Current Population Conditions

Snake River Basin spring Chinook salmon are currently listed as threatened under the U.S. Endangered Species Act within the Blue Mountains analysis area. Middle Columbia River spring Chinook salmon are not listed at this time. Only the anadromous (steelhead) forms of *O. mykiss* are listed as threatened (two steelhead DPSs); whereas resident redband trout remain unlisted. Bull trout are also listed as threatened (two DPSs). Each listed DPS and ESU is considered a separate species under the Endangered Species Act, with recovery goals both for component populations of each listed DPS and ESU at the subbasin scale or comparable scales and for the DPS/ESU as a whole.

Status reviews for listed species populations occur about every 5 years after they have been listed. The most recent status review for listed anadromous species was based on the criterion of self-sustainability (Ford 2011). The majority of the biological review team members concluded that Snake River spring/summer Chinook salmon ESU and both Middle Columbia River and Snake River Basin steelhead DPS are still high risk and should remain listed as threatened. The recent 5-year status and trend assessment summaries (NMFS 2011a, 2011b) indicate that although most listed spring Chinook salmon and summer steelhead populations are still considered nonviable, most populations are generally increasing. The National Marine Fisheries Service describes and monitors population viability for anadromous fish populations and major population groups at different scales by subbasin, major tributary watershed, or groups of adjoining subbasins, depending on the population of interest.

For purposes of bull trout recovery planning, core populations have been designated as population units that correspond scalewise to anadromous populations (Whitsell et al. 2004). These core populations have been generally defined at the subbasin scale, but may also be described based on groups of adjoining subbasins, depending on the population of interest. Core populations in the occupied subbasins are all part of the Columbia River bull trout DPS, which is listed as threatened. For the remainder of this analysis, core populations for Columbia River bull trout will be referred to simply as “populations,” and Columbia River bull trout will be referred to simply as “bull trout.” The most recent status and trend assessments for bull trout in the analysis area indicate that most populations are presently stable or increasing (USFWS 2008; http://www.fws.gov/pacific/bulltrout).

Interagency conservation planning efforts have stratified redband trout populations in the analysis area into spatially discrete conservation population groups based on several geographic clusters of subbasins (May et al. 2012) within each of the four major hydrologic basins draining the Blue Mountains. Most of these large-scale population groups were targeted for conservation efforts.

Redband populations in the Middle Columbia River and Lower Snake River basins where resident populations co-occur with steelhead are generally considered by local biologists to be depressed. They parallel steelhead population conditions but to an unknown extent, because as resident individuals, redband trout do not experience the challenges that affect anadromous steelhead during the years spent outside their natal subbasins. Those challenges include adverse conditions in freshwater migratory corridors in the larger rivers, passage through and around mainstem hydropower dams, physiological transitions to and from saltwater environments in the Columbia River estuary, and additional hazards as they feed in the open ocean before returning to their natal streams. Interbreeding between redband and steelhead (Kostow 2003) may support population viability for both life histories where they co-occur, but the extent to which this occurs or the extent to which each life history supports viability of the other, is unknown.

Redband trout populations, which have long been naturally isolated from steelhead in the Oregon Closed Basin (*O. mykiss newberryi*), have also been separated from other redband populations in the Columbia and Snake River basins (*O. m. gairdnerii*) for millennia, and are especially targeted for conservation. The redband populations in this group of subbasins are also collectively known as the Great Basin DPS. Although still considered viable (USFWS 2009), these populations are believed to be declining, primarily owing to land management impacts, particularly downstream of national forest lands.

Current Fish Habitat Conditions

The majority of resident bull trout populations and spawning habitats are located in high-elevation habitats where management is limited. These areas are mostly allocated to wilderness, wild and scenic river corridors, municipal watersheds, and backcountry nonmotorized use where timber harvest, livestock grazing, and roaded access are limited. Disturbances in high-elevation spawning areas generally operate at natural frequencies, magnitudes, and rates to which bull trout have adapted over centuries.

Habitat conditions in downstream migratory corridors, however, may affect fluvial bull trout adults as well as anadromous species. Current connectivity and habitat conditions in the Blue Mountains, especially in middle and lower elevations, are the result of past natural disturbances, particularly floods and wildfire, and past land management activities such as grazing, mining, timber harvest, irrigation diversion, and road construction. These disturbances have also occurred in private and state lands, including private inholdings that create checkerboard patterns of land ownership within national forest boundaries.

Many kilometers of fish habitat for one or more species within national forest lands are blocked.

This diversity of land uses interacting with natural disturbance regimes has contributed over time to degradation of stream channels and downcut floodplains, resulting in less water storage and release as baseflows during the summer season. Water storage behind impassible dams, water withdrawals, and irrigation diversions for downstream use also contribute to reduced baseflows and can result in high summer water temperatures that create thermal barriers to fish movement in lower river corridors. Dams and irrigation diversion structures reduce habitat and population connectivity wherever they occur, by partially or totally blocking fish passage, depending on the design and use of the individual structures. Fish habitats are naturally fragmented in the Oregon closed basins but are further fragmented by urban development and water withdrawals.

Many kilometers of fish habitat for one or more species within national forest lands are blocked, or seasonally blocked, by culverts under roads. An inventory conducted in national forest lands in 2000 and 2001 revealed numerous passage concerns created by culverts, particularly in the (1) Upper and Lower Grande Ronde subbasins and the upper Imnaha subbasin in the Lower Snake Basin, (2) North and Middle Forks John Day subbasins in the Middle Columbia River Basin, (3) Upper Malheur subbasin in the Middle Snake River Basin, and (4) Silvies River subbasin in the Oregon Closed Basins. Most of these passage barriers can impede passage at baseflow for juveniles of the various species, and some impede adult passage for one or more species like bull trout or steelhead/rainbow in headwater streams. Passage barriers generally do not exist in the larger tributaries and rivers that provide spawning and rearing habitat for Chinook salmon.

Although many effects from past and current management will likely continue for the foreseeable future, restoration efforts have been ongoing for over 20 years in the Blue Mountains, achieved in part by reducing land management effects under direction in national forest land management plans, as amended by PACFISH and INFISH (USDA FS 1995, USDA FS and USDI BLM 1995). Current Forest Service watershed restoration programs emphasize whole-watershed restoration, and strategic investment in accelerated watershed and habitat restoration are focused on the Blue Mountains to provide better protections from further effects of land use activities. Fish habitat trend analyses indicate improvements are occurring in the condition of aquatic and riparian habitats in national forest lands throughout the Blue Mountains (Archer et al. 2009, 2012).

Analysis of Projected Climate Change Effects

To assess the potential effects of climate change on stream environments in the Blue Mountains, we used national geospatial data products to delineate the stream network. Streamflow and temperature values from high-resolution stream climate models were then linked to reaches in that network to create a geospatial database that could be queried to summarize climate effects at different time periods.

Stream Network and Hydrology Model

To delineate a stream network for this assessment, geospatial data for the NHDPlus 1:100,000-scale national stream hydrography layer (Cooter et al. 2010) were downloaded from the Horizons Systems website (http://www.horizon-systems.com/NHDPlus/index.php) and clipped to the major watershed boundaries associated with the Blue Mountains. The network was filtered to exclude reaches with minimum summer flows less than 0.034 $m^3 s^{-1}$, which approximates a low-flow wetted width of 1.5 m (based on an empirical relationship developed in Peterson et al. [2013]) in which fish occurrence is rare. For purposes of this assessment, the summer flow period was defined as beginning with the recession of the spring flood to September 30, and is considered to be a critical period for many fish populations because it coincides with maximum temperatures (Arismendi et al. 2013).

Summer flow values predicted by the VIC model (Hamlet et al. 2007, Wenger et al. 2010) were downloaded from the Western United States Flow Metrics website (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml) and linked to each reach in the hydrography layer through the COMID field. The VIC model is a distributed, physically based model that balances water and energy fluxes at the land surface and takes into account soil moisture, infiltration, runoff, and baseflow processes within vegetation classes (Liang et al. 1994). It has been widely used in the Western United States to study past and potential future changes to waterflow regimes (Hamlet et al. 2007, 2013), snowpacks (Hamlet et al. 2007), and droughts (Luo and Wood 2007).

Application of the minimum summer flow criteria reduced the original set of blue-lines in the NHDPlus hydrography layer for the Blue Mountains region to 20 123 stream km, of which 6907 km were on U.S. Forest Service lands (fig. 5.2). In addition to summer flows, earlier validation work (Wenger et al. 2010) suggests the VIC model accurately predicts several other flow metrics relevant to fish: center-of-flow mass (date at which 50 percent of annual flow has occurred), winter 95 percent flow (number of days from December 1 to February 28 when flows are among highest 5 percent of the year), and mean annual flow (Wenger et al. 2010).

Climate Scenarios

To assess stream responses to climate change, the VIC model was forced by an ensemble of 10 GCMs that best represented historical trends in air temperatures and precipitation for the northwestern United States during the 20th century (Hamlet et al. 2013, Mote and Salathé 2010). We considered changes associated with the A1B emission scenario (moderate emissions as defined by the Intergovernmental Panel on Climate Change) and summarized flow characteristics during a historical baseline period (1970–1999, hereafter the 1980s) and two future periods (2030–2059 hereafter 2040s; 2070–2099 hereafter 2080s). Within the Blue Mountain region, summer air temperatures were projected to increase 3.3 °C by the 2040s and 5.4 °C by the 2080s, with smaller increases during other seasons. Summer precipitation was projected to decrease 11 percent by the 2040s and 14 percent by the 2080s, but slight increases during other seasons meant total annual precipitation was projected to change less than 5 percent (Hamlet et al. 2013, Mote and Salathe 2010).

Most GCM projections are relatively consistent until the mid-21st century and diverge primarily in late century owing to uncertainties about future greenhouse

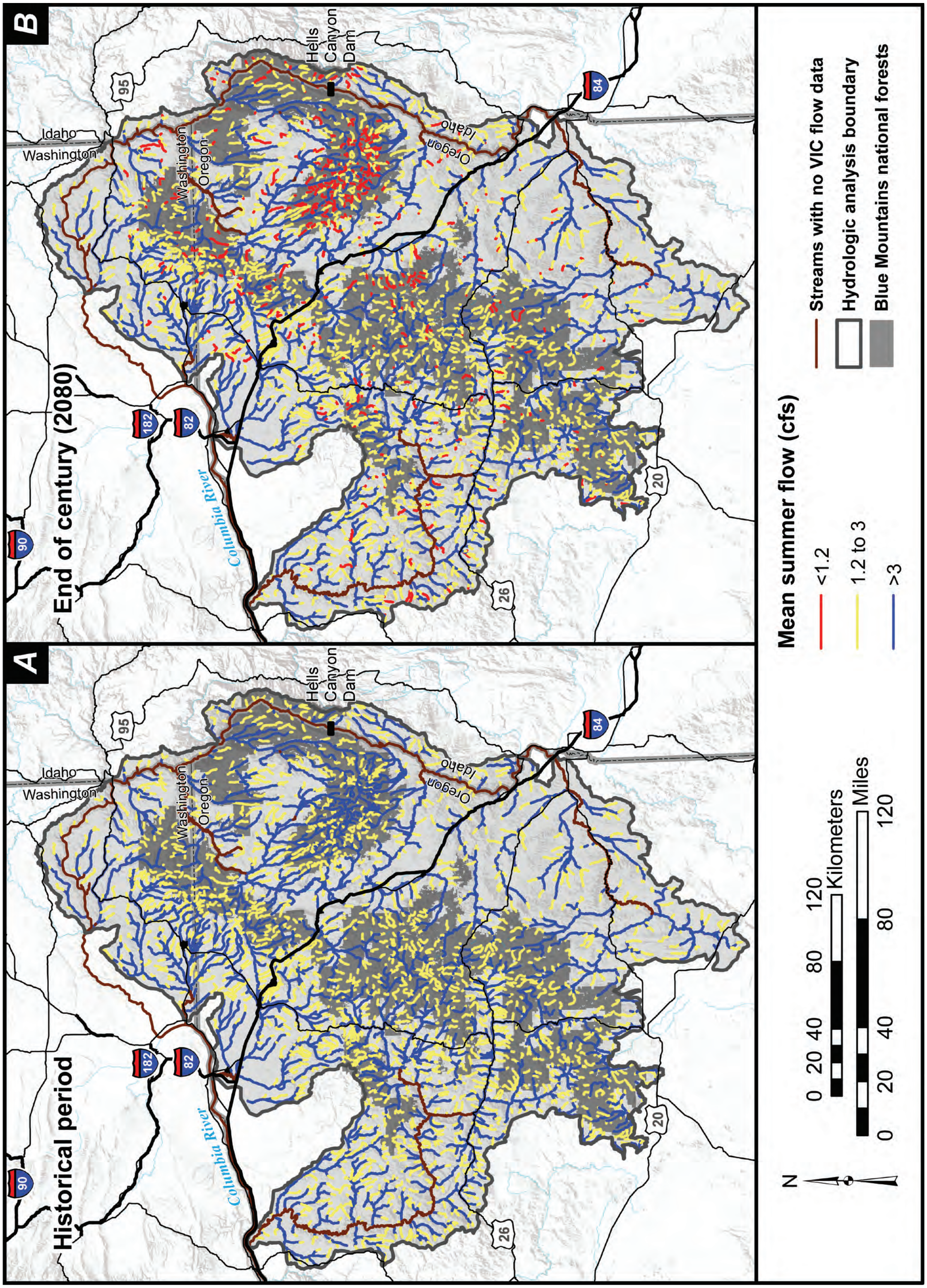

Figure 5.2—Maps showing stream reaches with mean summer flows sufficient to support fish populations for the 1980s (A) and 2080s (B) based on the A1B emissions trajectory. Red stream reaches depict locations where summer flows are projected to drop below 0.034 m^3s^{-1} and become intermittent fish habitat. VIC = Variable Infiltration Capacity.

gas emissions (Cox and Stephensen 2007, Stocker et al. 2013). The climatic conditions associated with the A1B trajectory and historical period bracket that range of possibilities. Given uncertainties about the magnitude and timing of changes, it is reasonable to interpret future projections as a moderate change scenario (2040s) and an extreme change scenario (2080s) relative to the baseline period (1980s).

NorWeST scenarios are developed by applying spatial statistical models for data on stream networks to a crowd-sourced database.

Stream Temperature Model and Scenarios

To complement the streamflow scenarios, geospatial data for August mean stream temperatures were downloaded for the same A1B trajectory and climate periods described above from the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). NorWeST scenarios are developed by applying spatial statistical models for data on stream networks to a crowd-sourced database contributed by more than 70 resource agencies (Isaak et al. 2011, 2014). NorWeST scenarios account for differential sensitivity of streams to climate forcing through application of basin-specific parameters (Isaak et al. 2011, Luce et al. 2014b). NorWeST scenarios are available at a 1-km resolution and were modeled in the study area from more than 9,000 summers of measurement with thermographs at more than 3,000 unique stream sites monitored intermittently with digital sensors from 1993 to 2011. The density and spatial extent of the temperature data set, combined with the predictive accuracy of the NorWeST model across those sites (r^2 = 0.94; RMSE = 0.90 °C) overcame the commonly cited weakness of coarse resolution in climate vulnerability assessments (Potter et al. 2013, Wiens and Bachelet 2010). The model also performed well over the wide range of climatic variation that occurred during the calibration period (interannual variation in August air temperatures of 5.0 °C and threefold variation in August flows), which is notable because the warmest and driest years exceeded mean conditions projected to occur by the 2040s.

Climate Change Effects on Fish and Fish Habitat

Streamflows–General Patterns

The broad elevation range across the Blue Mountains translates to significant spatial heterogeneity in stream hydrology. Streams in low-elevation catchments have rain-dominated hydrographs with peak flows occurring much earlier in the year than high-elevation streams dominated by snowmelt runoff. Relative to the 1980s baseline period, runoff timing (center of flow mass) of all streams are projected to advance 9 to 23 days earlier in the year, with larger changes anticipated by the 2080s and at higher elevations (table 5.1, fig. 5.3). Similar patterns are projected with regards to larger changes late in the 21st century, and on national forests with

Table 5.1—Summary of streamflow statistics relevant to fish populations in the Blue Mountains climate change analysis area, based on changes associated with the A1B emission trajectory

		All lands		Forest Service lands	
Flow metric	**Climate period**	**Day of year[a]**	**Days advance**	**Day of year**	**Days advance**
Center of flow mass	1980s	181	—	189	—
	2040s	172	-9	176	-13
	2080s	165	-16	166	-23
		Number of days	**Days increase**	**Number of days**	**Days increase**
Winter 95% flow	1980s	5.7	—	4.6	—
	2040s	7.3	1.6	6.7	2.1
	2080s	8.7	3.0	8.6	4.0
		Stream kilometers	**Percent change**	**Stream kilometers**	**Percent change**
Stream length[b]	1980s	20 123	—	6907	—
	2040s	19 130	-4.9	6362	7.9
	2080s	18 681	-7.2	6070	-12.1
		Cubic meters per second	**Percent change**	**Cubic meters per second**	**Percent change**
Mean summer flow[c]	1980s	0.98	—	0.68	—
	2040s	0.83	-15.3	0.48	-28.9
	2080s	0.77	-21.7	0.40	-41.4
Mean annual flow	1980s	1.65	—	1.09	—
	2040s	1.75	5.8	1.17	7.0
	2080s	1.82	10.1	1.23	12.5

— Signifies that data are not available.

[a] Refers to day of water year starting October 1.

[b] Stream reaches in network with mean summer flows greater than 0.039 m^3s^{-1}.

[c] Average flow across all reaches in the network.

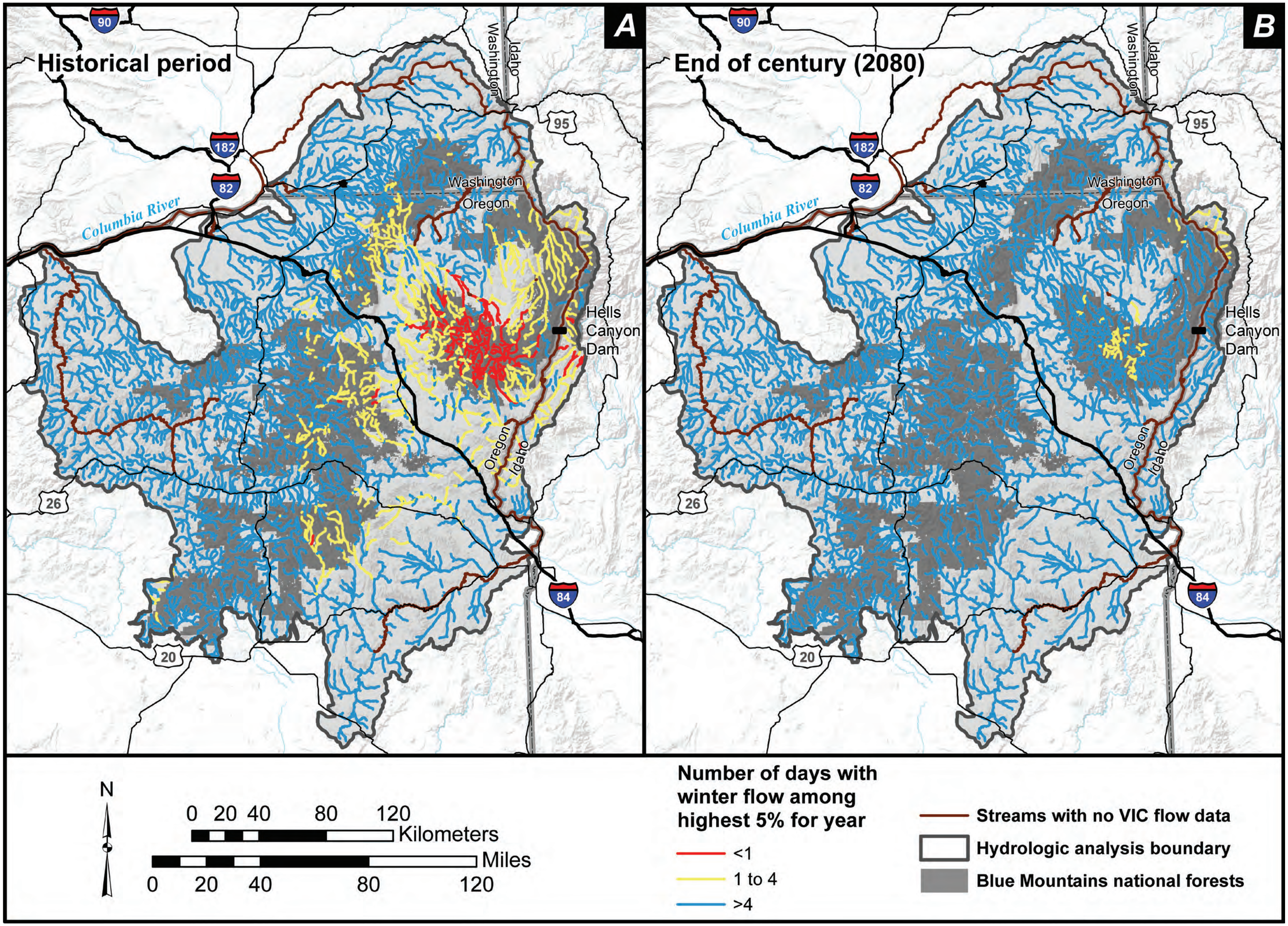

Figure 5.3—Maps showing the frequency of days when winter high flows are among the highest 5 percent of the year for the 1980s (A) and 2080s (B) based on the A1B missions trajectory. VIC = Variable Infiltration Capacity.

respect to number of winter high-flow days (fig. 5.4) and declines in average summer flows.

If summer flows decline by the projected 15 to 41 percent (table 5.1), the linear extent of the network supporting fish (flows greater than 0.034 $m^{3} \cdot s^{-1}$) could decrease by 5 to 12 percent, as the smallest headwater streams become more frequently intermittent (fig. 5.2). Summer flow reductions are predicted to be most prominent in the highest elevation watersheds like the Eagle Cap Wilderness where stream hydrologies are most dependent on winter snow accumulation. The direction of projected trends in stream hydrologic attributes is similar to that observed during the last 50 years of the 20th century across the Pacific Northwest (Isaak et al. 2012a, Luce et al. 2009, Safeeq et al. 2013, Sawaske and Freyberg 2014), but future changes and associated rates of change are expected to be larger.

Winter high-flow frequency—

As air temperatures increase, the rain-on-snow (ROS) zone will move up in elevation, increasing stream flooding where the current ROS zone is lower in a subbasin. In contrast, subbasins with an already higher elevation ROS zone will see only modest increased flooding risks (Hamlet and Lettenmaier 2007, Tohver et al. 2014). As ROS zones move higher over time, the zones themselves will shrink, reducing the potential contribution to peak winter runoff in some subbasins. The probability of ROS events occurring is also expected to decrease with warmer temperatures because of decreased snow occurrence and length of time that snow is on the ground (McCabe et al. 2007), especially in lower elevation subbasins in the northern Blue Mountains.

Most high-elevation areas under the baseline conditions (1980s) have 1 to 6 days (mean 4.6 days) of winter high flows, with the exception of the Wallowa Mountains in the Eagle Cap Wilderness, which have less than a day (fig. 5.3). The highest elevations in the analysis area occur within the Wallowa Mountains at 3000 m. Projections indicate that risks from mid-winter peak flows triggered by ROS events increase moderately by 2040 (2.1 days) and accelerate in 2080 (4 days) for national forest lands under the A1B emission scenario (table 5.1). By 2080, all areas, with the exception of the highest terrain in the Wallowa Mountains, almost double the number of days (mean 8.6 days) with the highest 5 percent flows (fig. 5.4).

Increased frequency and severity of flood flows during winter can affect overwintering juvenile fish and eggs incubating in the streambed. Eggs of fall spawning spring Chinook salmon and bull trout may suffer higher levels of mortality when exposed to increased flood flows (Jager et al. 1997). Scouring of the streambed can dislodge eggs (Schuett-Hames et al. 2000), and elevated sediment transport caused

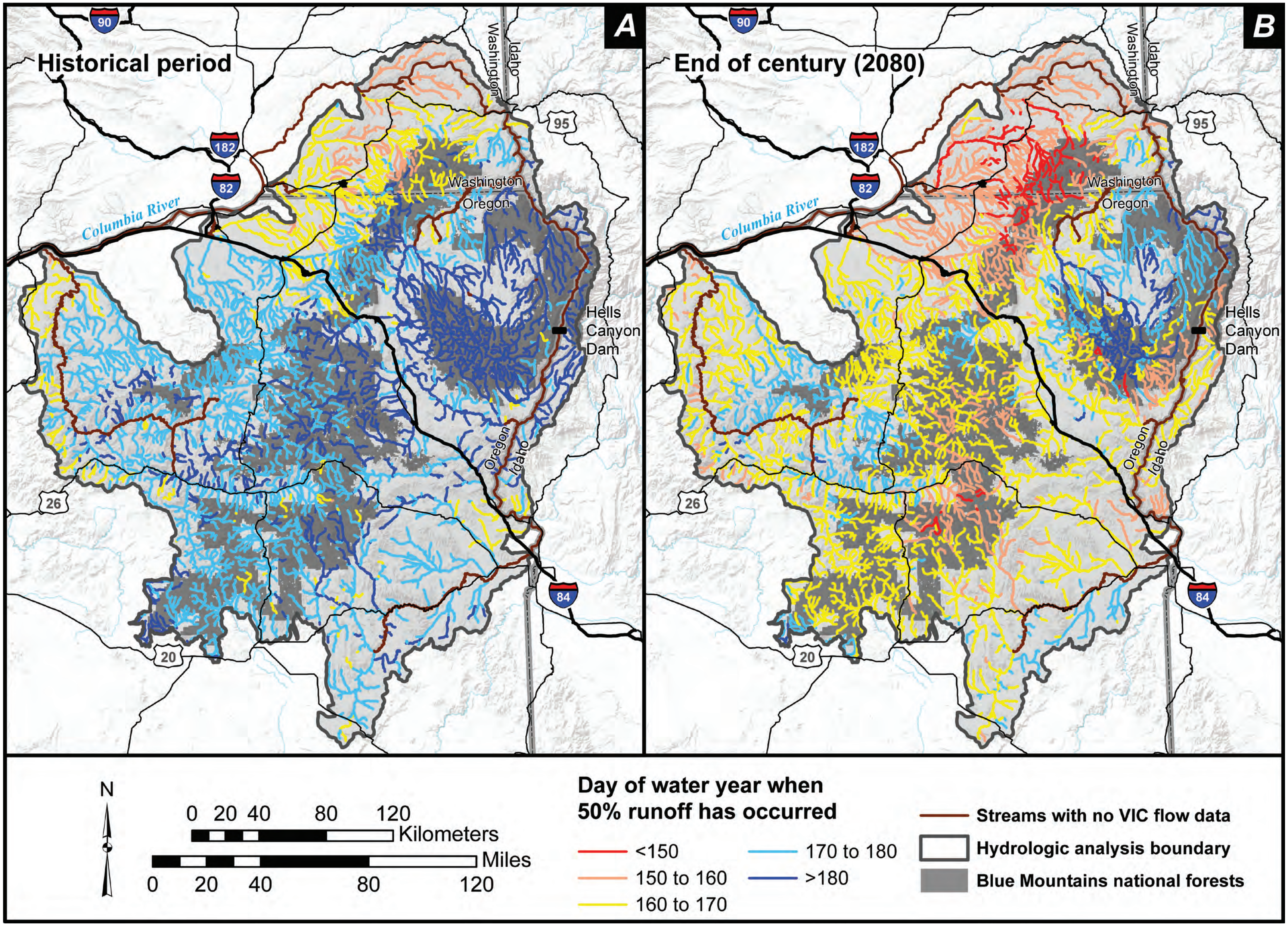

Figure 5.4—Maps showing dates of the center of annual flow mass (50 percent of annual flows) for the 1980s (A) and 2080s (B) based on the A1B emissions trajectory. Cool colors indicate streams with snowmelt-dominated hydrographs, and warm colors indicate rainfall-dominated hydrographs. VIC = Variable Inflirtation Capacity.

Potential effects to fish from altered winter peak flows will likely vary by species and strength of each population.

by high flow can increase sediment deposition in redds, suffocating eggs (Peterson and Quinn 1996). Potential effects to fish from altered winter peak flows will likely vary by species and strength of each population. Eggs from smaller fall spawning fish (e.g., bull trout) will likely be at higher risk from winter channel scour events than larger fall spawning fish (e.g., spring Chinook salmon) because of shallower egg depths (Bjornn and Reiser 1991, Montgomery et al. 1999, Shellberg et al. 2010). Smaller fish also use smaller gravels that are more easily scoured than gravels used by larger spawning fish.

Despite similar incubation timing, bull trout had a higher risk of scour than spring Chinook salmon, which bury their eggs deeper (40 cm vs. 10 to 20 cm for bull trout) in the Middle Fork of the Salmon River (Goode et al. 2013). The risk of scour was also greater for resident bull trout (10 cm egg burial depth) than for larger, migratory forms (20 cm egg burial depth) for identical spawning locations and timing. Spring Chinook salmon had lower risk of channel scour associated with climate change because of their spawning preference for unconfined alluvial valleys that are somewhat buffered from scour caused by increased winter flows (Goode et. al. 2013). Spring Chinook salmon redds also have lower risk because they are generally constructed from larger substrates that would be mobilized only during large flood events.

Winter floods may increase risks to fry that are vulnerable to displacement during the first month after emergence (Fausch et al. 2001, Nehring and Anderson 1993) or to juveniles with poor swimming ability in high-velocity water (Crisp and Hurley 1991, Heggenes and Traaen 1988). The retreat of snow level to higher elevations may lead to earlier fry emergence for some populations (Healey 2006). Individual populations have spawning times and egg development rates matched to the long-term environmental conditions of their spawning stream (Beacham and Murray 1990, Tallman 1986). Earlier emergence may expose the fry to increased mortality because of a lack of food or increased predation (Brannon 1987, Tallman and Healey 1994).

The above potential effects are most likely to occur in years with higher ROS risk. However, they will not occur every year or in every subbasin across the Blue Mountains. Risks of winter peak flow to fish habitat will differ by habitat and subbasin condition, valley confinement, and frequency and intensity of each ROS event. Smaller watersheds with higher road densities may concentrate flows into streams and magnify channel scour. Habitats that offer fewer refugia (e.g., infrequent pools, shallow pools, less woody debris) from high flows may result in higher fish mortality from winter floods.

Risks from winter peak flow will almost double in some Blue Mountains subbasins in the future, although risk will differ at different locations. Because salmonids have evolved within a highly dynamic landscape (Benda et al. 1992, Montgomery 2000), they may have sufficient phenotypic plasticity to buffer environmental changes, assuming that such changes are within the historical range of variability (Waples et al. 2008). However, it is unknown if phenotypic adjustment can keep pace with evolving disturbance frequency induced by contemporary climate change (Crozier et al. 2008, 2011).

Summer flows—
As described previously, spring and early summer flows have been decreasing as a result of earlier snowmelt and runoff over the last 50 years (Safeeq et al. 2013, Stewart et al. 2005). Streamflow magnitude in the Pacific Northwest also declined between 1948 and 2006, including decreased 25th percentile flow (Luce and Holden 2009), which means that the driest 25 percent of years have become drier across the majority of the Pacific Northwest. Overall, trends in the Blue Mountains suggest summer flows decreased 21 to 28 percent in the period from 1949 to 2010 (Safeeq et al. 2013). This trend is expected to continue because large portions of the Blue Mountains could lose all or significant portions of April 1 snow-water equivalent (SWE) in future periods because of reduced snow accumulation and increased ROS events that reduce snowpack SWE prior to April 1. Snowpack sensitivity differs with elevation, and risk of loss is higher where snowpack currently persists in higher elevation subbasins (see chapter 3).

Effects on fish and their habitats from changes in summer low flows will differ by the intensity and frequency of drought and early season runoff, as a function of geology, drainage elevation, and fish species across the Blue Mountains. Streams more dependent on snowmelt with minimal groundwater contribution will be affected more than streams sustained by groundwater. However, even these groundwater streams will have lower baseflows in sustained droughts.

Fish populations most affected by this change will likely be in headwater areas inhabited by steelhead, redband trout, and bull trout. However, all fish populations will be stressed as streamflows decrease over the summer. Increased intensity of extreme low flows reduces the probability of survival in rearing juveniles (May and Lee 2004), with evidence that summer and early autumn low flows cause greater impacts (Crozier and Zabel 2006, Harvey et al. 2006). In some stream reaches, riffles will become shallower and perhaps intermittent (Sando and Blasch 2015). This may result in disconnected stream reaches, isolated pools, overcrowding of fish, increased competition for food and cover, and greater vulnerability to predators in remaining deep water habitat.

In years of extreme drought, native trout and salmon populations may retreat to shrinking coldwater refuges in drainages where unimpeded access allows fish to avoid warmer downstream conditions. Changes in low flow may reduce the likelihood of successful adult migration (Rand et al. 2006, Zeug et al. 2011) as adult fish return from the ocean and have difficulty negotiating waterfalls and other barriers.

Steelhead have high phenotypic plasticity and may shift the timing of a life stage transition to reduce probability of exposure to changes in stream temperature and flow. However, steelhead are limited in their ability to shift the timing of their life stages. Because changes in both temperature and flow initiate transitions among salmon life stages (Bjornn and Reiser 1991, Quinn and Adams 1996), the likelihoods of a temporal disparity between life stages and a decrease in probability of persistence increase when temperature and flow are beyond some critical threshold (Reed et al. 2010, Schlaepfer et al. 2002).

Stream Temperatures—General Patterns

Considerable thermal heterogeneity exists across Blue Mountain streams owing to the complex topography and range of elevations within the area (table 5.2, fig. 5.5). August stream temperatures in the 1980s baseline period averaged 15.5 °C and ranged from 4.7 to 23.5 °C. Temperatures of streams flowing through higher elevation national forest lands were cooler, averaging 12.4 °C. Summer temperatures are projected to increase across the Blue Mountains by an average of 0.9 °C in the 2040s and 1.9 °C in the 2080s. Larger than average increases are projected to occur in the warmest streams at low elevations, and smaller than average increases are projected for the coldest streams. This differential warming occurs because

Table 5.2—Summary of August mean stream temperatures in the Blue Mountains climate analysis area during the baseline period and two future periods associated with the A1B emission trajectory

	< 8 °C	8–11 °C	11–14 °C	14–17 °C	17–20 °C	> 20 °C
	Stream kilometers					
All lands:						
1980s	448	1672	5150	8846	5000	1496
2040s	131	1122	3082	7640	7679	2959
2080s	46	770	2240	6351	8457	4752
Forest Service lands:						
1980s (1970–1999)	441	1457	3237	1525	263	124
2040s (2030–2059)	131	1054	2353	2716	588	203
2080s (2070–2099)	46	739	1867	3187	923	284

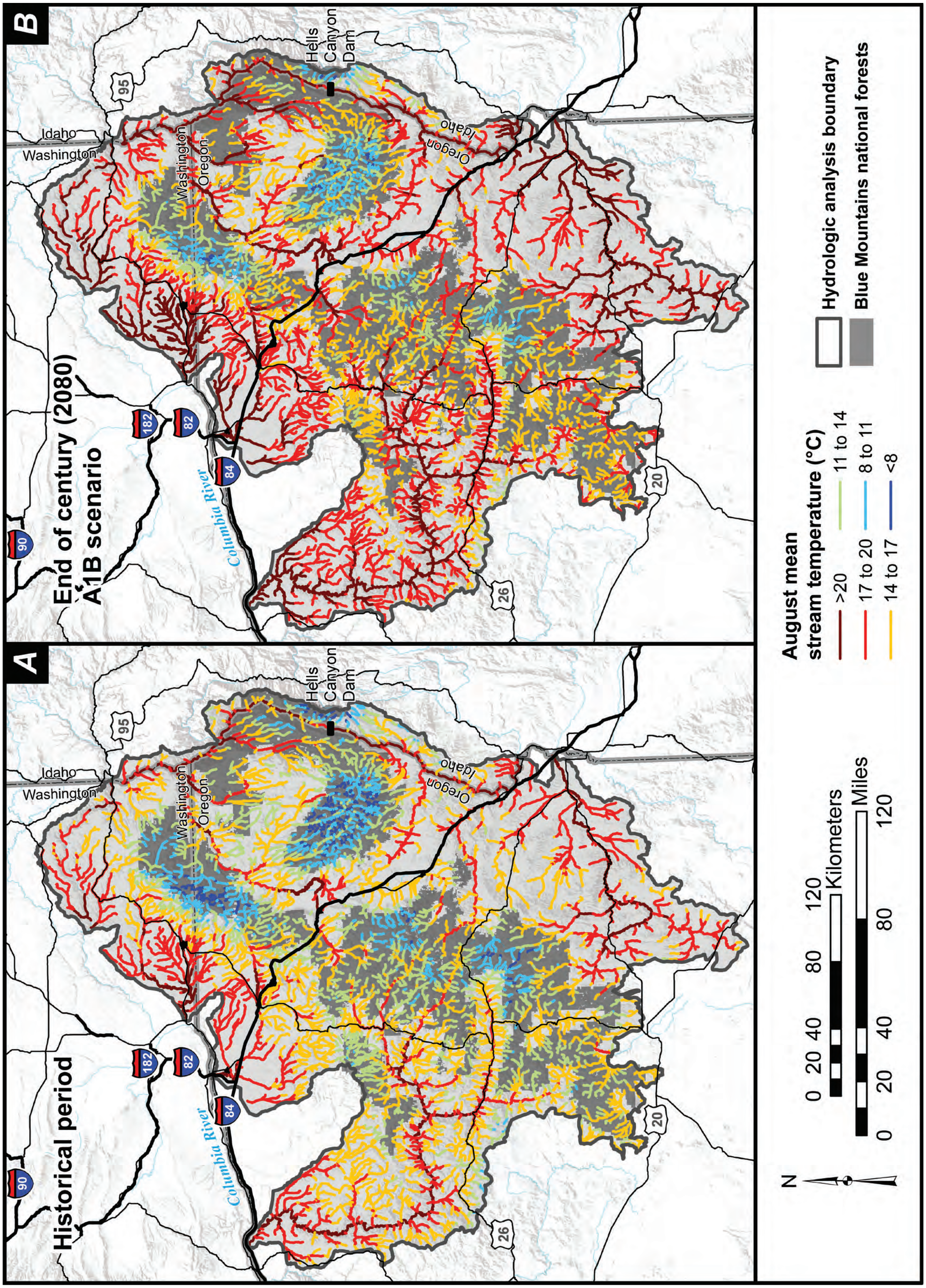

Figure 5.5—Summer stream temperature map for the 1980s (A) and 2080s (B) based on NorWeST scenarios and the A1B emissions trajectory.

cold streams are usually more buffered by local groundwater contributions than are warm streams (Luce et al. 2014a, Mayer 2012). Those projected temperature increases are smaller than the 2- to 4-°C increases projected for Pacific Northwest streams for the same A1B trajectory (Beechie et al. 2012, Mantua et al. 2010, Wu et al. 2012). But previous studies modeled short-term weekly maxima that often changed more rapidly than mean temperature conditions (Meehl and Tebaldi 2004).

Stream temperature increases will almost certainly continue, but with some uncertainty about site-specific rates.

In all cases, projections imply faster rates of stream temperature warming than has been observed in recent decades. Most streams in the Pacific Northwest have been warming 0.1 to 0.2 °C per decade (Isaak et al. 2012a, 2012b), which is slower than the rates of air temperature increases. Stream warming rates differ by season, with rates usually highest in summer and lower during winter and spring (for which a cooling trend has occurred in recent decades; Isaak et al. 2012a). Regional rates of stream warming have been dampened in recent years by a cool phase of the Pacific Decadal Oscillation (PDO; Mote et al. 2003; see http://cses.washington.edu/cig/pnwc/aboutpdo.shtml), a phenomenon that will not persist indefinitely as the PDO continues to cycle.

Stream temperature increases will almost certainly continue, but with some uncertainty about site-specific rates. Fish species in Blue Mountain streams will respond by adjusting their spatial distributions and phenologies to the evolving thermal environment. Adjustments in spatial distributions will be most pronounced near distributional boundaries that are currently mediated by temperature. Range contractions and habitat losses near warm downstream boundaries are often the focus of climate vulnerability assessments, but upstream boundaries controlled by cold temperatures may be equally relevant for some species. Colonization of new habitats farther upstream as warming progresses could offset a portion of downstream habitat losses for some species and populations (Isaak et al. 2010). Populations may also adapt phenologically by using habitats at different times of the year to avoid stressful conditions.

Evidence exists that migration dates of some salmon species have been advancing in recent decades (Crozier et al. 2008, Keefer et al. 2008, Petersen and Kitchell 2001) and that these trends are related to warmer temperatures (Crozier et al. 2011). However, phenological adaptations involve tradeoffs elsewhere in the life cycle. In the case of salmon, earlier migrants have spent less time in the ocean and have smaller body sizes (Rand et al. 2006), and these fish arrive in spawning areas sooner where they may be more susceptible to thermal events and predation risks. Documentation of phenological shifts for fish species and life stages beyond adult migrations are limited, but the strong temperature dependencies of physiological and metabolic processes usually translate to earlier timing of life history events in most species (Parmesan and Yohe 2003, Root et al. 2004).

Spring Chinook salmon—

Populations of spring Chinook salmon in the Blue Mountains will be sensitive to future temperature increases because many of their primary spawning and rearing streams occur at low elevation and are relatively warm for this species. Moreover, adults in these populations already exhibit heat-related stress symptoms, including clustering in coldwater refugia during warm periods (Torgersen et al. 1999, 2012) and occasional thermally induced mortality events in the lower river migration corridors in the John Day River system during upriver spawning migrations. The large body size of salmon and preference for spawning in unconfined valleys with gravel substrates (Isaak et al. 2007) may preclude their colonization of new habitats upstream from historical ones, so these fish are expected to lose habitat as warming continues.

To estimate potential habitat losses for spring Chinook salmon, a 19 °C temperature threshold was applied to the stream temperature scenarios described previously (table 5.2; fig. 5.5), and these were clipped to match the upstream distribution of spring Chinook salmon in the Blue Mountains. This temperature was chosen because streams with higher temperatures are susceptible to invasion by nonnative smallmouth bass that predate heavily on juvenile Chinook salmon (Lawrence et al. 2014). Chinook salmon populations in streams warmer than 19 °C also exhibit consistently higher prespawn mortality rates than populations in cooler streams (Keefer et al. 2010). Based on that criterion, it was estimated that 1921 km of salmon habitat existed during the 1980s baseline across the Blue Mountains region, 854 km of which were on national forest lands (table 5.3, fig. 5.6). In the future, 24 to 38 percent of streams across the analysis area are projected to exceed

Table 5.3—Changes in stream length (kilometers; percent change in parentheses) across the Blue Mountains analysis area with temperatures suitable for spring Chinook salmon spawning and rearing during three climate periods associated with the A1B emission trajectory

Climate period	All lands	Forest Service lands
	Kilometers <19.0 °C[a]	
1980s (1970–1999)	1921	854
2040s (2030–2059)	1453 (-24.4%)	767 (-10.2%)
2080s (2070–2099)	1200 (-37.5%)	673 (-21.2%)

[a] A critical temperature threshold of 19 °C was chosen because reaches warmer than this are susceptible to invasion by nonnative smallmouth bass that predate on juvenile salmon (Lawrence et al. 2014), and because prespawn mortality rates of adult salmon are much higher above this threshold (Keefer et al. 2010).

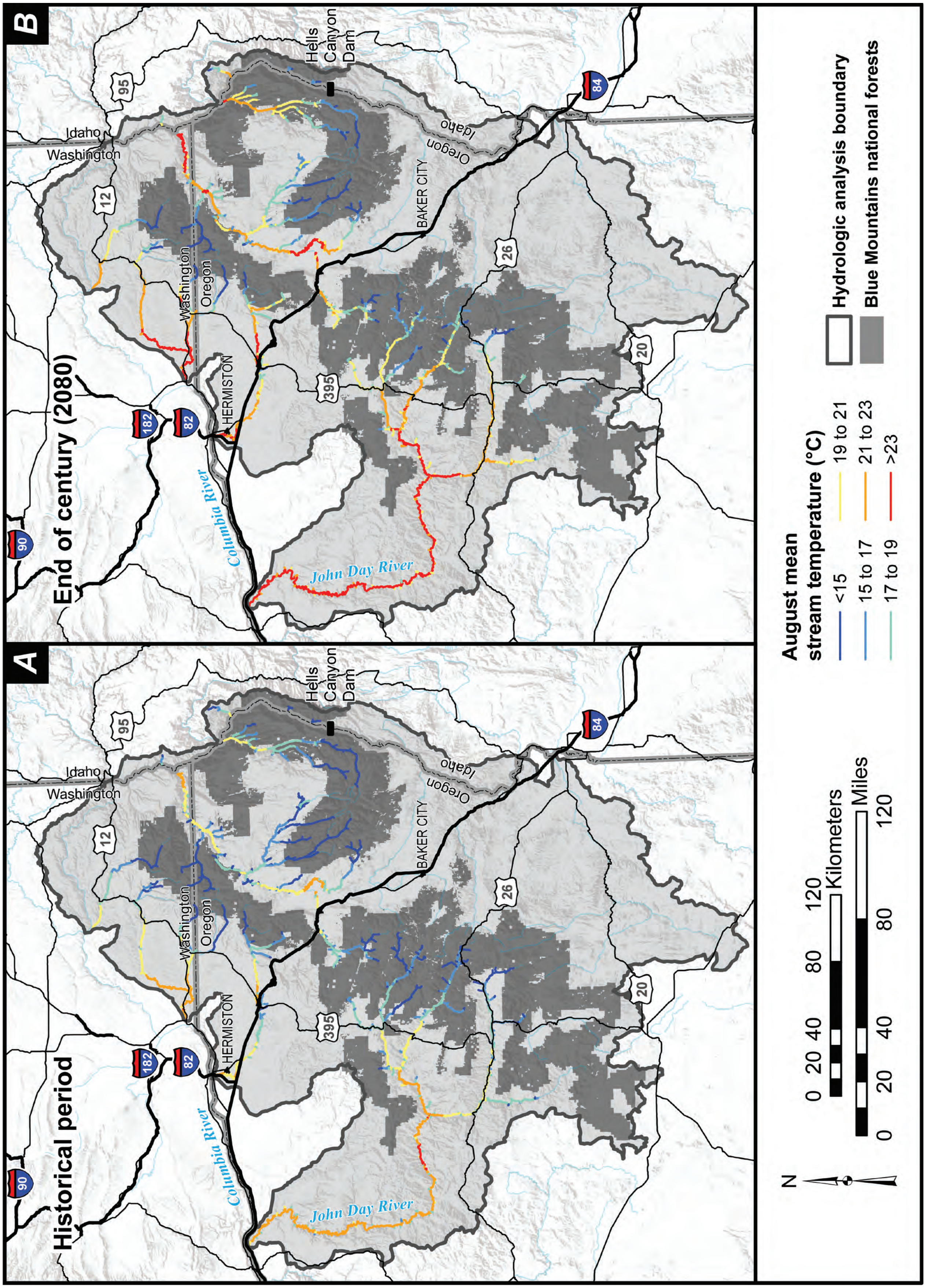

Figure 5.6—Distribution of thermally suitable habitat for spring Chinook salmon downstream of Hells Canyon during the 1980s (A) and 2080s (B) based on the A1B emissions trajectory.

19 °C, but only 10 to 21 percent reductions are expected on national forest lands because streams are colder and farther from the temperature threshold. An earlier estimate of Chinook salmon habitat loss in a subset of the Blue Mountains, the John Day River basin, predicted larger reductions (30 to 75 percent decreases for similar time periods; Reusch et al. 2012), but also showed a similar pattern of larger habitat losses in warmer downstream areas.

Bull trout—

Populations of bull trout in the Blue Mountains will be sensitive to future temperature increases because this species requires streams with very cold temperatures (Dunham et al. 2003, Mesa et al. 2013, Selong et al. 2001). Although adult bull trout sometimes use main-stem rivers at times of year when temperatures may be relatively warm (Howell et al. 2010, Monnot et al. 2008), spawning and juvenile rearing during the first few years of life occur exclusively in the coldest streams (Isaak et al. 2010, Rieman and McIntyre 1995). Consequently, existing populations of bull trout in the Blue Mountains are constrained and heavily fragmented among a few small headwater networks. The upstream extent of bull trout in those networks is further limited by stream slope and small flow volumes, so colonization of new upstream habitats in response to climate change is not possible.

A variety of temperature thresholds have been used in bull trout climate vulnerability assessments (Isaak et al. 2010; Rieman et al. 2007; Ruesch et al. 2012; Wenger et al. 2011a, 2011b), but most focus on temperature criteria associated with spawning and rearing habitats because these are critical to bull trout population persistence. An 11.0 °C temperature criterion was chosen for this assessment because

Table 5.4—Changes in stream length (kilometers; percentage change in parentheses) across the Blue Mountains analysis area with temperatures suitable for bull trout spawning and rearing during three climate periods associated with the A1B emission trajectory

	All lands	Forest Service lands
	Kilometers < 11.0 °C[a]	
1980s (1970–1999)	1953	1827
2040s (2030–2059)	1174 (-40%)	1129 (-38%)
2080s (2070–2099)	786 (-60%)	771 (-58%)

[a] Stream reaches with mean August temperatures >11.0 °C are warmer than optimal for bull trout spawning and rearing, so future warming will decrease habitat suitability in these areas. More than 90 percent of bull trout spawning and early juvenile rearing occurs in reaches with August temperatures <11.0 °C, so these areas are critical to population persistence (Isaak et al. 2010, 2014, 2015; Rieman et al. 2007).

cross-referencing of extensive fish survey databases (Rieman et al. 2007; Wenger et al. 2011a, 2011b) with stream temperature measurements suggest more than 90 percent of juvenile bull trout (defined as fish less than 150 mm in length) occur in streams at least this cold (Isaak et al. 2010, 2014, 2015). Moreover, most juveniles found in reaches more than 11 °C probably originated in colder, upstream areas and have subsequently moved downstream.

Based on that criterion, it was estimated that 1953 km of bull trout habitat existed during the baseline 1980s conditions across the Blue Mountains, 94 percent of which occurred on national forest lands (table 5.4, fig. 5.7). Future projections suggest that 38 percent and 58 percent of those streams will exceed 11 °C by mid and late 21st century, respectively. Ruesch et al. (2012) made a comparable estimate of bull trout habitat loss over similar time periods in the John Day River system that predicted larger losses (66 to 100 percent decreases), but projected a qualitatively similar pattern of decline as temperatures increase in the future. None of the available estimates accounts for reductions in habitat volume that would be caused by ongoing decreases in summer flows. Neither do those estimates account for potential negative synergies between reductions in habitat size and increased environmental disturbances such as wildfires, debris flows, winter high flows, and drought (Dunham et al. 2007, Hamlet and Lettenmaier 2007, Littell et al. 2010, Luce and Holden 2007).

Populations of steelhead and redband trout will be affected by future temperature increases in the Blue Mountains.

Steelhead trout/redband trout—
Populations of steelhead and redband trout will be affected by future temperature increases in the Blue Mountains, but probably less negatively than bull trout and spring Chinook salmon. Temperature and food availability play important roles in mediating the relative proportions of the two life history forms, but both have relatively warm thermal niches (Richter and Kolmes 1995, Rodnick et al. 2004, Zoellick 1999) and upstream distributions that are limited by cold temperatures in many streams (Isaak et al. 2015). The latter provides some flexibility as warming proceeds because the thermal suitability of upstream habitats will improve and may partially compensate for losses where streams become too warm. Several temperature categories were used to represent the breadth of the thermal niche for steelhead and redband trout, with temperatures less than 9 °C considered unsuitably cold, 13 to 20 °C optimal, and greater than 25 °C unsuitably warm.

Summaries of future stream lengths in those categories indicate that upstream habitat gains could occur in many streams that were too cold for this species historically, and a small net increase in the length of thermally suitable habitat may occur (tables 5.5, 5.6; figs. 5.8, 5.9). That result contrasts with a loss of 10 to 43 percent of habitat in the John Day system projected by Ruesch et al. (2012), but that estimate

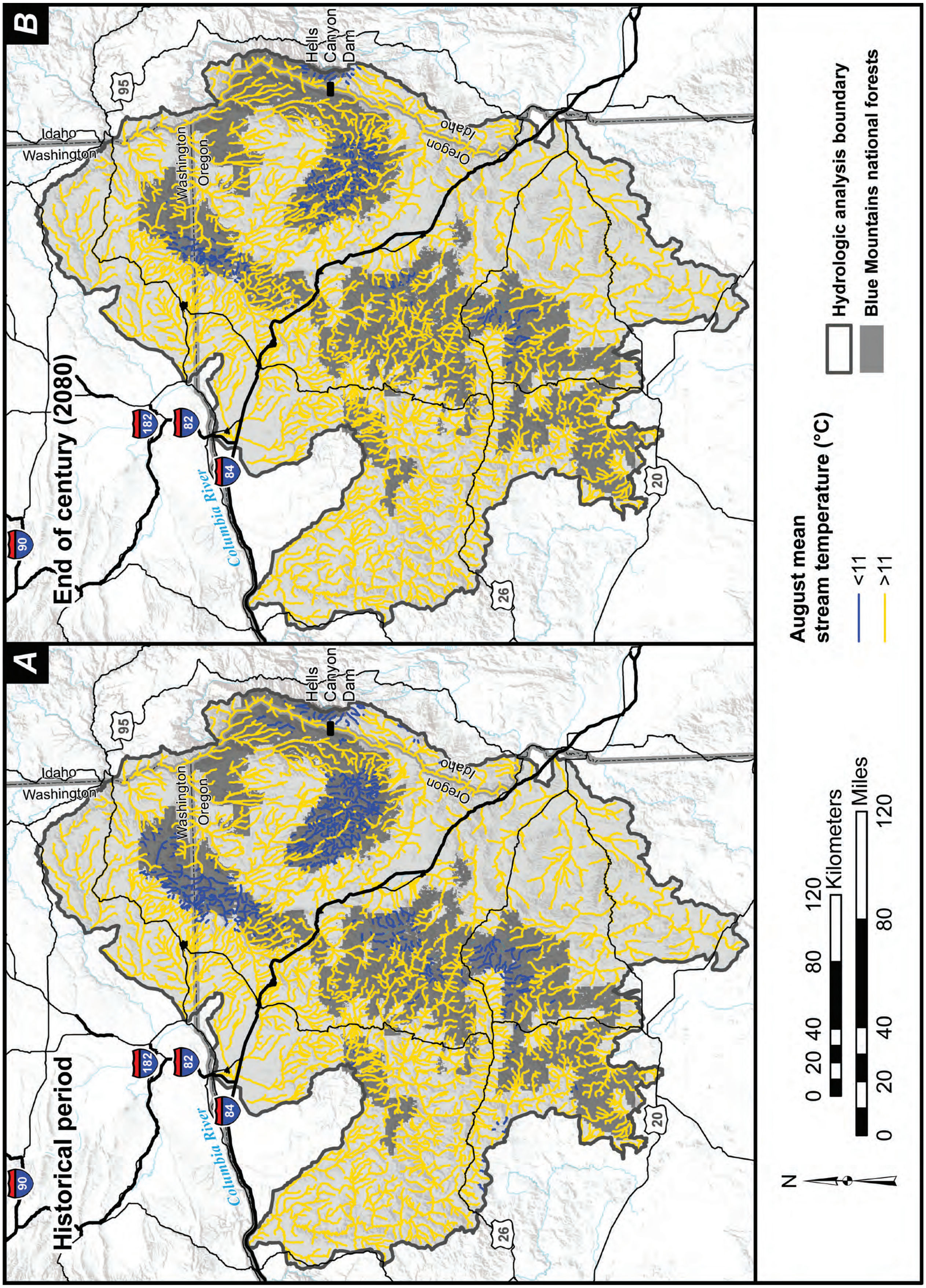

Figure 5.7—Distribution of thermally suitable habitat for bull trout during the 1980s (A) and 2080s (B) based on the A1B emission trajectory.

Table 5.5—Changes in stream length (kilometers; percentage change in parentheses) with suitable temperatures for steelhead and redband trout downstream of Hells Canyon within the Blue Mountains analysis area during three climate periods associated with the A1B emissions trajectory

	Kilometer			
	<9 °C[a]	9–13 °C	13–20 °C	20–25 °C[b]
All lands:				
1980s (1970–1999)	685	2684	10 630	358
2040s (2030–2059)	246 (-64%)	1724 (-36%)	11 182 (5%)	1208 (337%)
2080s (2070–2099)	105 (-85%)	1317 (-51%)	10 423 (-2%)	2512 (702%)
Forest Service lands:				
1980s (1970–1999)	681	2183	2185	8
2040s (2030–2059)	246 (-64%)	1555 (-29%)	3181 (46%)	75 (937%)
2080s (2070–2099)	105 (-85%)	1262 (-42%)	3527 (61%)	163 (2,037%)

[a] Stream reaches with mean August temperatures <9 °C are too cold for redband trout, so future warming will increase habitat suitability in these areas.

[b] Stream reaches with mean August temperatures >20 °C are warmer than optimal for steelhead/redband trout so future warming will decrease habitat suitability in these areas. Temperatures >25 °C are considered unsuitable (Cassinelli and Moffitt 2009, Rodnick et al. 2004, Sloat and Reeves 2014).

Table 5.6—Changes in stream length (kilometers; percent change in parentheses) with suitable temperatures for redband trout upstream of Hells Canyon within the Blue Mountains analysis area during three climate periods associated with the A1B emissions trajectory

	Kilometers			
	< 9 °C[a]	9–20 °C	20–25 °C[b]	>25 °C
All lands:				
1980s (1970–1999)	168	3914	71	0
2040s (2030–2059)	73 (-57%)	3516 (-10%)	565 (796%)	0
2080s (2070–2099)	34 (-80%)	3179 (-19%)	941 (1,325%)	0
Forest Service lands:				
1980s (1970–1999)	158	976	0	0
2040s (2030–2059)	70 (-56%)	1062 (9%)	2	0
2080s (2070–2099)	34 (-78%)	1094 (12%)	6	0

[a] Stream reaches with mean August temperatures <9 °C are too cold for redband trout, so future warming will increase habitat suitability in these areas.

[b] Stream reaches with mean August temperatures >20 °C are warmer than optimal for redband trout, so future warming will decrease habitat suitability in these areas. Temperatures >25 °C are considered unsuitable (Cassinelli and Moffitt 2009, Rodnick et al. 2004, Sloat and Reeves 2014).

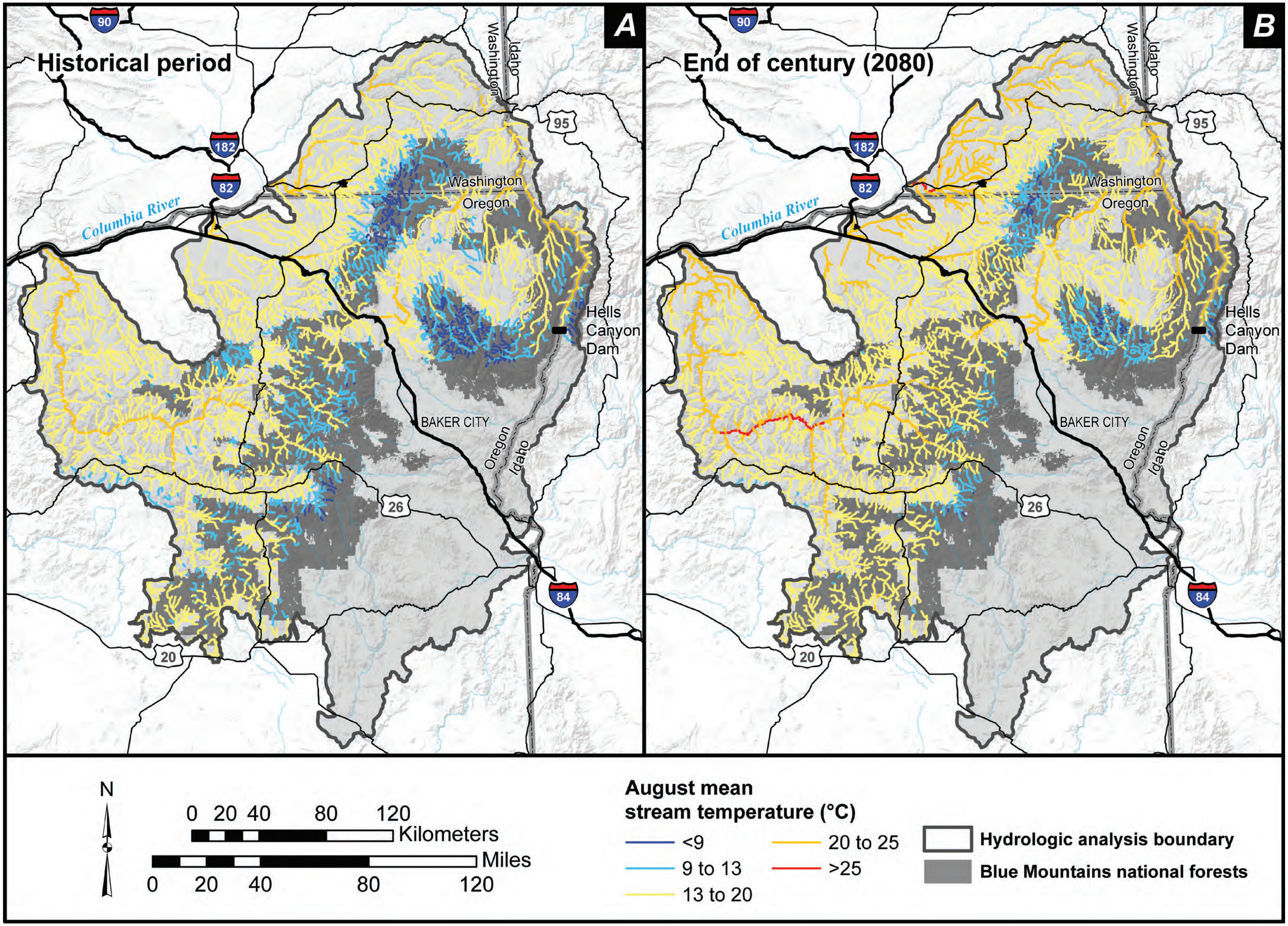

Figure 5.8—Distribution of thermally suitable habitat for steelhead and redband trout downstream of Hells Canyon in the 1980s (A) and 2080s (B) based on the A1B emission trajectory.

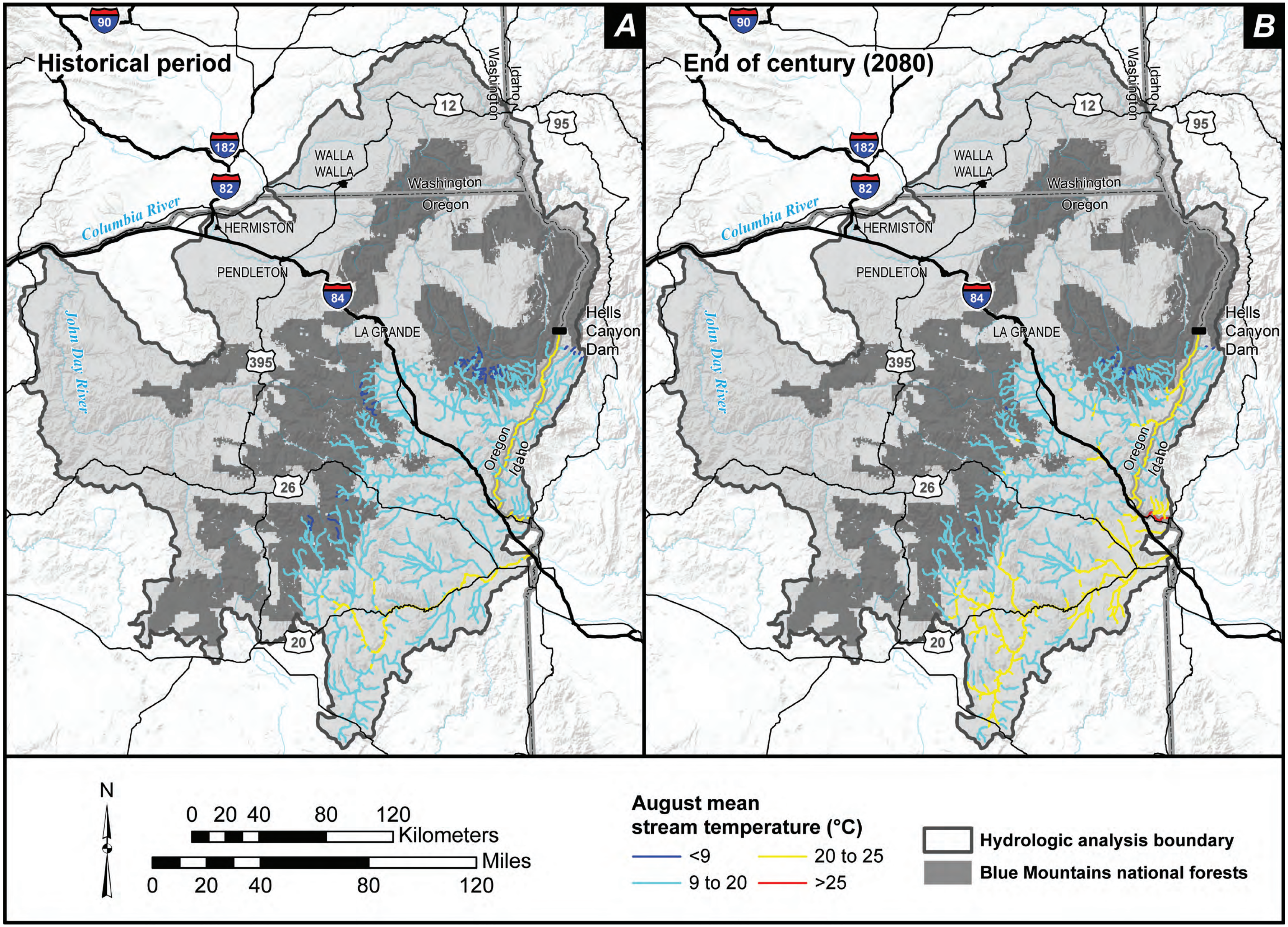

Figure 5.9—Distribution of thermally suitable habitat for redband trout upstream of Hells Canyon and in the Oregon Closed Basins in the 1980s (A) and 2080s (B) based on the A1B emission trajectory.

was based on the assumption that unsuitably cold habitats were not upstream of current steelhead and redband trout in some streams. In a regional climate vulnerability analysis, Wade et al. (2013) indicated that steelhead migrating through the lower Columbia River and many large rivers and tributaries will be negatively affected by future temperature increases. However, the spatial resolution of the model was limited to the largest rivers, so their analysis could not assess effects throughout the full network of streams draining the Blue Mountains. Taken in combination, these studies suggest that although there may be some thermal effects on steelhead and redband trout (Ebersole et al. 2001, Torgersen et al. 2012), the species have some flexibility to adapt to temperature increases through different life histories, phenological adjustments, and distribution shifts.

Population dynamics and abundance of spring Chinook salmon and steelhead are strongly affected by conditions in the ocean environment.

Climate Cycles and Ocean Effects on Fisheries

The biology and legal status of anadromous steelhead and spring Chinook salmon in the Middle Columbia River and Snake River basins demonstrate that anadromous fish populations are heavily influenced by many factors outside and downstream of national forest-administered lands. For example, population dynamics and abundance of spring Chinook salmon and steelhead are strongly affected by conditions in the ocean environment (Mantua et al. 1997). The productivity of that environment for salmon growth and survival varies through time in response to sea surface temperatures and strength of coastal upwelling tied to regional climate cycles like the El Niño Southern Oscillation (ENSO; 5- to 7-year periods) and PDO (20- to 40-year periods). Although ocean productivity and climate cycles most strongly affect anadromous fishes, these cycles are also relevant to resident species like bull trout and redband trout because of inland effects on temperature, precipitation, and hydrologic regimes that alter the quality and quantity of freshwater habitat (Kiffney et al. 2002). In the Pacific Northwest, cool (wet) phases of ENSO and PDO are more beneficial to fish populations than are warm (dry) phases (Copeland and Meyer 2011, Mote et al. 2003).

Research summarized in the recent Intergovernmental Panel on Climate Change report (Stocker et al. 2013) provides little evidence to support concerns about climate change affecting the periodicity or magnitude of ENSO or PDO, either in the historical record, or in future climate projections. Therefore, we can expect climate cycles to periodically dampen or exacerbate the effects of climate change on fish populations and stream habitats. A cool PDO phase began in about 2000 and has largely persisted to the present (see http://www.jisao.washington.edu/pdo), but it is unknown how long this PDO phase will persist and help buffer fish populations against climate change.

Adapting Fish Management to Climate Change in the Blue Mountains

Management strategies and tactics for increasing resilience of fish populations to a warmer climate in streams of the Western United States have been well documented in the scientific literature (e.g., Isaak et al. 2012a, ISAB 2007, Luce et al. 2013, Mantua and Raymond 2014, Rieman and Isaak 2010). This documentation and feedback from resource specialists contributed to a summary of climate change adaptation options for the Blue Mountains (table 5.7). Implementation of climate-smart management actions and watershed restoration objectives will benefit from a strategic hierarchical approach to ensure the most important work is occurring in the most important places (Hughes et al. 2014). Stream restoration, which is already well underway in the Blue Mountains and elsewhere, will in turn need to consider future biophysical conditions that will be affected by a warming climate (Beechie et al. 2012).

Responding to Shifts in Timing and Magnitude of Streamflow

Reduced snowpack as a function of increasing temperature has already been documented in the Pacific Northwest, including the Blue Mountains (see chapter 3 and previous discussion in this chapter). As this trend continues, hydrologic regimes will shift towards increasing dominance by rainfall and decreasing dominance by snow at all but the highest elevations, altering the timing and magnitude of streamflows. Specifically, winter peak flows will be higher, and extreme flows will be more frequent than they are now, causing considerable stress for some fish species.

Maintaining the overall integrity and functionality of stream systems will be critical for minimizing the effects of higher winter flows (table 5.7a). This can be accomplished by increasing soil water storage in floodplains and on hillslopes for instream baseflows, thus reducing the "flashiness" of stormflows. Decreasing fragmentation of stream networks, currently somewhat disrupted by roads and water diversions, will ensure that aquatic organisms have options for accessing favorable habitats during extreme flows. Better information about streamflow regimes will ensure that climate change adaptation and stream restoration will be conducted effectively and efficiently (Luce et al. 2012, Wigington et al. 2013).

Many management tactics are available to alter the effects of increasing winter streamflows, including managing upland and riparian vegetation, managing roads to reduce accelerated runoff, reconnecting and increasing off-channel habitat in side channels and wetlands, and promoting American beaver (*Castor canadensis* Kuhl) populations and beaver-related overbank flow processes (Pollock et al. 2014). It is also desirable to identify critical downstream areas where leased water rights or

Table 5.7a—Adaptation responses for fisheries and aquatic environments to climate change in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Shift in hydrologic regime involving changes in timing and magnitude of flows. Anticipated changes include lower summer flows and higher, more frequent winter peak flows.				
Adaptation strategy: Maintain or restore natural flow regime to buffer against future changes.				
Use Watershed Analysis, Watershed Condition Framework, etc. to develop integrated, interdisciplinary tactics associated with vegetation and hydrology	<10 years	Collaborate with nongovernmental organizations, other federal and state agencies, and private landowners	Competing priorities Lack of funding	Compare Mid-Columbia River Steelhead Recovery Plan and Oregon Department of Fish and Wildlife climate change analysis and other products Identify priority areas
Protect groundwater and springs	<10 years	Explore opportunities with range permittees, nongovernmental organizations, and others	Lack of information on locations of groundwater and springs Lack of funds to address sites affected by livestock Competing priorities	Identify locations of groundwater-dependent systems and spring influences
Restore riparian areas and beaver populations to maintain summer baseflows and raise water table	<10 to >30 years	Collaborate with states, range permittees, and private landowners regarding beaver reentry Use range allotment management, riparian shrub planting and protection, riparian aspen restoration and management, road infrastructure planning, and valley form analysis to assess potential sites for beaver colonies and channel migration	Effects on infrastructure (culverts and diversions) Adequate food supply for growing beaver colonies and dispersing individuals Public and private landowner acceptance of beaver colonies Effects of rising water levels on streamside roads and camping grounds	Inventory riparian vegetation Monitor beaver populations Identify potential watersheds or stream reaches Inventory riparian vegetation and stream morphology status and trends
Address water loss at water diversions and ditches	<10 years	Coordinate with the water district managers, water master, and water users	Competing priorities Lack of funding Water law does not address ditch water loss and inefficiencies	Identify diversions and ditches with water losses or other resource issues
Reconnect and increase off-channel habitat and refugia in side channels and channels fed by wetlands	<10 to >30 years	Collaborate with partners	Competing priorities Lack of funding	Identify potential watersheds or stream reaches

Table 5.7a—Adaptation responses for fisheries and aquatic environments to climate change in the Blue Mountains (continued)

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Revegetate, use fencing to exclude livestock	<10 years	Collaborate with partners on fencing or acquire/lease water rights Plant in and protect riparian areas Restore aspen	Competing priorities Lack of funding Difficulty of maintaining livestock and ungulate exclosures	Investigate baseline vs. desired conditions in riparian corridors Conduct effectiveness monitoring
Acquire water rights, use low-flow channel design	<10 years	Collaborate with partners in acquiring and leasing water rights	Competing priorities Lack of funding Opposition from permittees	Investigate baseline vs. desired conditions in riparian corridors Identify water rights holders willing to collaborate
Disconnect roads from streams to reduce drainage efficiency	<10 to >30 years	Identify areas with high drainage efficiency, using geographic information system (GIS) and Netscape and Geomorphic Road Analysis and Inventory tools	Controversial from a political perspective Lack of travel plan Competing priorities Lack of funding Time and cost for full analyses	Acquire GIS data to identify areas with high drainage efficiency Identify problematic road segments contributing high sediment
Adaptation strategy: Decrease fragmentation of stream network so aquatic organisms can access similar habitats.				
Identify stream crossings that impede fish movements and prioritize culvert replacements	<10 to >30 years	Collaborate with partners	Competing priorities Lack of funding	Update culvert inventory
Use stream simulation design (e.g., bottomless arches, bridges), adjusting designs to provide low-flow thalweg	<10 to >30 years	Collaborate with partners to enhance skills and funding Use GIS analyses to inform low-flow and high-flow stream design at specific crossings	Insufficient staff time for design, contracting, and effectiveness monitoring Insufficient National Environmental Policy Act funding and staff time for project planning	Incorporate climate change information to ensure culvert priorities consider long-term cost-effectiveness and ecological effectiveness
Rebuild stream bottoms by increasing floodplain connectivity, riparian vegetation, and water tables; decrease road connectivity	<10 to >30 years	Restore beaver habitat and beaver colonies Relocate streamside roads away from streams when possible Manage roads, vegetation, and fuels to ensure large wood recruitment for in-channel potential	Hazard tree management, roadside salvage, firewood cutting, road proximity to stream channels and beaver colonies, developed recreation site locations Mining claim and private land access obligations Competition with livestock and large ungulates for limited food supply	Assess beaver habitat potential Compare natural fire regime restoration with potential for fish habitat restoration Options for alternate access routes for mining claims and private land access

Table 5.7a—Adaptation responses for fisheries and aquatic environments to climate change in the Blue Mountains (continued)

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Maintain minimum streamflows (buy and lease water rights, install modern flow structures, monitor water use)	<10 to >30 years	Collaborate with partners	Competing priorities Lack of funding and personnel Few opportunities to acquire senior water rights	Identify areas of concern and opportunities for return on investment
Design channels at stream crossings to provide a deep thalweg for fish passage during low-flow periods	<10 to >30 years		Competing priorities Lack of funding	Identify and prioritize channels and crossings of high concern
Design stream crossings to accommodate higher peak flows	<10 to >30 years		High costs Competing priorities	Update stream crossing inventory
Adaptation strategy: Develop better information about streamflow regimes.				
Increase flow data collection and monitoring to better describe patterns in flow and improve hydrologic models	<10 to >30 years	Collaborate with U.S. Geological Survey, watershed councils, etc.	Competing priorities Lack of funding and personnel	Identify and prioritize areas to monitor

Table 5.7b—Adaptation responses for fisheries and aquatic environments to climate change in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Streams and other water bodies (e.g., springs) will be affected by more wildfires and disturbances associated with sediment pulses and debris-flow torrents.				
Adaptation strategy: Develop wildfire-use plans that address sediment inputs and road failures; reduce sediment input from roads and management activities.				
Restore and revegetate burned areas to store sediment and maintain channel geomorphology	<10 years	Collaborate with fire management program	Lack of funding if outside of Burned Area Emergency Rehabilitation Competing priorities	
Develop a geospatial layer of debris-flow potential for prefire planning	<10 years	Collaborate with soils and geology programs	Lack of funding and personnel Competing priorities	
Use Montgomery-Buffington classification and other tools to calculate runout distance and woody debris source areas	<10 years		Lack of funding Competing priorities	
Adaptation strategy: Identify hillslope landslide hazard areas and at-risk roads prior to wildfires and as part of fire planning.				
Link stream inventory with topographic, geomorphic, and vegetation layers to assess existing hazard and risk	<10 years	Collaborate with soils and geology programs	Lack of funding Competing priorities	Identify hillslope landslide hazard areas and at-risk roads
Develop a process to prioritize tactics needed to protect multiple fish species and populations	<10 years	Collaborate with fisheries at multiple levels	Competing forest priorities Lack of funding	Need updated fish distribution layer

Table 5.7c—Adaptation responses for fisheries and aquatic environments to climate change in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Stream temperatures will increase, owing to rising air temperatures and declining summer flows, which will affect many life stages of aquatic organisms.				
Adaptation strategy: Maintain or restore natural thermal conditions to buffer against future climate changes.				
Maintain or restore riparian vegetation to ensure channels are not exposed to increased solar radiation	<10 to >30 years	In project analysis, consider departure from desired conditions/natural range of variability	Competing priorities Lack of funding	Conduct ecologically based investigations into appropriate vegetation for restoration
Manage livestock grazing to restore ecological function of riparian vegetation and maintain streambank conditions	<10 to >30 years	Work with range permittees, watershed councils, and other partners to fund or install fencing	Reluctant permittees do not want to do more fence maintenance Competing priorities Lack of funding	Identify streams within range allotments, then prioritize streams based on fish population status
Work with vegetation managers to identify interdisciplinary tactics for restoring riparian function and hydrologic processes	<10 to >30 years	Vegetation management is a high priority for resource management	Project planning and objectives are largely limited to timber products	Identifying how to pay for additional riparian treatments
Increase floodplain connectivity, diversity, and water storage to improve hyporheic and baseflow conditions	<10 to 30 years	Can identify treatment areas during project planning	High cost or social barriers to restoration	Identify and prioritize areas for treatment
Adaptation strategy: Increase connectivity within stream networks so aquatic organisms can access cold water refugia when needed.				
Same as above in table 4.7c	Same as in table 4.7c	Same as in table 4.7c	Same as in table 4.7c	Same as in table 4.7c
Adaptation strategy: Develop better information about stream temperature regimes.				
Increase temperature data collection and monitoring to better describe patterns in thermal regimes and improve hydrologic models	<10 to 30 years	Collaborate with federal and other partners	Competing priorities Lack of funding	Identify and prioritize areas for data collection

Table 5.7d—Adaptation responses for fisheries and aquatic environments to climate change in the Blue Mountains

Adaptation tactic	Timeframe	Opportunities for implementation	Barriers to implementation	Information needs
Sensitivity to climatic variability and change: Headwater and other intermittent streams and water bodies (e.g., springs) will be vulnerable to increasing wildfire; sediment pulses and altered flood patterns and magnitudes will increase with increasing fire frequency.				
Adaptation strategy: Develop wildfire-use plans that address sediment delivery.				
Restore and revegetate burned areas to store sediment and maintain channel geomorphology	<10 years	Burned Area Emergency Rehabilitation (BAER) and fire-restoration planning for road decommissioning Fire-killed timber management can provide large wood for slope stabilization per natural fire regime characteristics Other fire-restoration needs can be included in fire salvage National Environmental Policy Act (NEPA)	Public/internal desire to provide useable wood to local mills and support local employment and economy Tight timelines for NEPA to conduct fire salvage Lack of funding to conduct non-BAER fire-restoration opportunities identified in fire salvage NEPA documents	Identify trees likely to live beyond 10 years postfire Assess how to balance ecological values and community economic needs
Develop a geospatial layer of debris flow potential for prefire planning	<10 years	Hydrologists and soil scientists can provide data and criteria to geospatial analyst	Competing priorities May not be a big concern, depending on current availability of data	Identify geology/topography/soil maps/locations of known slide areas and their characteristics
Use Montgomery-Buffington classification and other tools to calculate runout distance and woody debris source areas	<10 years	Runout distance matters only if debris-flow potential is an actual concern	Minimal concerns	Identify geology/topography/soil maps/locations of known slide areas and other areas of concern
Adaptation strategy: Identify hillslope landslide hazard areas and at-risk roads prior to, and as part of, fire planning.				
Link stream inventory with topographic, geomorphic, and vegetation layers to assess existing hazard and risk	<10 years	Hydrologists and soil scientists can provide data and criteria to geospatial analyst	Minimal concerns	Identify geology/topography/soil maps/locations of known slide areas and other areas of concern
Develop a process to prioritize tactics needed to protect multiple fish species and populations	<10 years	Convene interdisciplinary fisheries, hydrology, soils, and roads discussions as part of development of watershed action plans, watershed restoration action plans, and water quality restoration plans	Staff time to integrate concerns and information	

short-term water swaps under low-flow conditions would benefit migrating spring Chinook populations subject to thermal stress, and where such actions would help sustain critical headwater areas for bull trout spawning and rearing. These adaptation tactics will be most efficient if they can be coordinated with existing stream management and restoration efforts conducted by the Forest Service and other landowners and stakeholders (Rieman et al. 2015).

Increased frequency of wildfire and annual area burned are a near certainty in the Blue Mountains region.

Responding to the Effects of Increased Disturbance on Sediment and Debris Flows

Climate change may increase the frequency of extreme events, which in turn would affect streams and aquatic habitat. Increased frequency of wildfire and annual area burned are a near certainty in the Blue Mountains region (see chapter 6). Increased area burned, especially if it includes increased fire intensity, will cause increased sediment removal from hillslope locations and higher episodic and chronic delivery of sediment to stream channels. Depending on the timing and magnitude of sediment delivery, some life-history stages of anadromous fish can be greatly affected. Large debris flows can be especially damaging to aquatic habitat.

Developing wildfire-use plans that specifically address postfire effects on streams and aquatic habitat can help reduce disturbance-related sediment input from roads and timber harvest (table 5.7b). Identifying hillslope landslide hazard areas and susceptible roads prior to the occurrence of wildfire, and as part of fire planning, will be critical to mitigating the effects of erosion.

Restoring and revegetating burned areas, often a component of Burned Area Emergency Rehabilitation programs, can help to store sediment and maintain channel geomorphology following large wildfires. Effective implementation will require thorough prefire assessment of geomorphic hazards, especially areas prone to debris flows. Fortunately, analytical and decision support tools are readily available to calculate debris-flow-runout distance and other parameters, and to map the location of hazards. Coordination with resource specialists and programs in vegetation, fire, hydrology, geology, and soils will ensure accuracy and efficiency in protecting multiple resources. Prioritizing the tactics needed to protect multiple fish species and populations in the face of increasing disturbance will be challenging but necessary for guiding implementation of management actions.

Responding to Increased Stream Temperatures

Increasing stream temperatures, combined with decreasing summer flows, will be one of the most obvious effects of climate change for several fish species in the Blue Mountains region, as detailed earlier in this chapter. Increased temperatures are expected to be widespread, especially at lower elevations where some species may already be at the limit of their thermal tolerance during the summer. Considerable variation exists in thermal regimes as a function of water sources (Ebersole et al. 2003, 2015; Fullerton et al. 2015), topography, aspect, and other factors, influencing where and how management actions might be implemented to reduce deleterious effects.

Maintaining and restoring natural thermal conditions will be the most effective strategy for buffering future increases in stream temperatures (table 5.7c). It will be especially important to increase connectivity within stream networks, so aquatic organisms can have year-round access to cold water, especially during stressful summer periods. An effective, climate-smart approach to managing for cold-water refugia will be possible only if stream temperature regimes are well understood. Fortunately, the expanding NorWeST stream temperature network, including in the Blue Mountains, is helping to provide a scientific foundation for site-specific adaptation tactics.

Increasing resilience of fish populations to higher stream temperature focuses primarily on maintaining existing cold-water refugia and improving the condition of streams that are vulnerable to increasing air temperature. Riparian function and hydrologic processes can be maintained by restoring riparian vegetation to ensure that exposure of stream channels to solar radiation is minimized. Increasing floodplain connectivity, diversity, and water storage will improve hyporheic and baseflow conditions. Reducing damage by livestock grazing on riparian vegetation and streambanks can result in rapid improvements but may also face opposition from those who access national forests for grazing. All of these adaptation tactics will be more effective if informed by stream temperature data collection and long-term monitoring.

Responding to Changes in Headwater and Intermittent Streams

Headwater and other intermittent streams and water bodies (e.g., springs, ponds) are vital for local and seasonal aquatic habitat. Although they may be transient, these water sources influence stream temperature and downstream water quantity and quality (Ebersole et al. 2015). Intermittent streams will be especially vulnerable to the effects of increasing wildfire on sediment pulses and altered flood patterns and magnitudes.

As noted above, wildfire-use plans will be needed to proactively reduce the effects of increasing fire disturbance and to identify hillslope landslide hazard areas and susceptible roads (table 5.7d). Restoring and revegetating burned areas can help to store sediment and maintain channel geomorphology following large wildfires, and should be informed by prefire assessment of geomorphic hazards, especially areas prone to debris flows. Coordination with resource specialists and programs in vegetation, fire, hydrology, geology, and soils will help ensure that multiple resources will be protected.

Conclusions

Adapting fisheries to the environmental trends associated with climate change will require a diverse portfolio composed of many strategies and tactics as described above (table 5.7). Equally important is understanding a new concept of dynamic disequilibrium in which stream habitats will become more variable, undergo gradual shifts through time, and sometimes decline in quality. Some fish species and populations will retain enough flexibility to adapt and track their habitats (Eliason et al. 2011), but others may be overwhelmed by future changes. It may not be possible to preserve all populations of all fish species across the Blue Mountains. However, as better information continues to be developed, resource managers will be able to identify where resource commitments are best made to enhance the resilience of fish and fish habitat. As many species and populations adjust their phenologies and distributions to track climate change, Forest Service lands will play an increasingly important role in providing aquatic habitats.

Three factors will be especially important for improving and maintaining resilience of fish species and aquatic systems to climate change. First, it will be critical to restore and maintain natural thermal regimes to minimize increases in summer stream temperatures and effects on cold-water species. As noted above, many techniques can be used to promote stream shading and narrow unnaturally widened channels. Second, a strategic approach is critical for climate-smart fisheries management and restoration during the current period of declining budgets and increasing stresses. For example, it is important to identify high-priority culvert barriers to fish movements, especially in areas with the potential to provide high-quality refugia for cold-water species in the future. These types of tactics need to be considered at both the reach and watershed scales. Finally, long-term monitoring is the only means by which the effectiveness of climate-smart resource management can be determined, thus reducing uncertainties and informing the broader mission of sustainable fisheries management. More and higher quality data are needed for streamflow (more sites), stream temperature (annual data from sensors maintained over many years), and fish distributions. These data will improve status and trend descriptions, while also contributing to models that more accurately predict responses to climate change and land management.

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