Chapter 5: Climate Vulnerability of Native Cold-Water Salmonids in the Northern Rockies Region

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Introduction

During the 21st century, climate change is expected to alter aquatic habitats throughout the Northern Rocky Mountains, intermountain basins, and western Great Plains. Particularly in montane watersheds, direct changes are likely to include warmer water temperatures, earlier snowmelt-driven runoff, earlier declines to summer baseflow, downhill movement of perennial channel initiation, and more-intermittent flows (see Chapter 4), as well as indirect changes attributable to altered and perhaps novel disturbance regimes. For animals restricted to freshwater aquatic environments for most or all of their lives—fishes, amphibians, crayfish, mussels, and aquatic macroinvertebrates—changes in habitat and in hydrologic regimes are likely to lead to marked shifts in their abundance and distribution. This is primarily because many of these species are ectothermic (cold blooded); thus, environmental conditions dictate their metabolic rates and nearly every aspect of their life stages, including growth rate, migration patterns, reproduction, and mortality (Magnuson et al. 1979).

A vast and growing literature describes the myriad interactions among climate change, aquatic environments, and biotic communities. Rather than revisit this topic, we refer the reader to syntheses of the nexus between climate change and aquatic species in the northwestern United States (especially Rieman and Isaak 2010, but also Independent Science Advisory Board 2007; Isaak et al. 2012a,b; Mantua and Raymond 2014; Mantua et al. 2010; Mote et al. 2003) and beyond (Ficke et al. 2007; Furniss et al. 2010, 2013; Luce et al. 2012; Poff et al. 2002; Schindler et al. 2008). However, assessments rarely provide empirically based, spatially explicit, and precise climate change projections for species across broad geographic regions.

To address this gap, we developed high-resolution stream temperature and flow scenarios that translate outputs from global climate models (GCMs) into reach-scale habitat factors relevant to aquatic biota (Isaak et al. 2015). Those scenarios were coupled with species distribution datasets crowdsourced from the peer-reviewed literature and State and Federal agency reports to develop accurate species distribution models for contemporary relationships between climate and biology. These models were used to project the probability of species habitat occupancy in streams throughout the inland northwestern United States, facilitating the identification of streams that are most likely to be occupied in the future and serve as invasion-resistant climate refugia.

We focused on climate vulnerabilities and current and projected distribution of two native salmonid fishes—bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarkii*)—because of their importance to society, the large amount of data on their distribution and abundance, and their sensitivity to warm stream temperature (Eby et al. 2014; USDA FS 2013). We confined our inferences to suitable habitat for juveniles of each native species because they are more thermally constrained than adults. We directly addressed how the presence of nonnative species, such as brook trout (*S. fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*O. mykiss*) (the latter native to a portion of the analysis area) further restricts climate-suitable habitats for native species now and in the future. A full explanation of our rationale, approach, and results are in Isaak et al. (2015). The associated Climate Shield website (USDA FS n.d.a) provides access to a comprehensive archive of user-friendly digital maps and ArcGIS (ESRI, Redlands, CA) databases showing stream-specific model projections for multiple climate and brook trout invasion scenarios across most of the northwestern and interior western United States.

In this assessment, we summarize information for stream populations of bull trout and cutthroat trout in the Northern Rockies and discuss adaptation measures and future research directions (see Rieman and Isaak 2010 for a more comprehensive discussion). We regard our inferences as robust, but foresee the arrival of improved models fostered by ongoing improvements in measuring and modeling the attributes of populations and streams. Databases describing the distributions of many aquatic species via rapid, cost-effective environmental DNA surveys (McKelvey et al. 2016a; Wilcox et al. 2016) are rapidly proliferating and can be used with new geostatistical stream models (Isaak et al. 2014; Ver Hoef et al. 2006) to develop more precise information for many aquatic taxa. This combination of advanced survey methods and sophisticated stream network models has already been adopted for assessing the validity and refining the predictions of the Climate Shield model for bull trout (M. Young, K. McKelvey, and D. Isaak, unpublished data).

Analysis Area and Methodology

This assessment encompasses all streams in national forests and national parks encompassed by the Northern Region of the Forest Service, U.S. Department of Agriculture (USFS) (fig. 5.1). To delineate a stream network for this area, geospatial data for the 1:100,000-scale National Hydrography Dataset (NHD)-Plus were downloaded from the Horizons Systems website (Cooter et al. 2010; Horizon Systems Corp. n.d.) and filtered by minimum flow and maximum stream slope criteria. Summer flow values predicted by the Variable Infiltration Capacity (VIC) hydrologic model (USDA FS n.d.; Wenger et al. 2010) were obtained from the Western United States Flow Metrics website (USDA FS n.d.c) and were linked to individual stream reaches.

Stream reaches with summer flows less than 0.2 cubic feet per second, approximating a wetted width of 3.3 feet (based on an empirical relationship developed in Peterson et al. [2013b]), or with slopes greater than 15 percent were trimmed from the network because they tend to be unoccupied or support very low numbers of fish (Isaak et al. 2015). In the case of the stream slope criterion, reaches steeper than 15 percent occur at the top of drainage networks where slopes become progressively steeper, and populations are more vulnerable to disturbances (e.g., post-wildfire debris torrents) that result in periodic extirpations (Bozek and Young 1994; Miller et al. 2003). The slope and flow criteria were set liberally to minimize the exclusion of fish-bearing reaches from the analysis, but doing so results in the inclusion of many reaches with intermittent flows or migration barriers that prevent fish access. Thus, the network extent of 113,733 miles used as baseline habitat in this assessment probably overestimates potential habitat, but the current resolution of the NHD-Plus hydrology layer and VIC flow model prevents further refinement.

Climate Scenarios

Average summer flow values for three 30-year climate periods were available from the flow metrics website: a baseline period (1970–1999, hereafter 1980s) and two future periods (2030–2059, hereafter 2040s; 2070–2099, hereafter 2080s) associated with the A1B (moderate) emissions scenario. An ensemble of 10 GCMs that best represented historical trends in air temperatures and precipitation for the northwestern United States during the 20th century was used for future projections (table 5.1). Due to the significant uncertainties about the timing of change in the future, we deemphasize the dates associated with scenarios and refer to them instead as baseline (1980s), moderate change (2040s), and extreme change scenarios (2080s). With respect to scenarios used in other chapters of this publication, the A1B scenario is similar to the RCP 6.0 scenario associated with Coupled Model Intercomparison Project 5 (CMIP5) simulations (see chapter 3).

To complement the streamflow information, geospatial data for August mean stream temperatures were downloaded for the same A1B trajectory and climate periods from the NorWeST website and linked to the stream hydrology layer (USDA FS n.d.b). Within the study area, the NorWeST scenarios were developed using spatial statistical network models (Isaak et al. 2010; Ver Hoef et al. 2006) applied to

Figure 5.1—Northern Rockies Adaptation Partnership analysis area for cutthroat trout and bull trout, including the U.S. Forest Service Northern Region (white border). Bull trout range encompasses basins west of the Continental Divide and the St. Mary River basin (yellow dashed line), whereas historical cutthroat trout range includes most of the analysis area.

Table 5.1—Projected changes in mean August air temperature, stream temperature, and streamflow for major river basins in the Northern Rockies.

	2040s (2030–2059)			2080s (2070–2099)		
NorWeST unit[a]	Air temperature[b] change	Streamflow[b,c] change	Stream temperature[d] change	Air temperature change	Streamflow change	Stream temperature change
	°F	*Percent*	°F	°F	*Percent*	°F
Yellowstone	5.06	- 4.1	1.82	9.14	- 5.4	3.26
Clearwater	5.71	-23.9	2.92	9.81	-34.2	5.00
Spokane-Kootenai	5.49	-20.1	2.29	9.59	-31.5	3.94
Upper Missouri	5.85	-14.9	2.11	9.85	-21.3	3.49
Marias-Missouri	5.24	-10.0	1.35	9.54	-18.7	2.47

[a] For boundaries of NorWeST production units, see the NorWeST Web site (USDA FS n,d,b).

[b] Changes in air temperature and streamflow are expressed relative to the 1980s (1970–1999) baseline climate period. Projections are based on the A1B emissions scenario represented by an ensemble of 10 global climate models that best projected historical climate conditions during the 20th century in the northwestern United States (Hamlet et al. 2013; Mote and Salathé 2010). Additional details about the scenarios are provided elsewhere (Hamlet et al. 2013; Wenger et al. 2010).

[c] For more information on streamflow, see the western United States flow metrics website (USDA FS n,d,c) and the Pacific Northwest Hydroclimate Scenarios Project website (University of Washington, Climate Impacts Group 2010).

[d] Changes in stream temperatures account for differential sensitivity to climate forcing within and among river basins as described in Luce et al. (2014) and at the NorWeST website (USDA FS n,d,b). For more information on stream temperatures, see Isaak et al. (2010), Luce et al. (2014), and the NorWeST website (USDA FS n,d,b).

data at 5,461 unique stream sites monitored with digital sensors during the summer from 1993 through 2011. The density and spatial extent of the temperature dataset, combined with the predictive accuracy (r^2 = 0.91; RMSE = 1.8 °F) and resolution (~0.62 mile) of the NorWeST model across those sites, were deemed sufficient for this assessment. Details about the rationales associated with climate scenarios and the stream temperature model are discussed in Isaak et al. (2015).

Focal Species

Bull trout in the Northern Rockies are largely from an inland lineage (Ardren et al. 2011) primarily west of the Continental Divide (U.S. Fish and Wildlife Service [USFWS] 2014). Bull trout may exhibit migratory or resident life histories. Migratory fish travel long distances as subadults to more-productive habitats and achieve larger sizes and greater fecundity as adults before returning to natal habitats to spawn. Resident fish remain in natal habitats and mature at smaller sizes, although often at the same age as migratory adults. Adults spawn and juveniles rear almost exclusively in streams with average summer water temperatures less than 54 °F and flows greater than 1.2 cubic feet per second (Isaak et al. 2010; Rieman et al. 2007). Relative to its historical distribution, this species has undergone substantial declines because of water development and habitat degradation (particularly activities leading to water temperature increases, but also cumulative losses of in-channel habitat complexity), elimination of migratory life histories by human-created barriers, harvest by anglers, and interactions with introduced nonnative fishes (Rieman et al. 1997). Nonnative species such as brook trout, brown trout, and lake trout (*Salvelinus namaycush*) may compete with or prey on bull trout (Al-Chokhachy et al. 2016; Martinez et al. 2009), or lead to wasted reproductive opportunities (Kanda et al. 2002). As a consequence, bull trout was listed as threatened under the U.S. Endangered Species Act (ESA) by the USFWS in 1998 (USFWS 2015).

Cutthroat trout are represented by two subspecies. Westslope cutthroat trout (*O. clarki lewisi*) has a complicated lineage structure that can be roughly broken into a single lineage in the north and east that occupied and colonized river basins directly influenced by glaciation or glacial dams, and a southern and western group of several presumably older lineages in basins never directly influenced by glaciation (M. Young, unpublished data). These fish also exhibit resident and migratory life history strategies. Spawning and juvenile rearing can occur in streams smaller (<2 feet wide) and warmer (up to 57 °F) than those used by bull trout (Isaak et al. 2015; Peterson et al. 2013a,b; M. Young, unpublished data). Yellowstone cutthroat trout (*O. c. bouvieri*) has an unresolved distribution because certain lineages are found in portions of the Bonneville basin (Campbell et al. 2011; Loxterman and Keeley 2012), probably because of periodic hydrologic connectivity between the Bonneville and Upper Snake River basins associated with passage of the North American plate across the Yellowstone mantle plume, Basin and Range faulting, and stream drainage reversals (Smith et al. 2002). Undisputed members of this taxon are represented by a single mtDNA clade found throughout the analysis area in the Yellowstone River basin (Campbell et al. 2011). For this analysis, we assume that life histories and presumably spawning and juvenile habitats are the same as for westslope cutthroat trout.

The distributions of both subspecies have declined substantially (>50 percent) in response to the same stressors affecting bull trout (Gresswell 2011; Shepard et al. 2005), although each subspecies appears to occupy a larger proportion of its historical habitat and is often found in larger populations at higher densities than are bull trout. Both subspecies of cutthroat trout have been petitioned under the ESA, but found not warranted for listing. Brook trout have replaced cutthroat trout in many waters in the region, disproportionately so in the Upper Missouri River basin (Shepard et al. 1997). These invasions in part seem influenced by the distribution of low-gradient alluvial valleys that may serve as nurseries for brook trout (Benjamin et al. 2007; Wenger et al. 2011a). Where rainbow trout have been introduced outside their native range, introgressive hybridization occurs with both taxa of cutthroat trout at lower elevations and in warmer waters (Rasmussen et al. 2012), similar to patterns where westslope cutthroat trout occurred historically with native rainbow trout (the Clearwater River basin in Idaho and the Kootenai River basin in Idaho-Montana) (McKelvey et al. 2016b). Yellowstone cutthroat trout have also been widely stocked throughout the historical range of westslope cutthroat trout (Gresswell and Varley 1988) and these two taxa readily hybridize to form hybrid swarms (Forbes and Allendorf 1991; McKelvey et al. 2016b). Lake trout predation decimated adfluvial populations of Yellowstone cutthroat trout in Yellowstone Lake at the beginning of the 21st century, but predator control efforts are enabling cutthroat trout populations to rebound (Syslo et al. 2011).

Trout Distribution Models

Species distribution models were developed that predicted the occurrence probabilities of juvenile bull trout and cutthroat trout. We focused on juveniles as indicators of important natal habitats and the presence of locally reproducing populations (Dunham et al. 2002; Rieman and McIntyre 1995). This approach provides more precision than also considering distributions of subadults and adults, which migrate widely, occupy an array of habitats, and occur with many other fish species (Behnke 2010). Juvenile distributions, by contrast, are restricted in ecological scope and geographic extent, especially with respect to temperature (Elliott 1994). For example, juvenile bull trout are rarely found where mean summer temperatures exceed 54 °F (Dunham et al. 2003; Isaak et al. 2010), whereas adult bull trout sometimes occupy habitats as much as 9 to 18 °F warmer (Howell et al. 2010). Similar patterns are evident with cutthroat trout (Peterson et al. 2013a; Schrank et al. 2003). Therefore, we used a thermal criterion to delimit potentially suitable habitats for juvenile native trout.

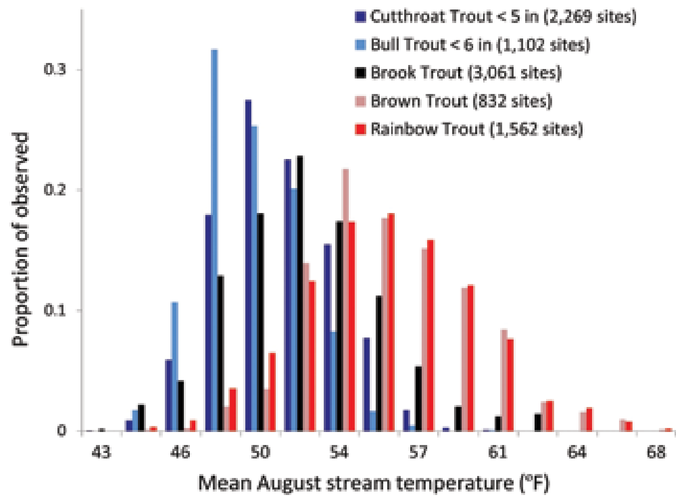

Figure 5.2—Presence of juvenile bull trout and cutthroat trout and all age classes of other trout species at sampling sites relative to temperature projections from the NorWeST baseline scenario of mean August temperature (figure reproduced from Isaak et al. (2015).

Temperature Criterion for Juvenile Trout Habitat

A mean August stream temperature of 52 °F was selected as the temperature criterion from a set of standardized thermal niches that were developed by cross-referencing thousands of species occurrence locations in Montana, Idaho, and Wyoming with the NorWeST baseline scenario (fig. 5.2). Fish data were contributed by national forest monitoring programs; Idaho Department of Fish and Game; Montana Fish, Wildlife and Parks; and Wyoming Game and Fish Department (Isaak et al. 2015). These niches revealed that most juvenile native trout (90 percent of bull trout observations and 75 percent of cutthroat trout observations) occurred at sites with temperatures less than 52 °F, whereas nonnative species such as brown trout and rainbow trout were rare at those sites. The thermal niche of brook trout overlapped that of the native species, but its occurrence peaked at a slightly warmer temperature and declined thereafter. Just as especially cold temperatures limit rainbow trout incursions, colder temperatures also restrict introgression with rainbow trout, such that stream reaches with temperatures less than 48 °F usually support only genetically pure cutthroat trout (McKelvey et al. 2016b; Rasmussen et al. 2012; Yau and Taylor 2013; M. Young, unpublished data).

Habitat Attributes and Logistic Regression Models

Spatially contiguous 0.6-mile reaches of stream with temperatures less than 52 °F were aggregated into discrete cold-water habitats (CWHs), and occupancy status (present or absent) of native trout juveniles and brook trout within a subset of those CWHs (bull trout, n = 512; cutthroat trout, n = 566) was determined using the fish survey database described earlier. Logistic regressions were used to model the probability of native trout occupancy as a function of CWH size, stream slope, brook trout prevalence, and stream temperature. Habitat size was represented as the channel length of each CWH, stream slope as the average value across all the reaches within a CWH, and brook trout prevalence as the percentage of sample sites within a CWH where they occurred. Temperature was represented as mean August temperature averaged across all 0.6-mile sections constituting a CWH or the lowest mean temperature of any 0.6-mile section within a CWH.

The four variables were good predictors of juvenile trout occurrence within the training dataset; classification accuracy of the models at a 50 percent occupancy threshold was 78.1 percent for bull trout and 84.6 percent for cutthroat trout. The final logistic regression models included the four main predictor variables and some interactions among those variables. Plots of species response curves from the final models matched expectations based on the ecology of bull trout and cutthroat trout, but also revealed important differences between the species (fig. 5.3). Habitat occupancy for both native trout was positively related to CWH size, but bull trout required habitats five times larger than cutthroat trout to achieve comparable probabilities of occupancy. Bull trout occupancy declined as minimum temperature warmed, whereas cutthroat trout occupancy was positively related to mean temperature. Stream slope negatively affected both species, as did their co-occurrence with brook trout, especially in small streams. The presence of brook trout masked

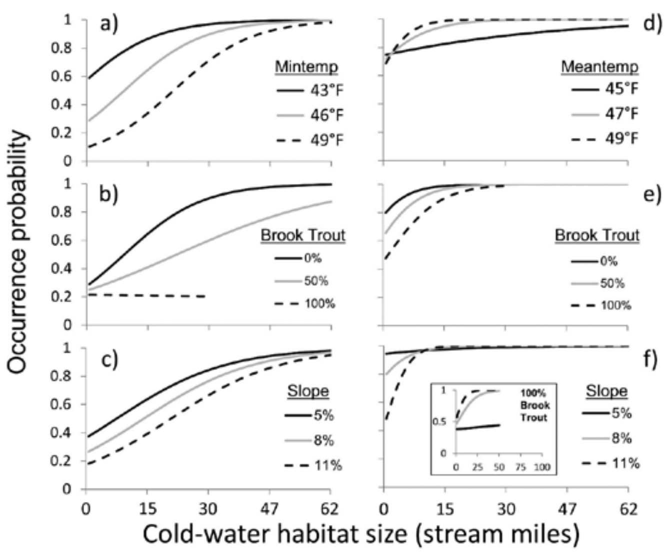

Figure 5.3—Relations between environmental covariates and probability of occupancy of juvenile native trout developed from 512 bull trout (a, b, c) and 566 cutthroat trout (d, e, f) cold-water habitats. Relations are conditioned on mean values of two independent variables not shown in a panel. An exception occurs for cutthroat trout with regard to stream slope (f) where brook trout values of 0% and 100% were used to highlight the interaction between these covariates (figure reproduced from Isaak et al. (2015).

the apparent preference of cutthroat trout for habitats with low slopes. Additional details on modeling procedures and variable selection are summarized in Isaak et al. (2015).

Application of Models for Status and Vulnerability Assessment

The logistic regression models were applied to the full set of CWHs within the historical range of each native species across the Northern Rockies to project probabilities of native trout occupancy. Projections were made for the baseline and future climate periods. To account for uncertainties in brook trout distributions, occupancy probabilities were calculated and mapped for a pristine scenario (no brook trout) and a broad invasion scenario that assumed brook trout would be present at half the sites within each CWH (50 percent brook trout). For this exercise, we did not map a scenario in which brook trout were present at all sites for two reasons. First, their prevalence rarely exceeded 50 percent in the large CWHs (i.e., >25 miles) that were most likely to serve as strongholds for native trout (Isaak et al. 2015) show brook trout prevalence in more than 500 streams; further, not all locations appear suitable for brook trout (Wenger et al. 2011a). In some small streams with native trout, brook trout prevalence occasionally reaches 100 percent, so probabilities for a full range of invasion scenarios were integrated into the ArcGIS databases at the Climate Shield website (USDA FS n.d.a) and can be used for stream-specific assessments of brook trout invasions.

After species probability maps were developed for all streams, the information was cross-referenced with land administrative status using geospatial data from the U.S. Geological Survey Gap Analysis Program (Gergely and McKerrow 2013). The total length and percentage of CWHs and stream temperatures were summarized by jurisdiction for different climate periods. Also noted were the proportions of CWHs that were administratively protected within national parks and wilderness areas. Finally, we denoted those CWHs with probabilities of occupancy exceeding 90 percent as climate refugia.

Native Trout Vulnerability to Climate Change

Stream Temperature Status and Projected Trends

Considerable thermal heterogeneity exists across Northern Rockies streams because of the complex topography and range of elevations in this region (fig. 5.4). Of the 114,000 miles of stream habitat within the analysis area, 43,000 miles (38 percent) had mean temperatures less than 52 °F (table 5.2). Most of those CWHs (86 percent) were in publicly administered lands, primarily (69 percent) in national forests. Areas with concentrations of cold streams were generally associated with high-elevation, high-relief

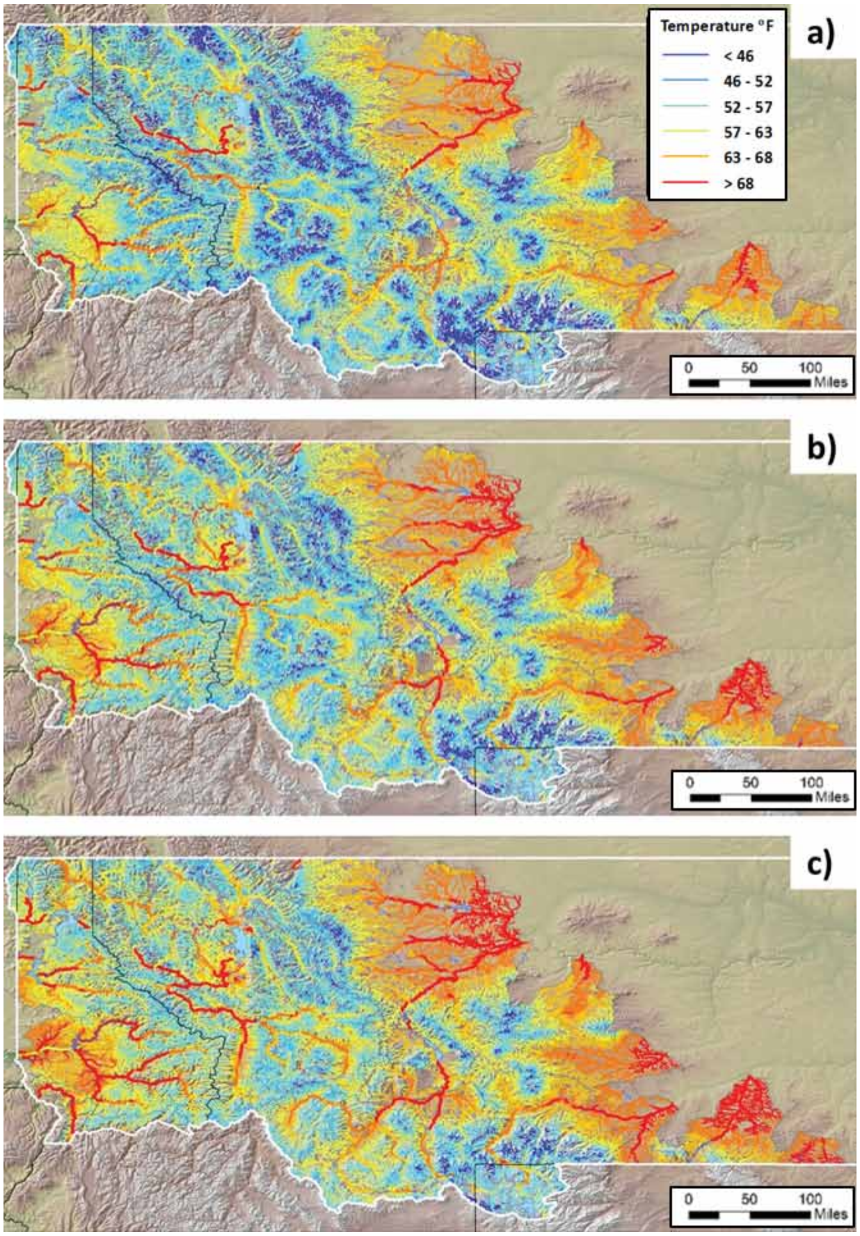

Figure 5.4—NorWeST August mean stream temperature maps interpolated from 11,703 summers of monitoring data at 5,461 unique stream sites across the 114,000 mi of streams in the analysis area. Map panels show conditions during baseline (a, 1980s), moderate (b, 2040s), and extreme change scenarios (c, 2080s). Networks were trimmed to represent potential fish-bearing streams by excluding reaches with slopes greater than 15 percent and Variable Infiltration Capacity model summer flows less than 0.20 $ft^3 s^{-1}$. High-resolution digital images of these maps and ArcGIS databases with reach-scale predictions are available at the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html).

mountain ranges in Montana (e.g., Whitefish Range, Mission Mountains, Swan Range, Flathead Range, Lewis and Clark Range, Sawtooth Range, Anaconda Range, Flint Creek Range, Big and Little Belt Mountains, Crazy Mountains, and ranges associated with the topographic rise produced by the Yellowstone mantle plume). In contrast, comparable mountain ranges and clusters of CWHs are absent in most of northern Idaho.

Mean August stream temperatures were projected to increase across the Northern Rockies by an average of 2.2 °F in the 2040s and 3.6 °F in the 2080s (table 5.1, fig. 5.4). Larger than average increases are expected in the warmest streams at low elevations, and smaller than average increases are expected for the coldest streams. Differential warming occurs because cold streams tend to be buffered by local influxes of groundwater (Luce et al. 2014), a trend represented in the NorWeST scenarios we used. Averaged across all streams, future projections imply faster rates of warming (0.4–0.5 °F per decade) than were observed in recent decades (0.2–0.3 °F per decade) (Isaak et al. 2012a). If future projections are accurate, the length of streams with temperature less than 52 °F will decrease to 27,000 miles in the 2040s and 17,000 miles in the 2080s (table 5.3). In both scenarios, more than 75 percent of these cold streams are in national forests. Groups of exceptionally cold streams still likely to support bull trout or cutthroat trout would originate from the Sawtooth and Lewis and Clark Ranges along the Continental Divide in northern Montana, several smaller mountain ranges scattered throughout central Montana, and along the northern flank of the Yellowstone topographic high (fig. 5.4). Persistent CWHs are more isolated elsewhere.

Table 5.2—Length of streams in the Northern Rockies, categorized by mean August stream temperature during the baseline climate period and by land administrative status. Values in parentheses are percentages of the total in the last row.

Land status [a, b]	<46 °F	46–52 °F	52–57 °F	57–63 °F	63–68 °F	>68 °F	Total
				Miles (percent of total)			
Private	274 (3.2)	5,494 (15.8)	16,524 (47.2)	14,465 (64.4)	8,178 (73)	1,067 (66.1)	46,002 (40.4)
The Nature Conservancy	1 (0)	191 (0.5)	99 (0.3)	9 (0)	1 (0)	0 (0)	301 (0.3)
Tribal	170 (2.0)	769 (2.2)	3,371 (9.6)	4,181 (18.6)	1,593 (14.2)	380 (23.5)	10,464 (9.2)
State/City	137 (1.6)	1,578 (4.5)	2,529 (7.2)	1,156 (5.1)	723 (6.5)	62 (3.8)	6,185 (5.4)
Bureau of Land Management	49 (0.6)	826 (2.4)	838 (2.5)	268 (1.2)	207 (1.8)	55 (3.4)	2,243 (2.0)
National Park Service	537 (6.2)	1,689 (4.9)	654 (1.9)	296 (1.3)	70 (0.6)	1 (0.1)	3,247 (2.9)
Forest Service Wilderness	2,269 (26.2)	3,516 (10.1)	1,174 (3.4)	175 (0.8)	39 (0.3)	1 (0)	7,174 (6.3)
Forest Service Non-Wilderness	4,825 (55.8)	19,299 (55.5)	8,168 (23.3)	1,041 (4.6)	206 (1.8)	16 (1)	33,555 (29.5)
Other	386 (4.5)	1,438 (4.1)	1,596 (4.6)	876 (3.9)	193 (1.7)	33 (2.1)	4,522 (4.0)
Total	8,648	34,800	34,953	22,467	11,210	1,615	113,693

[a] Stream reaches with slope less than 15 percent and summer flows greater than 0.20 $ft^3 s^{-1}$, based on the Variable Infiltration Capacity model (see text).
[b] Other category includes U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and lands with undesignated status.

Table 5.3—Length of streams in the Northern Rockies, categorized by mean August stream temperature during the baseline and two future climate periods and by land administrative status (Forest Service [FS] and non-Forest Service [Non-FS]). Values in parentheses are percentages of the total in the last column.

Land status [a]	<46 °F	46–52 °F	52–57 °F	57–63 °F	63–68 °F	>68 °F	Total
				Miles (percent of total) [b]			
FS lands							
1980s	7,094 (17.4)	22,815 (56.0)	9,342 (22.9)	1,216 (3.0)	244 (0.6)	17 (0)	40,728
2040s	2,504 (6.3)	17,858 (44.7)	15,911 (39.8)	3,092 (7.7)	445 (1.1)	121 (0.3)	39,931
2080s	961 (2.4)	12,701 (32.3)	19,051 (48.5)	5,525 (14.1)	836 (2.1)	237 (0.6)	39,311
Non-FS lands							
1980s	1,554 (2.1)	11,986 (16.4)	25,645 (35.1)	21,260 (29.1)	10,963 (15.0)	1,597 (2.2)	73,005
2040s	569 (0.8)	5,960 (8.4)	20,980 (29.5)	24,422 (34.3)	15,434 (21.7)	3,820 (5.4)	71,185
2080s	253 (0.4)	3,448 (4.9)	16,401 (23.3)	25,128 (35.7)	18,410 (26.1)	6,798 (9.7)	70,438

[a] Stream reaches with slope less than 15 percent and summer flows greater than 0.20 $ft^3 s^{-1}$, based on the Variable Infiltration Capacity model (see text).
[b] Reductions in network extent result from projected decreases in summer flows as described in table 5.1.

Table 5.4—Number and length of cold-water habitats for juvenile cutthroat trout by probability of occurrence for three climate periods and two brook trout invasion scenarios across the Northern Rockies.

		Probability of occurrence (percent)					
		<25	**25–50**	**50–75**	**75–90**	**>90**	**Total**
Cold-water habitat number							
0% brook trout prevalence	1980s	71	392	1,140	1,817	1,739	5,159
	2040s	41	328	1,405	1,505	1,148	4,427
	2080s	86	659	949	977	770	3,441
50% brook trout prevalence	1980s	73	501	2,790	1,384	581	5,329
	2040s	41	382	2,571	1,065	367	4,426
	2080s	86	684	1,837	673	161	3,441
Cold-water habitat length				*Miles*			
0% brook trout prevalence	1980s	268	794	4,068	7,730	32,646	45,506
	2040s	78	558	3,832	6,034	17,964	28,466
	2080s	142	1,031	2,938	4,151	10,459	18,721
50% brook trout prevalence	1980s	387	1,456	6,413	8,203	12,023	28,482
	2040s	126	855	5,079	5,451	6,404	17,915
	2080s	228	1,238	3,931	3,908	2,857	12,162

Cutthroat Trout Status and Projected Trends

The historical range of cutthroat trout extends through most of the Northern Rockies. The number of discrete CWHs for cutthroat trout during the baseline climate period was estimated to exceed 5,000 and encompass over 28,000 miles of streams (table 5.4, fig. 5.5). More than 90 percent of the CWHs were predicted to have probabilities of occupancy exceeding 50 percent (table 5.4), largely because of the relatively small stream networks that cutthroat trout populations require for persistence (6 miles is associated with a 90-percent probability of occupancy) (Peterson et al. 2013a) (fig. 5.3). Nonetheless, the largest CWHs accounted for a disproportionate amount of the habitat most likely to be occupied; 32.6 percent of CWHs were climate refugia, but these accounted for 70.7 percent of the length of CWHs. As expected, the number and extent of CWHs decreased by 20 to 60 percent in future periods, but nearly 3,500 potential habitats encompassing over 12,000 miles were projected to remain under the extreme scenario.

Some streams are currently too cold for cutthroat trout, so future warming will increase the probability of occupancy in some basins (e.g., the Teton River basin along the Rocky Mountain Front and streams in the northern portion of Yellowstone National Park). Assuming that brook trout were present within half of each CWH did not affect the number or amount of CWHs, because the habitats remained potentially suitable for cutthroat trout, but occupancy probabilities declined (table 5.4). Reductions were particularly severe in categories with the highest probabilities of occupancy (>75 percent). The sensitivity of streams to brook trout invasions varied with local conditions, but reductions were most pronounced in small streams with relatively low slopes.

Bull Trout Status and Projected Trends

The historical range of bull trout covers a smaller portion of the Northern Rockies than cutthroat trout, but the number of discrete CWHs for bull trout during the baseline climate period was still estimated to exceed 1,800 and encompass over 14,000 miles (table 5.5, fig. 5.6). Probabilities of occupancy for most bull trout CWHs were less than 50 percent because of the relatively large stream networks that bull trout require for persistence (30 miles is associated with a 90 percent probability of occupancy; fig 5.3). Although fewer than 6 percent of CWHs constituted climate refugia, they provided 30 percent of the total length of CWHs, emphasizing the contribution of large CWHs to the amount of habitat projected to be occupied. The requirement for larger CWHs caused projected decreases in the number and network extent of bull trout CWHs to be more substantial (38–71 percent) than those for cutthroat trout, particularly

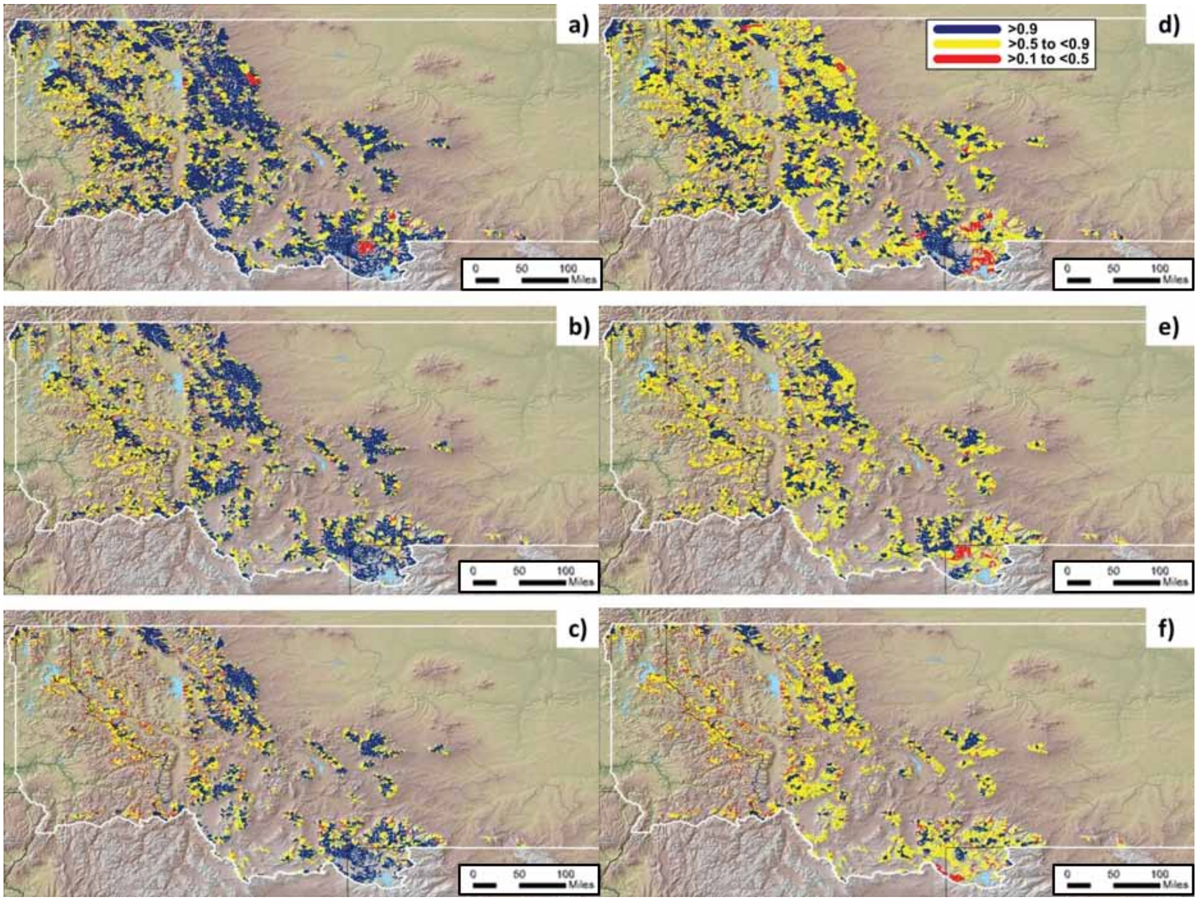

Figure 5.5—Distribution of cold-water habitats with probabilities of occupancy greater than 0.1 for juvenile cutthroat trout during baseline (a and d, 1980s), moderate change (b and e, 2040s), and extreme change scenarios (c and f, 2080s). Panels a–c illustrate occupancy when brook trout are absent. Panels d–f illustrate occupancy when brook trout prevalence is 50 percent. High-resolution digital images and ArcGIS databases of these maps with stream-specific projections are available at the Climate Shield website (http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield/maps.html).

for the CWHs with the highest probabilities of occupancy. More than 800 CWHs representing over 4,200 miles were projected to remain, even in the extreme scenario.

Brook trout invasions reduced bull trout occupancy rates. These declines were more pronounced for bull trout than cutthroat trout, especially in the CWHs most likely to be occupied (those with greater than 50-percent probability of occupancy); fewer than 10 climate refugia for juvenile bull trout are projected to remain under any warming scenario if brook trout occupy half of each CWH. However, many of the large habitats that bull trout require appear less susceptible to broad-scale brook trout invasions (Isaak et al. 2015). As expected, CWHs with the highest bull trout occupancy probabilities during all climate periods and brook trout invasion scenarios coincided with river networks with the largest number of cold streams: headwater portions of the North and Middle Forks of the Flathead River, the Whitefish River, and the North Fork Blackfoot River (figs. 5.4, 5.6). Due to the lower elevations and warmer streams in northern Idaho, few or no climate refugia were projected to remain under either warming scenario.

Additional Fish Species

See boxes 5.1 and 5.2 for narratives on other fish species in the Northern Rockies that are at risk from climate change and are candidates for the habitat occupancy-climate vulnerability approach described here.

Interpreting and Applying the Assessment

The assessment just described provides accurate, spatially explicit projections of habitat occupancy in the Northern Rockies by combining (1) ecological understanding of cutthroat trout and bull trout, (2) distribution data from public data sources, and (3) broad-scale, high-resolution stream temperature and flow projections. Assuming that species responses are related to the effects of climate on stream ecosystems—and the accuracy of the models supports this contention—the models also provide reasonably robust projections of habitat occupancy in light of anticipated climate

Table 5.5—Number and length of cold-water habitats for juvenile bull trout by probability of occurrence during three climate periods and two brook trout invasion scenarios in the Northern Rockies.

		Probability of occurrence (percent)					
		<25	**25–50**	**50–75**	**75–90**	**>90**	**Total**
Cold-water habitat number							
0% brook trout prevalence	1980s	875	534	248	92	106	1,855
	2040s	664	314	98	41	32	1,149
	2080s	474	274	81	24	13	866
50% brook trout prevalence	1980s	995	484	181	65	28	1,753
	2040s	697	270	63	17	5	1,052
	2080s	535	260	49	5	3	852
Cold-water habitat length				*Miles*			
0% brook trout prevalence	1980s	2,906	3,168	2,565	1,616	4,657	14,912
	2040s	2,222	1,934	1,129	769	1,340	7,394
	2080s	1,310	1,324	773	386	579	4,372
50% brook trout prevalence	1980s	3,920	3,762	2,712	1,891	2,351	14,636
	2040s	2,728	2,208	1,191	589	408	7,124
	2080s	1,569	1,645	704	153	266	4,337

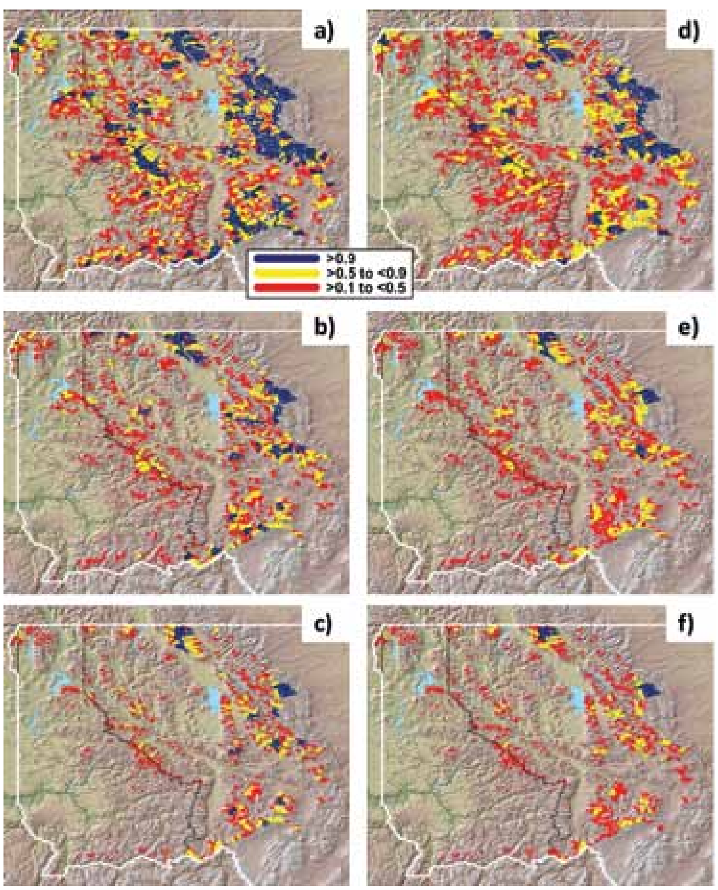

Figure 5.6—Distribution of cold-water habitats with probabilities of occupancy greater than 0.1 for juvenile bull trout during baseline (a and d, 1980s), moderate change (b and e, 2040s), and extreme change scenarios (c and f, 2080s). Panels a–c illustrate occupancy when brook trout are absent. Panels d–f illustrate occupancy when brook trout prevalence is 50 percent. High-resolution digital images and ArcGIS databases of these maps with stream-specific predictions are available at the Climate Shield website (http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield/maps.html).

Box 5.1—Effects of Climate Change on Arctic Grayling

Arctic grayling (*Thymallus arcticus*) is a salmonid species native to Arctic Ocean drainages in North America and northern Eurasia, and Pacific Ocean basins in Alaska and British Columbia, with two disjunct inland groups in Michigan (now extinct) and the Upper Missouri River basin in Montana and Wyoming (Kaya 1992; Scott and Crossman 1998). Within its range in Montana and Wyoming, grayling was represented by four adfluvial (lake-living, stream-spawning) populations in the Red Rock and Big Hole River basins, and by fluvial populations widely but irregularly distributed in the Missouri River basin above the Great Falls (USFWS 2014). Relative to this historical distribution, the current range and abundance of Arctic grayling have decreased greatly. Lacustrine populations are more common recently because of introductions inside and outside its historical range (Kaya 1992). Declines of riverine populations were caused by habitat degradation and fragmentation, inundation by reservoirs, overharvest, and interactions with nonnative fish, particularly rainbow trout, brook trout, and brown trout (Kaya 1992). The distinct population segment in the Upper Missouri River basin was petitioned for listing under the Endangered Species Act, but has not been listed (USFWS 2014). Evidence indicates that recent activities focused on increasing instream flows, improving habitat connectivity, supplementing existing populations, and founding new populations (some in historically fishless lakes) have arrested declines in most grayling populations in this basin (USFWS 2014).

Arctic grayling is regarded as a cold-water species (Elliott and Elliott 2010). Grayling life histories are often characterized by extensive movements to habitats for growth, reproduction, and overwintering, especially in riverine systems (Northcote 1995). Access to thermal refugia may be important to population persistence at the southern extreme of its range; many of the fluvial systems that retain grayling in the Upper Missouri River basin are heavily influenced by groundwater inputs (USFWS 2014). Although the thermal preferences of this species are uncertain, the upper thermal limits of grayling in the Big Hole River basin are comparable to those of cutthroat trout (Johnstone and Rahel 2003; Lohr et al. 1996; Wagner et al. 2001).

The influence of climate change on Arctic grayling is uncertain because of insufficient data, but its reliance on mobility emphasizes the need for connectivity among complementary habitats. Ameliorating the effects of low summer discharge has been a target of management (USFWS 2014), but this problem may become more severe and difficult to overcome if projected climate-related changes in discharge (Chapter 4) are realized. Many of the extant populations are in high-elevation lakes that are presumed to be less vulnerable to the effects of warming or reduced streamflow (USFWS 2014).

Responses to warmer stream temperatures may be complex. With warming summer water temperatures, initiation of the spawning season advanced by more than 3 weeks during four decades in a population of adfluvial European grayling (*T. thymallus*) in Switzerland (Wedekind and Küng 2010). Paradoxically, earlier spawning meant a longer exposure of incubating eggs and fry to colder spring water temperatures, patterns that coincide with substantial declines in the number of female spawners. This pattern may reflect declining survival of juvenile fish (Wedekind and Küng 2010) or sex-specific vulnerability to changes in thermal regimes (Pompini et al. 2013). Whether this is symptomatic of a broader trend or case study is unknown, but warming stream temperatures, population declines, and sex ratio shifts in salmonids have been observed elsewhere in Europe (Hari et al. 2006). Regardless, the few Arctic grayling populations extant in their historical range are likely to remain the focus of management efforts (USFWS 2014), and the continuation of these efforts may play a significant role in the near-term persistence of grayling in the Upper Missouri River basin. At longer time scales, the “climate velocity” associated with warming of low-gradient stream habitats (Isaak and Rieman 2013) may challenge our ability to maintain recent improvements in the conservation status of this species.

change. These projections have several implications for the future viability of native fish populations in the Northern Rockies and for developing management strategies targeted at conservation of these species.

Although both native trout species require cold-water habitat, their response to a changing climate is expected to differ. Bull trout, and most members of the genus *Salvelinus*, are adapted to some of the coldest freshwater environments in the Northern Hemisphere (Klemetsen et al. 2003). These species also tend to inhabit variable environments, often with strong gradients in productivity that appear to favor migration as a life history tactic (Klemetsen 2010). It is unsurprising that a species near the southern end of its distribution that relies on large areas of CWHs and is often found at low density (High et al. 2008) would be susceptible to range contraction as temperatures warm. In the Northern Rockies, we anticipate large declines in their distribution because relatively few areas have the capability to serve as climate refugia. Nevertheless, retention of at least some climate refugia implies that bull trout will not be extirpated from the region. However, the conditions favoring migratory or resident life histories may change, although how to accommodate or exploit this is uncertain. As we learn more about the extent and prevalence of populations occupying CWHs with varying probabilities of occupancy, a better understanding of environmental drivers of bull trout life history may emerge.

Box 5.2—Effects of Climate Change on Fish Species in the Grassland Subregion

Several native fish species are found in the Grassland subregion of the NRAP. Located in the eastern portions of the Custer-Gallatin National Forest and the Dakota Prairies National Grassland, these species have received little scientific study and monitoring compared to cold-water salmonids and warm-water sportfish. Many prairie streams have never been sampled or are sampled sporadically at best. As a result, fish distribution and aquatic habitat are poorly understood at all spatial scales. However, as in most dendritic stream networks, small streams constitute the majority of fish habitat, and species favoring those habitats are likely to be the most common. Small streams may also provide seasonal habitats for spawning and rearing of species favoring larger streams, rivers, and lakes (Thornbrugh and Gido 2009).

Prairie streams are dynamic, tending to vary between periods of floods and flow intermittency, among and sometimes within years (Dodds et al. 2004). Extirpation and recolonization of local habitats by fish species is typical (Falke et al. 2012), and patterns of occupancy by fish species can be considered in the context of metapopulation theory, in which the presence of subpopulations of each species depends on habitat connectivity and duration (Falke and Fausch 2010). Although it is typical for prairie streams to be reduced to sets of disconnected pools in some years, this pattern is more prevalent in agricultural landscapes where surface and groundwater withdrawals are common (Falke et al. 2011; Gido et al. 2010). Climate change is expected to exacerbate these patterns (Jaeger et al. 2014) and lead to greater extremes, including severe droughts and more-intense storms and wet intervals in plains and dryland systems (Michels et al. 2007; Starks et al. 2014).

Projecting the responses of prairie fishes to climate change is complicated by difficulty in identifying habitat preferences, partly because many fish species are habitat generalists (Wuellner et al. 2013) and because the dynamics of prairie streams lead to difficulties in predicting interannual habitat occupancy (Falke et al. 2012). Prairie fish assemblages in the analysis area are represented by four species guilds—northern headwaters, darter, madtom, and turbid river guilds (Clingerman et al. 2013)—that are likely to differ in their vulnerability to climate change. Annual air temperature and various indicators of streamflow are strong predictors of presence for the northern headwaters, madtom, and darter guilds.

Observed and modeled patterns allow some inferences to be made about climate vulnerability and adaptation for prairie fishes. First, the northern headwaters guild may be most vulnerable to increasing temperature, as well as to climate-related decreases in groundwater recharge (Clingerman et al. 2013). This guild includes the northern redbelly dace (*Chrosomus eos*), a sensitive species in the USFS Northern Region, that occupies small, stable, and relatively cool headwater streams (Stasiak 2006). Accurate mapping of habitat types and species assemblages present in them, and monitoring of habitat conditions will help refine possible climate change effects on both habitat and species, as well as define appropriate management responses. Buffering variations in flow extremes (e.g., securing instream flows) and encouraging the presence of riparian vegetation are practical responses to climate change where the northern headwaters guild is present. Although the other prairie fish guilds seem less vulnerable to changes to temperature, all are influenced by amount and timing of flow. Therefore, climate change adaptation strategies for the northern headwater guild should also be appropriate for the other guilds. Finally, all guilds are currently at risk, and may become more so if flow regimes become more variable, especially if migration barriers prevent fish from moving along stream courses. Many of these species may be ill-adapted to surmounting either height or velocity barriers (Perkin and Gido 2012; Rosenthal 2007). Therefore, removing barriers to fish passage between habitats is a prudent adaptation strategy. This strategy carries the risk of allowing nonnative species to invade, so it should be implemented within the larger context of conservation of a site (Fausch et al. 2009).

By contrast, cutthroat trout can accommodate a wider range of thermal environments, commensurate with its broad latitudinal distribution and an evolutionary history (since the late Miocene or early Pliocene) that exposed them to fluctuation in warm/arid and cold/moist periods in western North America (McPhail and Lindsey 1986; Minckley et al. 1986). They are relatively flexible with respect to life history strategies, ranging from highly migratory populations dependent on large rivers or lakes for growth and fecundity, to resident populations that move little and have been isolated for many decades (Northcote 1992; Peterson et al. 2013a). Although we anticipate net losses in their distribution within the Northern Rockies, losses are not expected to be as severe as for bull trout, and some basins that are currently too cold to support cutthroat trout will become high-quality climate refugia (Coleman and Fausch 2007; Cooney et al. 2005). Of greater importance may be how nonnative salmonids, which often displace or replace cutthroat trout, respond to warming conditions (Wenger et al. 2011a).

The presence of brook trout is problematic for both native species. The tolerance of brook trout to cold temperature is nearly equivalent to that of cutthroat trout, and brook trout favor the low-gradient environments preferred by cutthroat trout and bull trout (Wenger et al. 2011a). Nonetheless, larger habitats (e.g., those >40 miles long) appear less susceptible to invasion by this species, which may be attributed to their preference for small streams but also to the likelihood that large systems will contain other salmonid species, such as rainbow trout or brown trout, that constrain brook trout distributions in their native range in eastern North America (Fausch et al. 2009). Rainbow trout and brown trout are expected to shift their distribution upstream as temperature isotherms optimal for these species move in that direction (Isaak and Rieman 2013; Wenger et al. 2011b). Both species appear to have negative effects on cutthroat trout, but cold headwaters that thwart their invasions are expected to remain widespread.

Most CWHs in the Northern Rockies are in national forests (tables 5.2, 5.3). This emphasizes the critical role that the USFS will play in the conservation of populations of native fish. Active management that conserves native fish will be possible, because most of the CWHs are outside designated wilderness areas and national parks that limit many management activities. Conservation options will vary by location. For example, even under extreme warming, some CWHs are expected to persist in some river basins in Montana. Maintaining those conditions may be all that is necessary to ensure the persistence of native fish populations. By contrast, very few habitats regarded as climate refugia are anticipated to remain in the Clearwater, Spokane, and Kootenai River basins in Idaho. Those circumstances favor more active yet strategic management to promote population persistence through manipulation of habitat, fish populations, or both. Many CWHs in Montana and Idaho are situated in landscapes where multiple resource values and ecosystem services are important (see chapter 11), so fish conservation strategies that are compatible with other resource objectives will be an important issue in public land management (Rieman et al. 2010). Retaining native trout populations in some areas may require conservation investments that are unacceptably high or that could prove ineffective as climate warms. In these circumstances, reallocating those investments to areas where native populations are more likely to persist may be preferable.

The model projections described earlier contain uncertainties associated with emissions scenarios and unanticipated characteristics of future climate (Hallegatte et al. 2012). The future scenarios we considered reflect trends qualitatively similar to those that have been occurring in the Northern Rockies during the last 50 years: summer streamflow decreases, air temperature increases, and stream temperature increases (Isaak et al. 2010, 2012a,b; Leppi et al. 2012; Luce and Holden 2009). Consequently, these estimates of occupancy probabilities should be a biologically robust and spatially explicit ranking of habitats critical to the persistence of native trout. The Climate Shield fish distribution maps (fig. 5.7) and databases developed in association with this project were designed for ease of use, allowing users to gauge the amount, distribution, and persistence of native trout habitats. In addition, this information can be summarized for multiple spatial scales and biogeographic entities (e.g., stream, river network, national forest, species or subspecies, State, region).

As with all models, current predictions and future projections of occupancy by juvenile native trout are estimates. These projections could be improved by including more local information on habitat conditions (Peterson et al. 2013a), the presence of barriers that influence habitat size and connectivity among populations (Erős et al. 2012), and the application of spatial statistical network models (Isaak et al. 2014). The potential for improvement notwithstanding, the accuracy of these simple models suggests that environmental gradients are the primary drivers of habitat occupancy by juvenile native trout.

The next step in an ongoing assessment process is to continue to reduce uncertainties associated with the distribution of aquatic species and their responses to a changing climate. Although we used data from thousands of sites to develop occupancy models, data on thousands of other sites would improve existing models and help build new ones for additional species. Compiling a comprehensive aquatic species database from all national forests has the potential to provide information on the recent presence of species in locations from which they may have disappeared, or from which they may have been absent but now exist. These data, and outputs from occupancy models, form the basis for projecting and detecting trends in aquatic species distributions, especially if coupled with new surveys, such as those based on rapid and reliable environmental DNA surveys (McKelvey et al. 2016a). Although DNA surveys are often conducted with one or a few species in mind, the samples constitute a snapshot of the entire aquatic community and can be archived to support future analyses of multiple species. Finally, better distribution data, an understanding of changes in occupancy, and geospatial analysis will improve the accuracy of existing species occupancy models and facilitate the development of new ones, ranging from an individual reach to an entire species range.

Adapting Fisheries to Climatic Variability and Change

Adaptation Strategies and Tactics

Many options are available to facilitate climate change adaptation and improve the resilience of fish populations, perhaps more options than for any other resource assessed in the Northern Rockies Adaptation Partnership (NRAP). Adaptation for fish conservation has been the subject of comprehensive reviews, including for the Northern Rockies (Rieman and Isaak 2010, especially table 2) and other parts of the Northwest (Beechie et al. 2013; Independent Science Advisory Board 2007; Isaak et al. 2012a; Luce et al. 2013; Williams et al. 2015). Having a relatively well-known set of climate sensitivities and adaptation options (Isaak et al. 2015; Mantua and Raymond 2014; Rieman et al. 2007) provides for credibility and consistency in sustainable

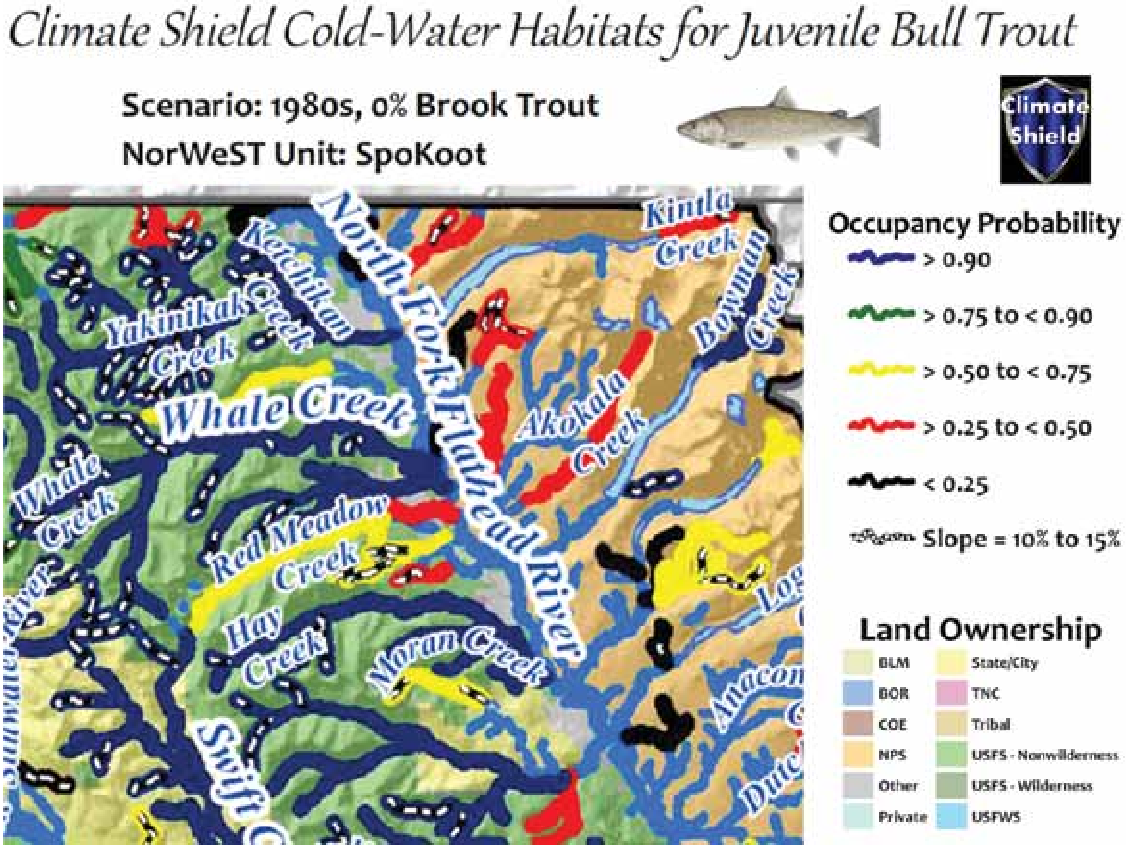

Figure 5.7—Example of a detailed Climate Shield map available at the project website that shows probabilities of juvenile bull trout occupancy in cold-water habitats during the 1980s baseline period in the North Fork Flathead River basin. Maps with identical formats for three climate periods and five brook trout invasion scenarios are available as .pdf and ArcGIS files for all bull trout and cutthroat trout streams across the northwestern United States.

management of fisheries in the Northern Rockies and beyond.

The Western Rockies, Central Rockies, Eastern Rockies, and Greater Yellowstone Area subregions within NRAP all have steep mountain topography, complex stream systems, and cold-water fish populations. Therefore, climate change sensitivities and adaptation options across this broad area tend to be similar (table 5.6), although the effects of livestock grazing as a stressor are more important in the Eastern Rockies subregion. The Grassland subregion has no cold-water fish species and is dominated by warm-water species, many of which are nonnatives. Although some concern exists about aquatic systems in this subregion, no adaptation options were developed for fisheries at the Grassland workshop (but see box 5.2).

Reduced snowpack is one of the best-documented effects of warmer temperatures in mountainous regions (see chapter 4), resulting in lower summer streamflows and warmer stream temperatures. Adaptation strategies can attempt to either maintain higher summer flows or mitigate the effects of lower flows (table 5.6). Specific adaptation tactics include pulsing flows from regulated streams when temperature is high, reducing water withdrawals for various human uses, and securing water rights for instream flows to maintain more control of overall water supply.

Another strategy is to increase CWH resilience by maintaining and restoring the structure and function of streams. Specific tactics include restoring the functionality of channels and floodplains to retain (cool) water and riparian vegetation, and ensuring that passages for aquatic organisms are effective. These tactics could be particularly appropriate in areas where restoration activities are already underway and where habitat is limiting or declining, especially near roads and where high peakflows are frequent. In addition, accelerating riparian restoration may be a particularly effective and long-lasting way to improve hydrologic function and water retention. Maintaining or restoring American beaver (*Castor canadensis*) populations provides a "natural" engineering alternative for retention of cool water. In conjunction with restoration, road removal and relocation from sensitive locations near stream channels and floodplains can significantly improve local hydrologic function.

Interactions with nonnative fish species and other aquatic organisms are a significant stress for native cold-water fish species in the Northern Rockies. One adaptation strategy is to facilitate movement of native fish to locations with

Table 5.6—Adaptation options that address climate change effects on fisheries in the Northern Rockies.

Sensitivity to climatic variability and change: Reduced snowpack will decrease summer streamflows.			
Adaptation Strategy / Approach: Increase streamflows and moderate changes in instream flows.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Pulse flows from regulated streams during critical times (high temperatures)	Reduce water withdrawals and improve efficiency for agriculture (especially irrigation), municipal, and industrial uses	Secure water rights for instream flows
Where can tactics be applied?	All regulated streams	Where water demands overlap with current and future suitable habitat	Where fish and suitable habitat overlap
Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.			
Adaptation Strategy / Approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Restore natural channel and floodplain form and function (e.g., restore areas with human-caused bank and bed instability)	Restore aquatic organism passage structures through design and placement of appropriate structures.	Maintain functional stream channel morphology with adequate width:depth ratios, pool frequency, and healthy riparian vegetation
Where can tactics be applied?	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)	Drainages with frequent high peakflows, areas with sensitive geology, areas with important rearing streams	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)
Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.			
Adaptation Strategy / Approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Restore riparian areas to increase hydrologic function and retain cold water	Reintroduce beaver where beaver and management of westslope cutthroat trout are compatible	Remove or relocate roads adjacent to riparian areas, channels, and floodplains where they inhibit complexity; minimize cumulative effect of road network on surface and subsurface flow
Where can tactics be applied?	Where riparian areas limit the availability of cold-water habitat	Where beaver will not affect barriers; in stream reaches >1 mile; in larger population conservation networks; where brook trout are absent	Where roads currently cause problems or may do so in the future, especially where roads occupy lengthy portions of the riparian zone

Table 5.6 (cont.)—Adaptation options that address climate change effects on fisheries in the Northern Rockies.

Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures, affecting native species and interactions between natives and nonnatives.			
Adaptation Strategy / Approach: Provide opportunities for native fish to move and find suitable stream temperatures.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Increase the patch size of favorable habitat to enhance viable populations and allow migratory life histories	Modify or remove barriers to increase connectivity between areas of cold-water habitat	Identify and map where groundwater inputs provide cold water
Where can tactics be applied?	Where native fish currently exist; where suitable habitat is nearby; where nonnatives are not present or can be effectively managed; where populations are fragmented and need greater connectivity	Where barriers prevent movement to suitable habitat, and where removal will not increase invasion of nonnatives	All locations
Sensitivity to climatic variability and change: Warmer temperatures will increase stream temperature and risk of invasion by nonnative fish species.			
Adaptation Strategy / Approach: Manage nonnative fish populations to eliminate or reduce their impact on native fish.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Encourage increased take/harvest of nonnatives, especially near long-term strongholds for natives	Remove nonnatives with manual or chemical techniques	Exclude nonnatives with physical or electrical barriers
Where can tactics be applied?	Areas with heavy recreation and sport fishing; most effective at the front of invasions	Where long-term suitable habitat for natives is available and nonnatives are present	Where long-term suitable habitat for natives is available and nonnatives are present
Sensitivity to climatic variability and change: Continued livestock grazing will compound stress caused by increased stream temperatures.			
Adaptation Strategy / Approach: Manage livestock grazing to restore ecological function of riparian vegetation and channels.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Comply with all existing standards and guidelines for maintaining water quality in streams and riparian areas; facilitate compliance through monitoring	Use innovative techniques to fund, maintain, and implement improvements (e.g., riparian fencing, rest-rotation systems, off-channel water, exclosures)	Identify and prioritize vacant allotments for retirement
Where can tactics be applied?	All locations, with emphasis on areas that are important in terms of ecological value and large financial investment	All locations, with emphasis on areas that are important in terms of ecological value and prior financial investment; prioritize areas with core conservation fish populations that are under imminent threat	All locations where vacant allotments exist and opportunities allow

Table 5.6 (cont.) —Adaptation options that address climate change effects on fisheries in the Northern Rockies.

Sensitivity to climatic variability and change: Higher temperatures will increase wildfire occurrence that can lead to erosion and mass wasting.			
Adaptation Strategy / Approach: Increase resilience to fire-related disturbance.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Implement fuel treatments (thinning, prescribed burning) to reduce wildfire severity and size	Disconnect roads from stream networks to reduce erosion and sediment delivery to streams	Install erosion control structures following wildfires
Where can tactics be applied?	Areas where canopy and surface fuels are high, adjacent to known native fish populations and habitat	Areas adjacent to known native fish populations and habitat	Where wildfire has occurred and erosion would affect known native fish populations and habitat

suitable stream temperatures. Adaptation tactics include increasing the patch size of suitable habitat, modifying or removing barriers to fish passage, and documenting where groundwater inputs provide cold water. All of these tactics will be more effective if native fish populations are healthy and nonnative species are not already dominant. Another adaptation strategy is to focus management on reduction of nonnative fish species. Adaptation tactics include increased harvest of nonnative fish (e.g., sport fishing), manual or chemical removal of nonnative species, and excluding non-natives with physical or electrical barriers where feasible. These tactics will generally be more effective if nonnative species are not already well established.

In stream systems adjacent to grasslands and shrublands, livestock grazing can damage aquatic habitat, causing stress that may be compounded by warmer stream temperatures. An important adaptation strategy is to manage grazing to restore as much ecological and hydrologic function of riparian systems as possible. Specific adaptation tactics include ensuring that standards and guidelines for water quality are adhered to and monitored, making improvements that benefit water quality (e.g., fencing), and reducing the presence of cattle through the retirement of vacant grazing allotments. It will make sense to prioritize these actions for locations that have high ecological value.

In a warmer climate, it is almost certain that increased wildfire occurrence will contribute to erosion and sediment delivery to streams, thus reducing water quality for fisheries. Increasing resilience of vegetation to wildfire may reduce the frequency and severity of fires when they occur. Hazardous fuels treatments that reduce forest stand densities and surface fuels are an adaptation tactic that is already widely used in dry forest ecosystems. Disconnecting roads from stream networks, another tactic already in practice, is especially important, because most sediment delivery following wildfire is derived from roads. Finally, erosion control structures can reduce postfire sediment delivery and are often a component of Burned Area Emergency Rehabilitation on Federal lands.

More-specific details on adaptation strategies and tactics that address climate change effects on fisheries in NRAP subregions are in Appendix 5A. The process used to elicit adaptation options differed among subregions; some information was general and some was geographically specific.

Toward Climate-Smart Management

The broad range of adaptation options summarized in table 5.6 and Appendix 5A provides a diverse toolkit for fisheries managers. In addition to specific strategies and tactics, several overarching issues help guide applications in Federal lands.

Be Strategic

Prioritizing watershed restoration such that the most important work is done in the most important places is critical because funds, labor, and time for management of native fish populations are limited (Peterson et al. 2013b). For example, climate refugia for native trout in wilderness areas may not require or be amenable to habitat modification to ensure the persistence of those populations. Similar refugia outside wilderness might be targeted to improve habitat conditions or reduce nonnative species, particularly if doing so increases the probability of occupancy of such habitats. Regardless of such efforts, some basins are unlikely to provide suitable habitat for native trout in the future, so directing conservation investments elsewhere, or for other species, may be prudent.

Implement Monitoring Programs

Being strategic means reducing current and future uncertainties for decisionmaking. In the case of fisheries, more data are needed for streamflow (more sites), stream temperature (annual data from sensors maintained over many years), and fish distributions. These data can be used for better status-and-trend descriptions, and to develop robust (more accurate and precise) models for species to understand the interaction of climate change, natural variation, and land management. The feasibility of monitoring at small to broad scales is increasing with the advent of rapid, reliable eDNA inventories of aquatic organisms (Thomsen et al. 2012) and the availability of inexpensive, reliable temperature and flow sensors (U.S. Environmental Protection Agency 2014).

Restore and Maintain Cold Stream Temperatures in Summer

Persistence of native trout species will depend on a variety of management techniques to restore and maintain stream shade and narrow unnaturally widened channels. Actions may include relocating roads away from streams, limiting seasonal grazing in some areas, and managing streamside riparian forest buffer zones to maintain effective shade and cool, moist riparian microclimates. The tactics described in this chapter have implications and consequences far beyond enhancing the persistence of native fish populations, but being open to opportunities to do so is part of strategic thinking.

Manage Connectivity

Beyond climate change concerns, obstacles to fish migration are often removed in hopes of enhancing the success of migratory life history forms, or permitting native species to reoccupy former habitat or supplement existing populations. However, this presents a dilemma: Accessible waters can be invaded by nonnative fish species that can replace native species (Fausch et al. 2009). In some cases, barriers can be installed to prevent these invasions. Native populations above barriers may be secure if they can adopt resident life histories, but could be susceptible to loss from extreme disturbance events in small habitats, requiring human intervention to reestablish or supplement populations. Barriers are usually temporary, and may require reconstruction if nonnative species remain downstream.

Remove Nonnative Species

Removal of nonnative fish species, although challenging in some locations, may be the best option for maintaining or restoring some native fish populations. These efforts typically consist of chemical treatments or electrofishing, and both tend to be feasible only in smaller, simpler habitats. Both are also costly, in part because they need to be conducted on multiple occasions to be effective. Chemical treatment can be controversial because of its perceived effects on water quality. Furthermore, any method of removal is successful only if the source of nonnative species is removed, often by installation of a migration barrier (see "Manage Connectivity"). Public resistance to removal of nonnative fishes may also be an obstacle, particularly if sport fish are involved. Unauthorized introductions are also common, and can undermine conservation efforts. Finally, using control measures to manage the abundance of nonnative species rather than removing all of them has been helpful in some areas (e.g., removal of lake trout to promote bull trout persistence, electrofishing to depress brook trout and favor cutthroat trout). Such activities will be successful only if conducted at regular intervals for the foreseeable future, which assumes social acceptance and indefinite availability of project funding.

Implement Assisted Migration?

Moving native fish species from one location to another, a historically common activity in fish management, has typically been used to found populations in previously fishless waters. This practice, alternately termed "assisted migration" or "managed relocation," has become controversial for some taxa in recent years. However, assisted migration may be useful in the Northern Rockies where basins are currently fishless (or contain nonnative species only in limited numbers) because of natural barriers such as waterfalls, and may constitute high-quality climate refugia in the future. Moving native fish to such areas is feasible, but potential effects on other native taxa (e.g., amphibians or invertebrates) must be considered. Reintroductions of native species may also be warranted when natural refounding is not an option, such as when populations in a specific location are isolated and periodically fail or suffer population bottlenecks (Dunham et al. 2011). This degree of management intervention requires a thorough understanding of genetic principles and broodstock establishment.

In conclusion, fisheries managers responding to the environmental trends associated with climate change will require a diverse portfolio comprising many of the actions described in this chapter. Equally important is adapting our mindsets—and our administrative processes—to a new paradigm of dynamic disequilibrium for the 21st century. Under this paradigm, stream habitats will become more variable, undergo gradual shifts through time, and sometimes decline. Many populations will retain enough flexibility to adapt and track their habitats, but others could be overwhelmed by future changes. It is unlikely that we will be able to preserve all populations of all fish species as they currently exist. However, as better information continues to be developed in the future, managers will have increasingly precise tools at their disposal to know when and where resource commitments are best made to enhance the resilience of existing fish populations or to benefit other species for which management was previously not a priority. There is much to do as climate change adaptation continues in future years, and Federal lands will play a critical role in providing important refuge habitats for aquatic resources.

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Appendix 5A—Adaptation Options for Fisheries in the Northern Rockies Adaptation Partnership Subregions

Geographically specific adaptation options for fisheries were compiled for four subregions of the Northern Rockies Adaptation Partnership.

Western Rockies Subregion

Adaptation options for fisheries in the Western Rockies subregion are summarized by climate change stressor.

Temperature

Adaptation tactics

- Identify and protect groundwater areas and side channels
  - Increase density of temperature sensor network
  - Develop GIS layer and incorporate into stream temperature maps
    - Action application: where groundwater has not yet been captured; everywhere native cold-water fish species occur
  - Remote sensing at microscale (longitudinal profile of larger rivers), which provides more fine-scale temperature mapping to help identify areas of groundwater inputs
    - Action application: Clearwater, St. Joe; anywhere there is private land or proposed development (feeds into floodplain or road development issues); rivers large enough to support this kind of sampling
- Restrict floodplain development and channelization
  - Action application: 3rd-order streams
- Remove/relocate roads from creeks/streams
  - Action application: prioritize areas based on proximity to and presence of fish doing well. For example, the Clearwater has one HUC 6 with no human effects that is prioritized for restoration. In contrast, the Selway is connected to large areas of good habitat so less important to prioritize for road removal/relocation.
    - At a site-specific scale, prioritize similarly to watershed but on smaller scale; look at the potential of that habitat to support native fish both now and in the future
- Limit exploitation of groundwater/water withdrawals
  - Action application: anywhere tied to groundwater upwelling
- Hypolimnitic withdrawal
  - Action application: where possible (e.g., Priest Lake, Libby Dam, Albany Falls, Dworshak and Clark Fork dams)

In some cases (e.g., Kootenai) the water has been too cold for fish species, but this may change in the future

- Use beaver or large woody debris, or both, to increase groundwater storage
  - Action application: headwaters/headwater storage in high elevation areas
- Maintain current shade and microclimate characteristics
  - Action application: everywhere
- Identify, prioritize, and protect high-quality watersheds (HUC 6/7) and generate specific standards and guidelines for the area
  - Implement in national forest land management plans. Use this as an overarching strategy to identify high, moderate, and low priority watersheds with specific actions in each
- Reduce grazing effects
  - Identify thresholds that, once exceeded, trigger movement of the cattle to another pasture
  - Generate and implement adaptive management scenarios (similar to those just described)
  - Reevaluate timing of grazing and the amount of time between grazing activities
  - Riparian fencing (not as feasible in forested environments)
  - Retire allotments
    - Action application: target areas most susceptible to grazing (low elevation meadows) (especially on Nez Perce-Clearwater NF)
- Remove barriers to fish passage
  - Action application: remove if barrier prevents bull trout migration (not necessarily westslope cutthroat trout)
  - Other: westslope cutthroat trout database can be compared with stream temperature maps

- Water temperature management through dams. For example, Dworshak dam has contributed to resilience of downstream fish because of temperature mitigations (i.e., by creating thermal refugia downstream of these facilities).
  - Need to match fish migration with thermal window (i.e., when fish migrate and when temperatures occur that are necessary to sustain that migration) and consider the possibility of longer periods of warmer stream temperatures in the future and how they may affect fish migration ability
  - Reexamine water temperature release in light of climate change (e.g., Kootenai)
  - Develop temperature models to better inform this action
- Install snowpack sensors to better anticipate changes in stream temperature and flow regimes

Runoff Regime

- Address site-specific activities that make narrower and deeper channels and affect runoff characteristics and peak flow (e.g., clearcutting) by reducing ratio of surface area to depth
  - Action application: anywhere with narrow and deep channels, clearcut areas
- Limit actions (e.g., vegetation removal) that contribute to peak yield
  - Action application: primarily in rain-on-snow areas; north end of Clearwater has private/State/Federal lands interspersed; need an analysis to determine effects from management activities (e.g., vegetation removal) on all lands to understand potential impacts on runoff characteristics and sedimentation
- Reconnect floodplains to improve the ability of system to deal with large flow events
  - Consider using beavers and large woody debris to facilitate this process
  - Action application: prioritize areas of past dredge mining, where possible/feasible given social/financial constraints
- Restore water holding capacity using beaver or mechanical storage methods
  - Action application: degraded headwater streams
- Reexamine flow release (variable Q) from dams with projected climate changes (currently use from 1999 and earlier)
  - Action application: dams
- Increase connectivity, where possible, to allow fish to move to cope with changing conditions
  - Action application: remove mainstem dam passages/impoundments (although these may also be selectors favoring nonnative species, so this needs to be considered at site level)
- Increase capacity of infrastructure to handle flows (e.g., upsizing culverts/structures to 100-year flood)
  - Action application: take advantage of Burned Area Emergency Rehabilitation and other vegetation projects to replace culverts; relocate roads and trails outside of 100-year floodplain
- Conduct roads analysis within proposed timber harvest areas, considering riparian/aquatic habitat and fish impacts (e.g., road density is a concern for fish)
- Hydrologically disconnect roads from streams (e.g., by adding cross-drains or culverts or outsloping roads)
- Examine current and proposed future campgrounds/dispersed campgrounds on creeks and potential future changes in flow regimes (permanent disturbance regimes for fish habitat)

Invasive Species

- Remove brook trout in higher elevations that are likely to be cold-water refugia for bull trout
  - Action application: headwater lakes in wilderness (rotenone can be used for brook trout suppression in wilderness); when removing fish, we need to provide an alternative for recreational fisheries
- Create an integrated strategy across the subregion that supports multiple species. For example, leave some lakes fishless for amphibians, incorporate brook trout strategy (following) at basin scale (HUC 5) to balance public need (i.e., recreational fishery) with ecological need (i.e., bull trout)
- Identify brook trout locations and prioritize where to eradicate
  - Need: strong partnership with State and other wildlife agencies to do a cross-agency effort (see preceding action as well); also support from leadership and funding
  - Eradication and preventing re-invasion by:
    - Installing barriers
    - Avoiding rotenone by using a combination of electrofishing and tiger muskie (*Esox masquinongy* × *Esox lucius*) (although may be difficult to eliminate source entirely)
    - Expanding options for brook trout management (e.g., gill netting)
    - Manipulating gametes and “swamping” current population so species essentially eradicates itself
  - Action application: meadow creeks in upper North Fork Clearwater
- Public education and outreach
- Brown trout and pike are newer invasive species, although management options are limited
  - Take limit off the fisheries (already done)

  - Where feasible and biology of species lends itself to it (e.g., Pend d'Oreille), can do some suppression
- Manage reservoirs and lakes (e.g., suppression efforts) to protect adult bull trout breeders from smallmouth bass and lake trout
- Utilize changing flow regimes and temperatures to keep invasives out
  - This has been used in Pend d'Oreille to keep pike out
  - Action application: dams/reservoirs
- Reservoir manipulation
  - Fertilization of species (kokanee; *Oncorhynchus nerka*); <u>application</u>: putting kokanee in headwater areas
- Establish barriers to invasive species movement
  - Have to make conscious decision to write off fluvial form of bull trout
  - Many factors have to coincide to make this work
  - Small-scale application for cutthroat (e.g., above barriers and more opportunistic)

In areas projected to be cold-water refugia until 2040:
- Suppress nonnative fish
- Conduct a status assessment of current species and management actions
- Manage fire and fire effects
- Note: many of these areas in Nez Perce-Clearwater NF are in wilderness, so fewer management options
- Aggressive fish management (e.g., hatcheries)
  - <u>Action application</u>: Lake Coeur d'Alene drainage is historical drainage and critical habitat for bull trout, but none there now
    - Questions: where to get fish and how many
    - This is a viable future habitat but there may be social barriers (cattlemen's association, political/social will) to implementation
    - Use this as template for future
  - <u>Action application:</u> in areas with nonnative species, use hatcheries to bring fish in, apply rotenone to habitat, and aggressively restock

In areas with fish currently, but projected to be gone by 2040:
- Suppress nonnative fish
- Improve connectivity
- Address higher river mainstem temperatures that act as barrier
- Monitor areas (fish present now, historical records, eDNA, presence/absence of juveniles, physical characteristics)

During warm phases of the Pacific Decadal Oscillation
- Warmer, drier conditions may affect year-class strength; potential barometer of how populations may respond in the future

High-severity wildfire areas
- With connectivity, fire effects and debris torrents may not be an issue
- Nez Perce-Clearwater National Forest probably would not move fish unless they were spawning populations with limited connectivity
  - Strategy: monitor over time to understand distributions of spawning populations and how they respond to disturbances
  - <u>Action application</u>: translocate brood stocks only in certain situations (no connectivity)

Valued Species Other Than Cold-Water Fish

- Sturgeon and burbot
  - Opportunities: management of dam (temperature and flow), specifically temperature for these species (dependent on season and species)
  - Potential conflict: want to reduce flow in winter for water to cool off, but Bonneville Power Administration wants to release more flow during this time to generate power
- Western pearlshell mussel: increased peak flows may wipe out colonies

Central Rockies Subregion

Following are adaptation tactics and other issues summarized for locations in the Central Rockies subregion as a complement to table 5A.1.

Table 5A.1—Adaptation options that address climate change effects on fisheries in the Central Rockies subregion.

Sensitivity to climatic variability and change: Reduced snowpack will alter the thermal regime of streams in space and time.			
Adaptation strategy/approach: Improve riparian function and increase functional riparian areas.			
Strategy objective: Promote resilience, reduce stressors.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Re-vegetate denuded sections of riparian areas (leading to additional refined tactics for grazing effects, fire effects, etc.).	Strategically relocate, eliminate, and minimize the effects of riparian and upland road segments.	Restore groundwater and hyporheic exchange through beaver reintroduction/protection, channel restoration, and re-establishment of fire regimes.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied?	All locations where riparian areas have been damaged, especially if native fish populations are present or nearby	All locations where streams have been or could be damaged, especially if native fish populations are present or nearby	All locations where each specific tactic is appropriate and likely to be effective
Opportunities for implementation			
Cost			
Barriers to implementation			

Flathead National Forest

- Need aggressive suppression and eradication of nonnative fish
- More brook trout are in the Middle Fork Flathead than in the North Fork; bull trout populations dropped sharply on the west side of Glacier National Park (Bowman, Logging, Kintla) because of brook trout; Quartz Lake has very active suppression of nonnative fish species
- Some effects from logging (lack of wood in streams, some roads) in Coal Creek, Big Creek, Whale, Red Meadow; active logging in Canada in same drainage has effects (nonnative fish going upstream, logging effects coming downstream)
- To protect westslope cutthroat trout, Montana Fish, Wildlife and Parks (FWP) is focused on eradicating rainbow trout through rotenone application and other techniques
- Efforts to slow spread of hybrids; targeting rainbow trout sources in lower Flathead
- Barriers being installed or removed in North Fork Flathead; removing barriers in Rose Creek; removing culverts in Langford tributary to Big Creek
- Ongoing habitat work by Montana FWP in South Fork of Cold Creek
- Suppression of brook trout in Flathead Lake is a high priority
- Translocated bull trout this year; can use stocks to move them above barriers
- Genetic rescue of westslope cutthroat trout (tributary to Swan Lake)
- Land acquisition presents huge opportunities for protection of habitat

South Fork of the Flathead River

- Try to maintain the status quo in Hungry Horse Reservoir, a genetic refuge for bull trout
- Try to manage more natural burns in South Fork of the Flathead; could apply this tactic to land around Hungry Horse Reservoir
- Need a check station at the dam and ranger station to prevent introduction of nonnative fish, in combination with public outreach on this issue
- Montana FWP restored connectivity around Hungry Horse reservoir (also around Emery Creek) that was severed when road was constructed, but additional opportunities exist

Swan River

- Nonnative issues are similar to Flathead River
- Westslope cutthroat trout are more hybridized with more brook trout characteristics
- Need small barriers to protect bull trout headwater populations
- Need to explore passage barrier issues
- Consider pulling road segments back from streams in critical locations
- Major road management issues exist on former Plum Creek lands, which have a large amount of spawning and rearing habitat relative to size
- Need thermographs throughout floodplains because of the importance of groundwater upwelling for bull trout; this will help improve models of these cold-water systems

Clearwater River, Blackfoot River

- Long-term effects of timber harvest and roads, including the effects of roads on connectivity of the hydrologic system
- Unmanaged roads deliver low amounts of sediment
- Continuing work with The Blackfoot Challenge to expand voluntary drought response plans; irrigation efficiency programs are addressing dewatering issues (particularly in drought years)
- Livestock grazing issues in Monture Creek
- Need to address contaminants issues near Mike Horse Mine
- Conservation easements need to be added more strategically (rather than only opportunistically)
- Restorative work is needed to narrow and deepen creeks to significantly reduce stream temperatures (Nevada Creek); could be applied strategically in other areas (Shanley Creek), as suggested by bull trout recovery plan
- Restoration of the main stem of the Blackfoot River is needed to reduce channel simplification and restore functionality and complexity
- One option is to identify reaches on private land and work to connect landscape and habitat up to higher elevation habitat on public lands

- Ongoing efforts to connect cold-water tributaries in the Upper Blackfoot; also need to restore streambanks in locations with land conversion
- This area has high use for recreation and fishing; this level of use may not be sustainable if habitat quality declines in the future

Upper Clark Fork River, Bitterroot River

- Heavy fishing pressure (catch and release) in this location
- East side of Bitterroot is a stronghold for native fish, but west side has no apparent occupancy (need to confirm)
- Dewatering events in tributaries are important, including issues for mitigation of water quality and quantity
- West Fork of Bitterroot above Painted Rocks Dam has been affected by forest management; road mitigation and removal are helping
- Sleeping Child/Darby timber land restoration is removing roads
- Habitat in Daily Creek (strong producer of bull trout out of Skalkaho) is being improved by placing woody debris in streams
- South Fork Lolo Creek is probably a native fish stronghold, although Highway 12 and private land management limit potential restoration options

Middle and Lower Clark Fork River

- Fish passage at the reservoir dams has a huge effect on downstream rearing of westslope cutthroat trout and bull trout
- Legacy effects of management (e.g., placer mining) on cold-water patches (Cedar Creek, Trout Creek) have degraded habitat, requiring structural channel remediation and road relocation and mitigation
- Thompson River native fish strongholds (Fish Trap, West Fork Thompson) provide options for improving channel complexity and habitat
- Little Joe River is a very cold water patch but with seasonal disconnection; unclear if this hinders access by bull trout
- Moore Lake is a source of brook trout to the South Fork Little Joe River

Rock Creek

- Bull trout populations are decreasing faster here than anywhere else; brown trout numbers are correspondingly increasing; East Fork above the reservoir has agricultural issues including effects of dewatering events caused by irrigation withdrawals
- Easy restoration options have already been implemented to improve connectivity
- Options on east side for road relocation (Burnt Fork)
- Lower Rock Creek has heavy angling pressure
- Water and land restoration options on Ranch Creek

Rattlesnake Creek

Current bull trout producer, but warming with few options for improving management
Large wood and channel complexity, especially in the urban interface.

Eastern Rockies Subregion

Adaptation options for fisheries in the Eastern Rockies subregion are summarized in tables 5A-2 through 5A-7

Table 5A.2—Adaptation options that address climate change effects on fisheries in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.			
Adaptation strategy/approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.			
Strategy objective: Promote resilience			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Restore natural channel and floodplain form and function (e.g., restore areas with human-caused bank and bed instability).	Restore aquatic organism passage structures through design and placement of appropriate structures.	Maintain functional stream channel morphology with adequate width:depth ratios, pool frequency, and healthy riparian vegetation.
Tactic effectiveness (risks)	Moderate–high	High	High
Implementation urgency	Near term (gradual process, but need to get started)	Near term	Near term
Where can tactics be applied? (geographic)	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)	Drainages with frequent high peak flows, areas with sensitive geology, areas with important rearing streams	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)
Opportunities for implementation	Mining restoration projects	Talk to insurance companies to see if they will fund replacements (e.g., in locations where flows can affect downstream communities)	
Cost			
Barriers to implementation			

Table 5A.3—Adaptation options that address climate change effects on fisheries in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.

Adaptation strategy/approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.

Strategy objective: Promote resilience

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Restore riparian areas to increase hydrologic function and retain cold water.	Reintroduce beaver where beaver and management of westslope cutthroat trout are compatible.	Remove or relocate roads adjacent to riparian areas, channels, and floodplains where they inhibit complexity; minimize cumulative effect of road network on surface and subsurface flow.
Tactic effectiveness (risks)	High	Moderate	High, but spatially limited
Implementation urgency	Near term	Long term	Near-medium term
Where can tactics be applied? (geographic)	Where riparian areas limit the availability of cold-water habitat	Where beaver will not affect barriers; in stream reaches >1 mile; in larger population conservation networks; where brook trout are absent	Where roads currently cause problems or may in the future, especially where roads have substantial linear effects
Opportunities for implementation	Mining restoration projects	Talk to insurance companies to see if they will fund replacements (e.g., in locations where flows can affect downstream communities)	
Cost			Very high cost
Barriers to implementation		Beaver habitat can enhance brook trout populations	

Table 5A.4—Adaptation options that address climate change effects on fisheries in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.		
Adaptation strategy/approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.		
Strategy objective: Promote resilience.		
	Specific tactic – A	**Specific Tactic – B**
Tactic	Acquire Montana water compact/rights in a strategic way.	Increase efficiency of irrigation techniques.
Tactic effectiveness (risks)	Low–moderate (for instream flows)	Low–moderate
Implementation urgency	Long term	Long term
Where can tactics be applied? (geographic)	Where future plans for water development may overlap with areas where native fish populations may be declining	Where future plans for water development may overlap with areas where native fish populations may be declining
Opportunities for implementation		
Cost		
Barriers to implementation		

Table 5A.5—Adaptation options that address climate change effects on fisheries in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Continued livestock grazing will compound stress caused by increased stream temperatures.

Adaptation strategy/approach: Manage livestock grazing to restore ecological function of riparian vegetation and channels.

Strategy objective: Promote resilience, reduce stressors

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Comply with all existing standards and guidelines for maintaining water quality in streams and riparian areas; facilitate compliance through monitoring.	Use innovative techniques to fund and maintain and implement improvements (e.g., riparian fencing, rest-rotation systems, off-channel water, exclosures).	Identify and prioritize vacant allotments for retirement.
Tactic effectiveness (risks)	Moderate	Moderate–high (high for techniques that physically prevent access)	High, but spatially limited and opportunistic
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All locations, with emphasis on areas that are important in terms of ecological value and large financial investment	All locations, with emphasis on areas that are important in terms of ecological value and prior financial investment; prioritize areas with pure native fish populations that are under imminent threat	All locations where vacant allotments exist and opportunities allow
Opportunities for implementation			
Cost			
Barriers to implementation	Lack of public support	Beetle-killed trees damage fences	

Table 5A.6—Adaptation options that address climate change effects on fisheries in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Continued livestock grazing will compound stress caused by increased stream temperatures.

Adaptation strategy/approach: Manage livestock grazing to restore ecological function of riparian vegetation and channels.

Strategy objective: Promote resilience, reduce stressors.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Incorporate aquatic resource values in prioritization and implementation of land management plans.	Convene regional meeting to identify and prioritize key fisheries areas; develop implementation plan that describes line officer actions.	Continue and formalize agency coordination for fish habitat conservation (where projects are planned).
Tactic effectiveness (risks)	Moderate–high, depending on how well values are incorporated	High, but depends on spatial extent and number of stakeholders involved	High, but spatially dependent
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All locations, as management plan revisions occur	All areas of Montana	Where projects are planned and where existing conservation issues related to grazing exist
Opportunities for implementation		East-side range meetings; efforts to avoid listing of westside cutthroat trout populations; monitoring plans	
Cost			
Barriers to implementation			

Table 5A.7—Adaptation options that address climate change effects on fisheries in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Warmer temperatures will increase stream temperature and risk of invasion by nonnative fish species.

Adaptation strategy/approach: Manage nonnative fish populations to eliminate or reduce their impact on native fish.

Strategy objective: Promote resilience, reduce stressors.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Construct barriers to restrict nonnative fish.	Remove nonnative fish and re-establish or restore western cutthroat trout populations.	Secure, maintain, and improve riparian stream function and flows, including temperature.
Tactic effectiveness (risks)	High	High	Moderate
Implementation urgency	Near term (Big Hole and other locations with urgent issues); Long term (everywhere else)	Near term (Big Hole and other locations with urgent issues); Long term (everywhere else)	Near term
Where can tactics be applied? (geographic)	Where feasible and necessary (Big Hole, Selway Meadows-Red Rock, all drainages on Rocky Mountains front)	Where feasible and necessary (Big Hole, Selway Meadows-Red Rock, all drainages on Rocky Mountains front)	Where native fish populations and impaired riparian function exist, as identified in annual coordination meetings
Opportunities for implementation		East-side range meetings; efforts to avoid listing of westside cutthroat trout populations; monitoring plans	
Cost		Potentially high	
Barriers to implementation	Not socially feasible	Not socially feasible (e.g., high value recreational fishery) or may be unacceptable to kill all nonnatives	

Greater Yellowstone Area Subregion

Adaptation options for fisheries in the Greater Yellowstone Area are summarized in tables 5A-8 through 5A-5A-13.

Table 5A.8—Adaptation options that address climate change effects on fisheries in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Reduced snowpack will reduce summer streamflows.			
Adaptation strategy/approach: Increase streamflows and moderate changes in instream flows.			
Strategy objective: Promote resilience.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Pulse flows during critical times (high temperatures) from regulated streams.	Reduce water withdrawals and improve efficiency for agriculture (especially irrigation), municipal, and industrial uses.	Secure water rights for instream flows.
Tactic effectiveness (risks)	Moderate–high	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All regulated streams	Where water demands overlap with current and future suitable habitat	Where fish and suitable habitat overlap
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 5A.9—Adaptation options that address climate change effects on fisheries in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Reduced snowpack will reduce summer streamflows.

Adaptation strategy/approach: Provide opportunities for native fish to move and find suitable stream temperatures.

Strategy objective: Promote resilience.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Increase the patch size of favorable habitat to enhance viable populations and allow adfluvial life histories.	Modify or remove barriers to increase connectivity between areas of cold-water habitat.	Identify and map where groundwater inputs provide cold water.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Mid term
Where can tactics be applied? (geographic)	Where native fish currently exist; where suitable habitat is nearby; where non-natives are not present or can be effectively managed; where populations are fragmented and need greater connectivity	Where barriers prevent movement to suitable habitat, and where removal will not increase invasion of non-natives	All locations
Opportunities for implementation		Locations that are economically advantageous	
Cost			
Barriers to implementation			

Table 5A.10—Adaptation options that address climate change effects on fisheries in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Water temperature will increase, and the hydrograph will change in terms of magnitude and seasonality.

Adaptation strategy/approach: Protect and enhance fish habitat.

Strategy objective: Promote resilience.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Restore degraded riparian vegetation, reconnect floodplains to rivers.	Reintroduce beaver, encourage beaver recolonization.	Disconnect roads from stream networks to reduce sedimentation.
Tactic effectiveness (risks)	Moderate–high	Moderate	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Smaller streams will be most effective, especially in lower-elevation valleys; prioritize areas with native fish or potentially suitable habitat	Where brook trout do not occur (beaver dams tend to facilitate brook trout) and where suitable beaver habitat exists	Where roads adjacent to streams have the potential to erode and deliver sediment
Opportunities for implementation	Smaller streams	Locations that are economically advantageous	
Cost			
Barriers to implementation			

Table 5A.11—Adaptation options that address climate change effects on fisheries in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Water temperature will increase, and cold-water fish habitat will decline.

Adaptation strategy/approach: Reduce stress on native fish species to enhance their ability to tolerate climate-induced stress.

Strategy objective: Reduce stressors

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Limit angling pressures on native fish.	Reduce effects of recreation and grazing disturbance in streams.	Reduce nonnative (non-fish) aquatic species and diseases.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Mid term	Mid term	Near term
Where can tactics be applied? (geographic)	Locations that are at or near temperature thresholds for native fish	Where recreation and grazing activities are high, coincident with occupied or projected suitable fish habitat	Where nonnative aquatic species and diseases occur, coincident with occupied or projected suitable fish habitat
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 5A.12—Adaptation options that address climate change effects on fisheries in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Warmer temperatures will increase stream temperature and risk of invasion by nonnative fish species.

Adaptation strategy/approach: Manage nonnative fish populations to eliminate or reduce their impact on native fish.

Strategy objective: Promote resilience, reduce stressors.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Encourage increased take/harvest of nonnatives, especially near long-term strongholds for natives.	Remove nonnatives with manual or chemical techniques.	Implement physical or electrical barriers to exclude nonnatives.
Tactic effectiveness (risks)	Low–moderate (need heavy harvest at the invasion front)	Moderate–high	Moderate–high
Implementation urgency	Mid term	Near term	Near term
Where can tactics be applied? (geographic)	Areas with heavy recreation and sport fishing; most effective at the front of invasions	Where long-term suitable habitat for natives is available and non-natives are present	Where long-term suitable habitat for natives is available and nonnatives are present
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 5A.13—Adaptation options that address climate change effects on fisheries in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Higher temperatures will increase wildfire occurrence that can lead to erosion and mass wasting.

Adaptation strategy/approach: Increase resilience to fire-related disturbance.

Strategy objective: Promote resilience, reduce stressors.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Implement fuel treatments (thinning, prescribed burning) to reduce wildfire severity and size.	Disconnect roads from stream networks to reduce erosion and sediment delivery to streams.	Install erosion control structures following wildfires.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Mid term	Mid term	Near term
Where can tactics be applied? (geographic)	Areas where canopy and surface fuels are high, adjacent to known native fish populations and habitat	Areas adjacent to known native fish populations and habitat	Where wildfire has occurred and erosion would affect known native fish populations and habitat
Opportunities for implementation	Areas that are already being targeted for fuel treatment, especially in the wildland-urban interface		
Cost			
Barriers to implementation			