Appendix S1. Regional fish survey database

To develop occupancy models, species-specific thermal niche definitions, and a reach slope value for delimiting the upper extent of the stream network used by fish (Fig. 1), we used the fish database previously assembled by Wenger et al. (2011) that consisted of 4,165 sites sampled across the northwestern U.S. However, fish length information to determine locations of juvenile BT and CT was rare in that database, so we compiled additional information about juvenile locations from 4,608 site surveys described in peer-reviewed studies (Rieman and McIntyre 1995; Dunham and Rieman 1999; Isaak and Hubert 2004; Shepard et al. 2005; Rieman et al. 2006; Benjamin et al. 2007; Dunham et al. 2007; Rieman et al. 2007; Al-Chokhachy and Budy 2008; Isaak et al. 2009; Allen et al. 2010; Isaak et al. 2010; Peterson et al. 2013; Young et al. 2013; Eby et al. 2014), and extensive monitoring programs run by U.S. Forest Service biologists (Bartel et al. 2009; Chatel and Vuono 2010, 2011, 2012; Chatel et al. 2009; Gamett and Bartel 2008, 2011; Gamett 1999; Kellett 2004, 2005, 2006, 2007, 2008; Kenney and Chatel 2008; Mitchell and Roerick 2012; Mitchell and Roerick 2013; Wofford and Chatel 2005, 2006, 2007). In those surveys, fish were collected at sample sites by 1–3 electrofishing passes through 50–200-m reaches in small mountain streams (1–7 m wetted width).

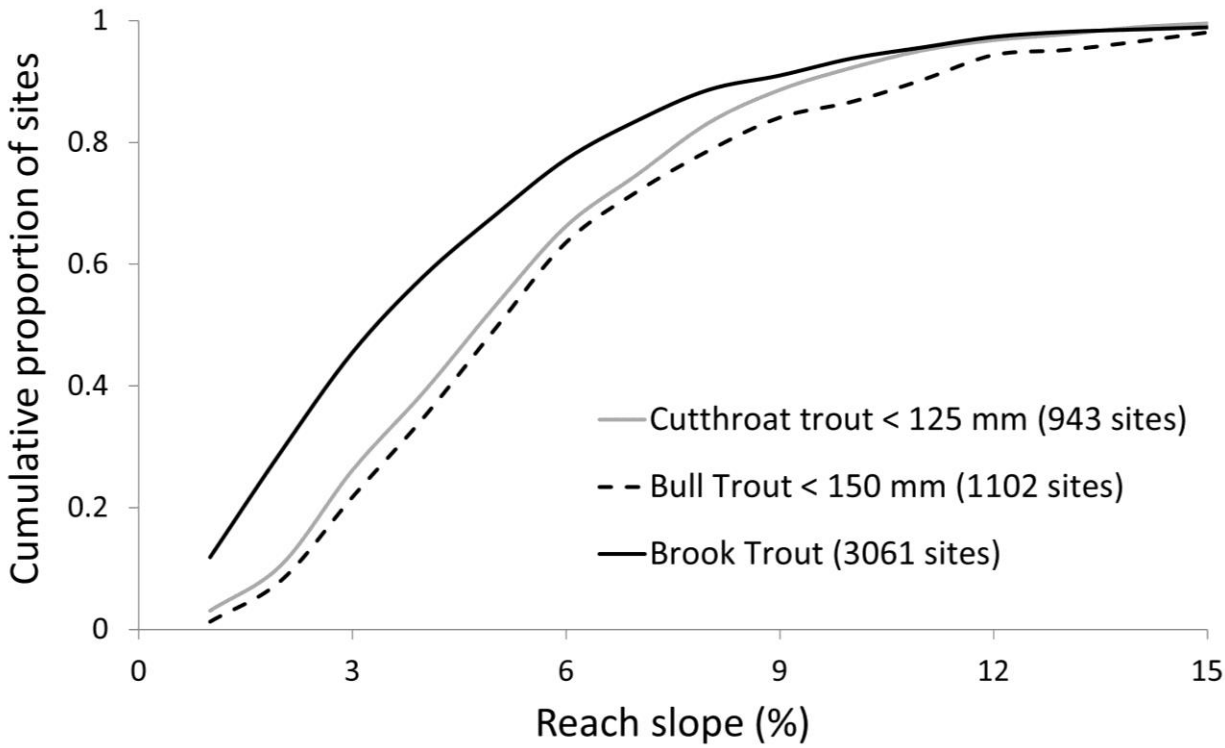

Fig. 1 Cumulative distributions of trout occurrence developed by cross-referencing sites from the regional fish database against reach-scale stream slope values. Because reaches with slopes ≤ 15% included the great majority of fish locations, steeper reaches were trimmed from the network used in the analysis and designation of CWHs.

References

Al-Chokhachy R, Budy P. 2008. Demographic characteristics, population structure, and vital rates of a fluvial population of bull trout in Oregon. *Transactions of the American Fisheries Society*, **137**, 1709–1722.

Allen MB, Connolly PJ, Mesa MG et al. (2010) Distribution and movement of Bull Trout in the upper Jarbidge River watershed, Nevada. U.S. Geological Survey, Open-File Report 2010-1033.

Bartel JA, Gamett BL, Pyron, JC (2009) The status of fishes on the Challis Ranger District, Salmon-Challis National Forest (2001-2004). Department of Agriculture, U.S. Forest Service, South Zone Fish Program Report, Salmon-Challis National Forest.

Benjamin JR, Dunham JB, Dare MR (2007) Invasion by nonnative brook trout in Panther Creek, Idaho: Roles of local habitat quality, biotic resistance, and connectivity to source habitats. *Transactions of the American Fisheries Society*, **136**, 875–888.

Chatel J, Vuono S (2010) Sawtooth National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Chatel J, Vuono S (2011) Sawtooth National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Chatel J, Vuono S (2012) Sawtooth National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Chatel J, Kenney D, Vuono S (2009) Sawtooth National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Dunham JB, Rieman BE. 1999. Metapopulation structure of bull trout: Influences of physical, biotic, and geometrical landscape characteristics. *Ecological Applications*, **9**, 642–655.

Dunham JB, Rosenberger AE, Luce CH, Rieman BE (2007) Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians. *Ecosystems*, **10**, 335-346.

Eby LA, Helmy O, Holsinger LM, Young MK (2014) Evidence of climate-induced range contractions for bull trout in a Rocky Mountain watershed, U.S.A. *PLoS One*, **9**, e98812.

Gamett BL, Bartel JA (2008) The status of fishes on the Yankee Fork Ranger District, Salmon-Challis National Forest. Department of Agriculture, U.S. Forest Service, South Zone Fish Program Report, Salmon-Challis National Forest.

Gamett BL, Bartel JA (2011) The status of fishes on the Middle Fork Ranger District, Salmon-Challis National Forest (2002-2008). Department of Agriculture, U.S. Forest Service, South Zone Fish Program Report, Salmon-Challis National Forest.

Gamett BL (1999) The history and status of fishes in the Little Lost River Drainage, Idaho. Department of Agriculture, U.S. Forest Service, South Zone Fish Program Report, Salmon-Challis National Forest.

Isaak DJ, Hubert WA (2004) Nonlinear response of trout abundance to summer stream temperatures across a thermally diverse montane landscape. *Transactions of the American Fisheries Society*, **133**, 1254-1259.

Isaak DJ, Rieman BE, Horan D (2009) A watershed-scale monitoring protocol for bull trout. General Technical Report. GTR-RMRS-224. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 25 p.

Isaak DJ, Luce C, Rieman BE et al. (2010) Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. *Ecological Applications*, **20**, 1350–1371.

Kellett M (2004) Boise National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Boise National Forest, Boise, Idaho.

Kellett M (2005) Boise National Forest aquatic management indicator species monitoring report. Boise National Forest, Boise, Idaho.

Kellett M (2006) Boise National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Boise National Forest, Boise, Idaho.

Kellett M (2007) Boise National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Boise National Forest, Boise, Idaho.

Kellett M (2008) Boise National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Boise National Forest, Boise, Idaho.

Kenney D, Chatel J (2008) Sawtooth aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Mitchell RG, Roerick HM (2012) Boise National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Boise National Forest, Boise, Idaho.

Mitchell RG, Roerick HM (2013) Boise National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Boise National Forest, Boise, Idaho.

Peterson DP, Rieman BE, Horan DL, Young MK (2013c) Patch size but not short-term isolation influences occurrence of westslope cutthroat trout above human-made barriers. *Ecology of Freshwater Fish*, **23**, 556-571.

Rieman BE, Isaak DJ, Adams S et al. (2007) Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River basin. *Transactions of the American Fisheries Society*, **136**, 1552–1565.

Rieman BE, McIntyre JD (1995) Occurrence of bull trout in naturally fragmented habitat patches of varied size. *Transactions of the American Fisheries Society*, **124**, 285–296.

Rieman BE, Peterson JT, Myers DL (2006) Have brook trout displaced bull trout along longitudinal gradients in central Idaho streams? *Canadian Journal of Fisheries and Aquatic Sciences* **63**, 63–78.

Shepard BB, May BE, Urie W (2005) Status and conservation of westslope cutthroat trout within the western United States. *North American Journal of Fisheries Management*, **25**, 1426–1440.

Wenger SJ, Isaak DJ, Dunham JB et al. (2011) Role of climate and invasive species in structuring trout distributions in the Interior Columbia Basin, USA. *Canadian Journal of Fisheries and Aquatic Sciences*, **68**, 988–1008.

Wofford J, Chatel J (2005) Sawtooth National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Wofford J, Chatel J (2006) Sawtooth National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Wofford J, Chatel J (2007) Sawtooth National Forest aquatic management indicator species monitoring report. Department of Agriculture, U.S. Forest Service, Sawtooth National Forest, Twin Falls, Idaho.

Young MK, McKelvey KS, Pilgrim KL, Schwartz MK (2013) DNA barcoding at riverscape scales: assessing biodiversity among fishes of the genus *Cottus* (Teleostei) in northern Rocky Mountain streams. *Molecular Ecology Research*, **13**, 583–595.

Appendix S2. Sampling effort to minimize false absences

Results of logistic regression occupancy models can be biased if used with datasets that include large numbers of "false absences" (i.e., instances when it is incorrectly concluded that a species is absent; Tyre et al. 2003; Comte and Grenouillet 2013). We minimized that bias by ensuring that a sufficient amount of sampling effort was conducted within each CWH to determine occupancy. That effort was estimated using the spreadsheet calculator developed by Peterson and Dunham (2003). The user inputs two values—a species-specific site-level detection efficiency and the prior probability that a sampling unit is occupied—to estimate the probability of a false absence given that a species was not detected (Bayley and Peterson 2001).

Estimates of detection efficiency were derived from a subset of CWHs with ≥ 10 fish samples that were occupied by juvenile native trout. The regional fish database included 118 such CWHs for BT and 181 for CT. Site-level detection efficiency estimates based on those habitats were 0.53 for BT and 0.81 for CT. Estimates of the prior probability of habitat occupancy were derived from simple summaries relating CWH size to the proportion of habitats occupied (Fig. 1). Entering those estimates into the calculator indicated that 2–6 sites needed to be sampled to reliably determine the absence of BT from a CWH while maintaining the false absence rate at ≤ 0.1. Two samples were needed in CWH ≤ 10 km because prior probabilities were ≤ 0.2; six samples were needed for CWH ≥ 50 km because prior probabilities were ≥ 0.9. For CT, 2–3 samples met the same false absence rate threshold because detection efficiency was higher for this species. Two samples were needed for CWH ≤ 3 km because prior probabilities were ≤ 0.2; three samples were needed for CWH ≥ 8 km because prior probabilities were ≥ 0.9. In most cases, the number of fish site samples within the 512 BT CWH and 566 CT CWH used to develop the occupancy models significantly exceeded minimum sample sizes (Fig. 2). For BT, the average number of samples within a CWH was nine (range, 2-81; total sites sampled within BT CWH was 4,608) and for CT, six (range, 2-47; total sites sampled within CT CWH was 3,396).

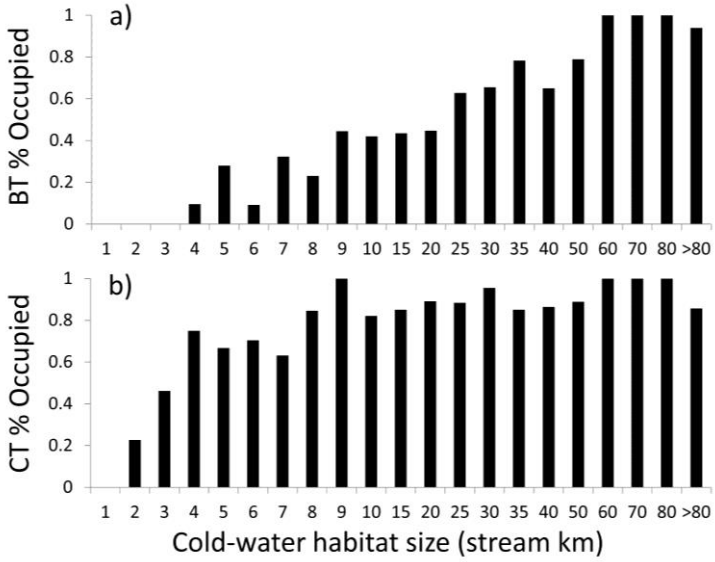

Fig. 1 Juvenile native trout occurrence relative to cold-water habitat size for 512 Bull Trout habitats (a) and 566 Cutthroat Trout habitats (b) that were screened for false absences and used to develop logistic regression occupancy models.

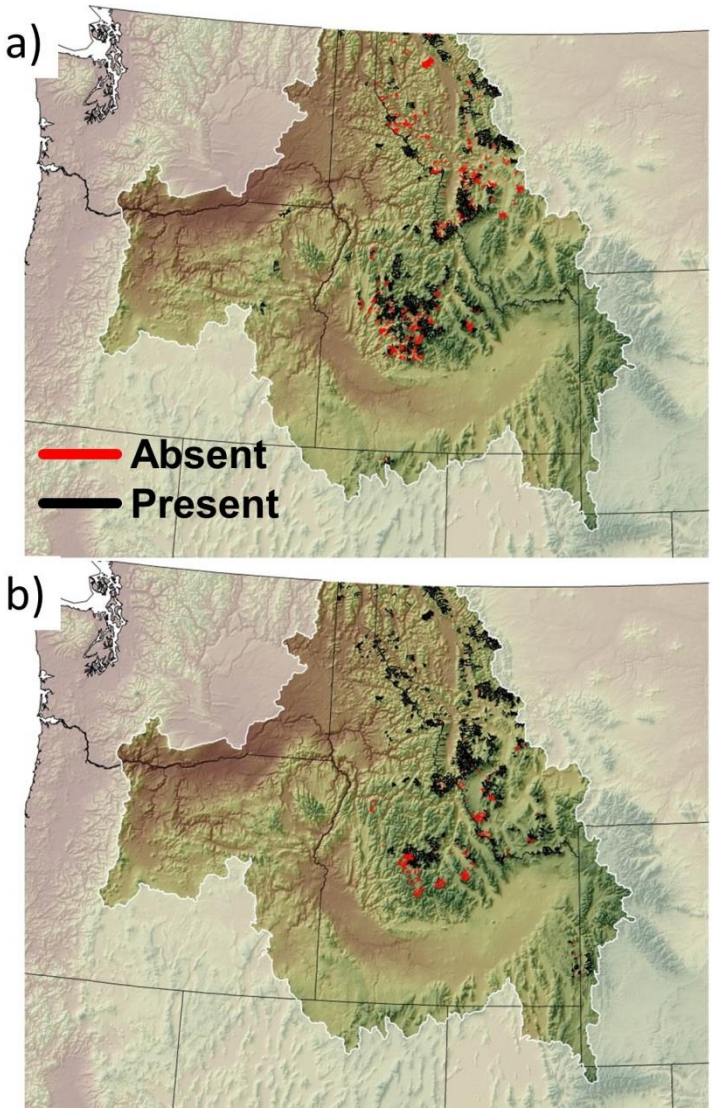

Fig. 2 Locations of cold-water habitats that were screened for false absences and used to develop logistic regression models for predicting occupancy by juvenile Bull Trout (a; *n* = 512) and juvenile Cutthroat Trout (b; *n* = 566).

References

Bayley PB, Peterson JT (2001) Species presence for zero observations: an approach and an application to estimate probability of presence of fish species and species richness. *Transactions of the American Fisheries Society*, **130**, 620–633.

Comte L, Grenouillet G (2013) Species distribution modelling and imperfect detection: comparing occupancy versus consensus methods. *Diversity and Distributions*, **19**, 996-1007.

Peterson JT, Dunham J (2003). Combining inferences from models of capture efficiency, detectability, and suitable habitat to classify landscapes for conservation of threatened bull trout. *Conservation Biology* **17**, 1070-1077.

Tyre AJ, Tenhumberg B, Field SA et al. (2003) Improving precision and reducing bias in biological surveys: estimating false-negative error rates. *Ecological Applications*, **13**, 1790-1801.

Table S1 Projected changes in mean August air temperatures, stream temperatures, and flow for major river basins across the study area. Projections are based on the A1B emissions scenario represented by an ensemble of ten global climate models that best predicted historical climate conditions during the 20th century in the northwestern U.S. (Mote and Salathe 2010; Hamlet et al. 2013). Additional details about the scenarios are provided elsewhere (Wenger et al. 2010; Hamlet et al. 2013; Western U.S. flow metrics website: http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml; Pacific Northwest Hydroclimate Scenarios Project website: http://warm.atmos.washington.edu/2860/; stream temperature (Isaak et al. 2010, Luce et al. 2014; NorWeST website: http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html).

	2040s (2030–2059)			2080s (2070–2099)		
NorWeST unit*	Air temperature Δ (ºC)†	Stream flow Δ (%)	Stream temperature Δ (ºC)‡	Air temperature Δ (ºC)	Stream flow Δ (%)	Stream temperature Δ (ºC)
Salmon	3.26	-22.3%	1.26	5.51	-31.4%	2.07
Clearwater	3.17	-23.9%	1.62	5.45	-34.2%	2.78
Spokoot	3.05	-20.1%	1.27	5.33	-31.5%	2.19
Missouri	3.25	-14.9%	1.17	5.47	-21.3%	1.94
SnakeBear	3.17	-7.6%	0.81	5.26	-9.5%	1.32
MidSnake	3.22	-19.5%	1.25	5.45	-26.7%	2.04
MidColumbia	3.27	-14.4%	1.43	5.44	-20.7%	2.38

*Boundaries of NorWeST production units as described at the NorWeST website: http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

†Changes in air temperature and stream flow are expressed relative to the 1980s (1970–1999) baseline climate period.

‡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.

References

Hamlet AF, Elsner MM, Mauger GS et al. (2013) An overview of the Columbia Basin Climate Change Scenarios Project: Approach, methods, and summary of key results. *Atmosphere-ocean*, **51**, 392-415.

Isaak DJ, Luce C, Rieman BE et al. (2010) Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. *Ecological Applications*, **20**, 1350–1371.

Mote PW, Salathé EP (2010) Future climate in the Pacific Northwest. *Climatic Change*, **102**, 29-50.

Luce CH, Staab BP, Kramer MG et al. (2014). Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest. *Water Resources Research*, **50**, 1-16.

Table S2 Model selection results for logistic regression analysis of factors that affected Bull Trout (BT) and Cutthroat Trout (CT) occupancy of cold-water habitats. Models were ranked from most plausible ($\Delta AIC_c = 0$) to least plausible; *p* is the number of parameters. The ratio of Akaike weights (w_1/w_i) indicates the plausibility of the best-fitting model compared to other models. Models shown in bold font below were used to predict species occurrence across the Northern Rocky Mountains.

Species	Model	Log likelihood	*p*	ΔAIC_c	Akaike weight (w_i)	w_1/w_i
BT	Size, MinTemp, Slope, BKT, Size*BKT, Slope*BKT, Size*Slope	-250.6	8	0.0	0.39	1.00
	Size, MinTemp, Slope, BKT, Size*BKT	**-252.9**	**6**	**0.5**	**0.30**	**1.28**
	Size, MinTemp, Slope, BKT, Size*BKT, Slope*BKT	-251.9	7	0.5	0.30	1.28
	Size, MinTemp, Slope, BKT	-257.5	5	7.8	0.01	49.4
	Size, MinTemp, BKT	-263.7	4	18.2	0.00	8.87×10^{3}
	Size, MeanTemp, BKT	-267.5	4	25.7	0.00	3.83×10^{5}
	Size, MinTemp, Slope	-269.5	4	29.7	0.00	2.81×10^{6}
	Size, MinTemp	-271.2	3	31.2	0.00	6.02×10^{6}
	Size, BKT	-280.5	3	49.7	0.00	6.20×10^{10}
	MinTemp, BKT	-283.0	3	54.7	0.00	7.55×10^{11}
	MinTemp	-288.5	2	63.7	0.00	6.80×10^{13}
	Size, Slope	-289.9	3	66.7	0.00	3.03×10^{14}
	Size	-289.9	2	68.5	0.00	7.49×10^{14}
	MeanTemp	-309.9	2	107	0.00	1.41×10^{23}
	BKT	-348.2	2	183	0.00	6.04×10^{39}
	Slope	-349.9	2	187	0.00	3.31×10^{40}
CT	**Size, MeanTemp, Slope, BKT, Size*Slope, Size*MeanTemp, Size*BKT, BKT*Slope, MeanTemp*Slope**	**-203.9**	**10**	**0.0**	**0.51**	**1.00**
	Size, MeanTemp, Slope, BKT, Size*Slope, Size*MeanTemp, BKT*Slope, MeanTemp*Slope	-205.2	9	0.6	0.38	1.35
	Size, MeanTemp, Slope, BKT, Size*Slope, Size*MeanTemp, BKT*Slope	-207.8	8	3.9	0.07	7.03
	Size, MeanTemp, Slope, BKT, Size*Slope, Size*MeanTemp, Size*BKT, BKT*Slope	-207.3	9	4.9	0.04	11.6
	Size, MeanTemp, Slope, BKT, Size*Slope, BKT*Slope	-220.2	7	26.6	0.00	5.97×10^{5}
	Size, MeanTemp, Slope, BKT, Size*Slope, Size*BKT, BKT*Slope	-219.4	8	27.0	0.00	7.29×10^{5}
	Size, MeanTemp, Slope, BKT, BKT*Slope	-223.7	6	31.6	0.00	7.28×10^{6}

Table S2 continued.

Species	Model	Log likelihood	p	ΔAIC_c	Akaike weight (w_i)	w_1/w_i
CT	Size, MeanTemp, Slope, BKT, Size*Slope	-243.8	6	71.9	0.00	4.10×10^{15}
	Size, Slope, BKT, Size*Slope	-246.7	5	75.7	0.00	2.74×10^{16}
	Size, MinTemp, Slope, BKT, Size*Slope	-246.7	6	77.7	0.00	7.45×10^{16}
	Size, MeanTemp, BKT	-254.9	4	90.1	0.00	3.67×10^{19}
	Size, BKT	-256.1	3	90.4	0.00	4.27×10^{19}
	Size, MinTemp, BKT,	-255.3	4	90.9	0.00	5.48×10^{19}
	Size, MeanTemp, Slope, BKT	-254.9	5	92.0	0.00	9.50×10^{19}
	Size, MinTemp, Slope, BKT	-255.2	5	92.7	0.00	1.35×10^{20}
	BKT	-271.9	2	120	0.00	1.20×10^{26}
	Size, MeanTemp	-275.5	2	127	0.00	4.18×10^{27}
	Size, MinTemp	-274.6	3	127	0.00	4.62×10^{27}
	Size	-275.8	2	128	0.00	5.93×10^{27}
	MinTemp	-280.1	2	136	0.00	4.16×10^{29}
	MeanTemp	-290.0	2	156	0.00	8.71×10^{33}
	Slope	-291.0	2	158	0.00	2.37×10^{34}

Table S3 Stream kilometers (% in parentheses) by land administrative status for Cutthroat Trout classified as cold-water habitat (<11°C) and climate refugia (>0.9 occurrence probability) during two climate periods in the Northern Rocky Mountains. The climate refugia summaries shown are based on a pessimistic assumption of Brook Trout presence at 50% of all stream sites.

	Cold-water habitat		Climate refugia	
Land status*	1980s	2040s	1980s	2040s
Private	6,661 (11.8)	2,947 (7.8)	2,145 (9.0)	659 (5.2)
TNC	157 (0.3)	80 (0.2)	64 (0.3)	5 (0.1)
Tribal	648 (1.1)	357 (0.9)	244 (1.0)	98 (0.8)
State/City	1,823 (3.2)	822 (2.2)	528 (2.2)	272 (2.2)
BLM	2,000 (3.5)	1,093 (2.9)	708 (3.0)	169 (1.3)
NPS	2,274 (4.0)	2,261 (6.0)	980 (4.1)	484 (3.8)
FS-wilderness	6,065 (10.7)	4,747 (12.6)	3,037 (12.7)	1,492 (11.8)
FS-nonwilderness	35,223 (62.3)	24,534 (64.8)	15,276 (64.0)	8,970 (71.2)
Other	1,693 (3.0)	1,000 (2.7)	882 (4.0)	449 (4.0)
Totals:	56,545	37,841	23,863	12,597

*Abbreviations: TNC, The Nature Conservancy; BLM, Bureau of Land Management; NPS, National Park Service; FS, Forest Service. Other category includes Corp of Engineers, Fish and Wildlife Service, Bureau of Reclamation, and lands with undesignated status.

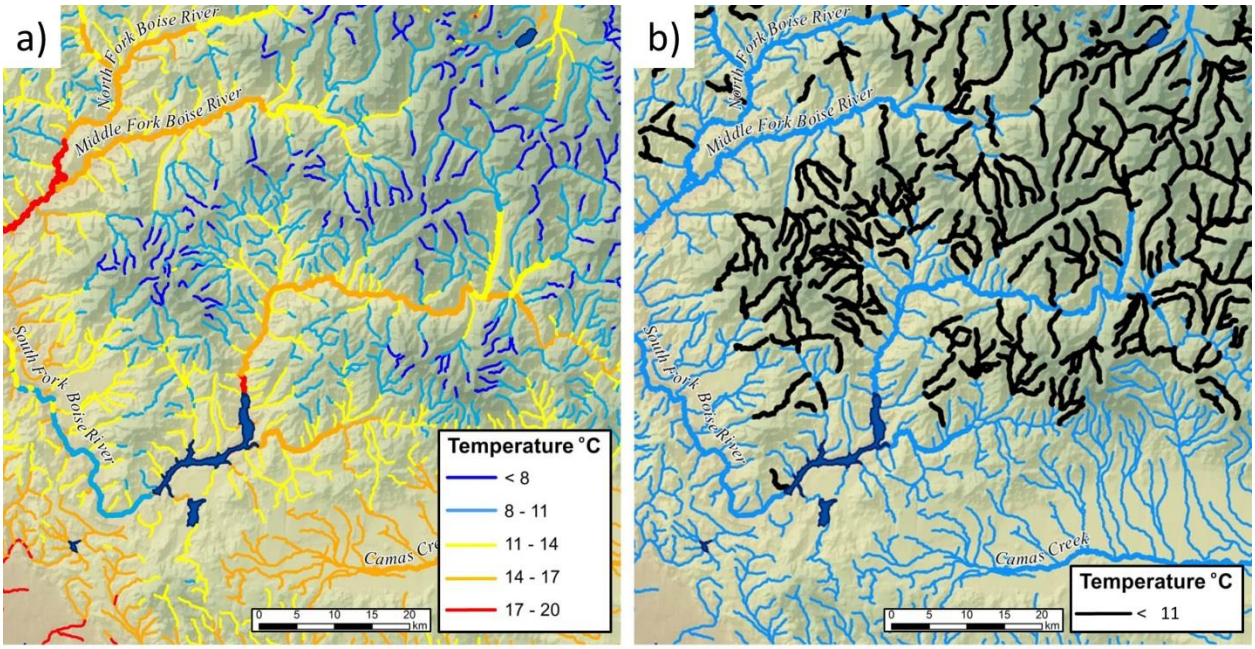

Fig. S1 Detailed view of NorWeST stream temperature map based on 1-km resolution data model (a) and discrete cold-water habitats created using an ArcGIS Python script that grouped 1-km reaches <11ºC (b). Python script is customizable based on user-defined values of stream temperature, flow, and slope that are associated with the hydrography layer.

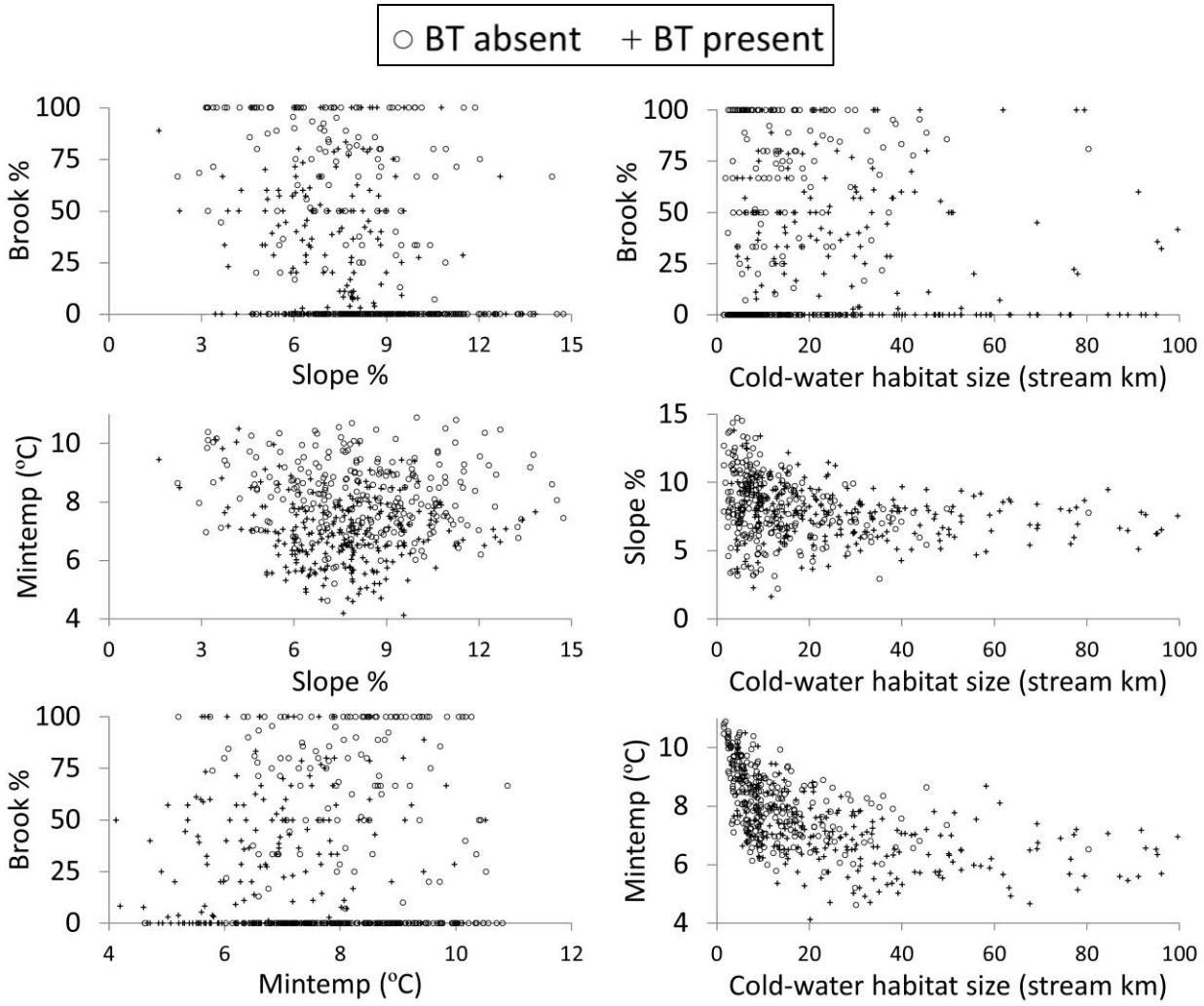

Fig. S2 Scatterplots of predictor variables associated with the 512 Bull Trout cold-water habitats used to develop occupancy models. Habitats >100 km are not shown.

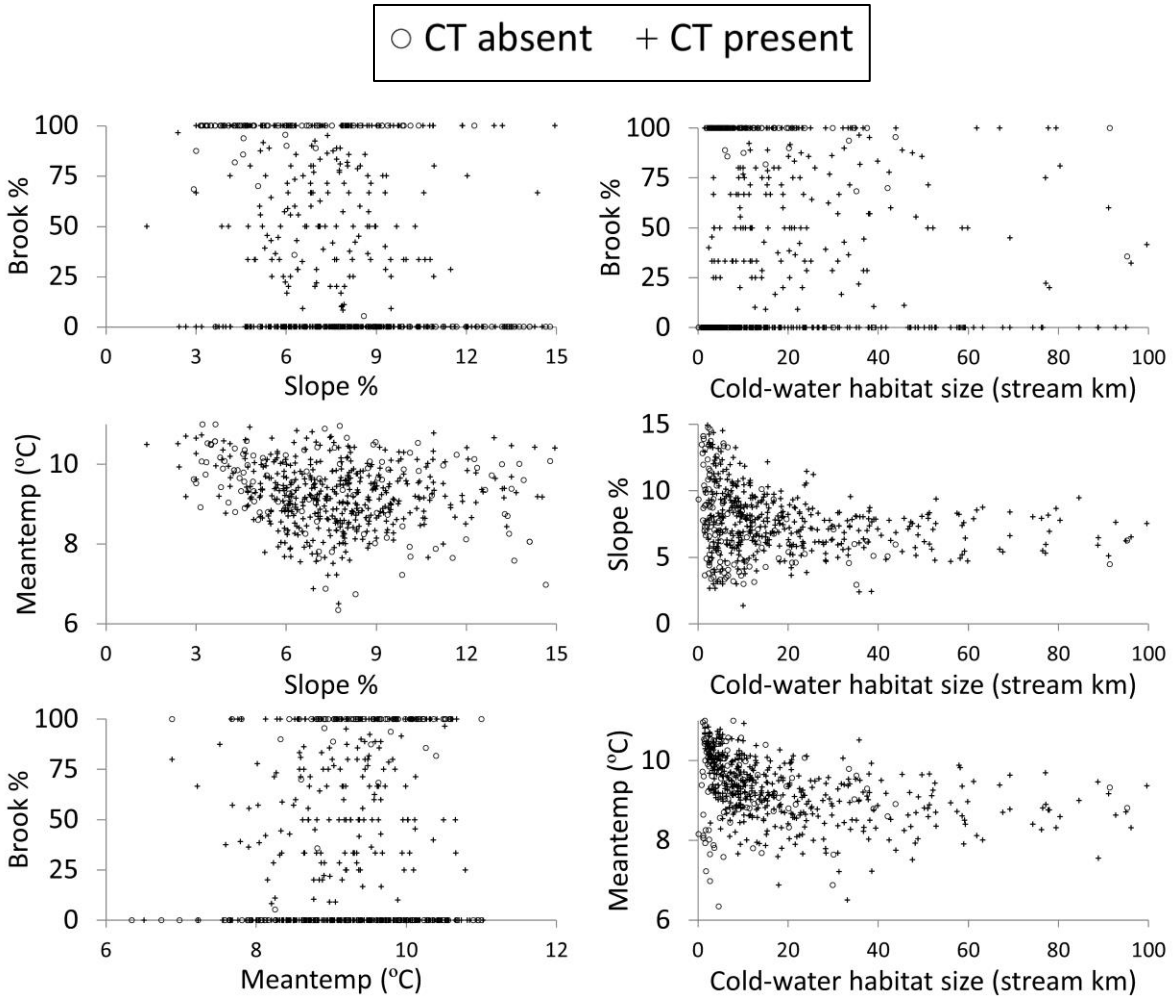

Fig. S3 Scatterplots of predictor variables associated with the 566 Cutthroat Trout cold-water habitats used to develop occupancy models. Habitats >100 km are not shown.

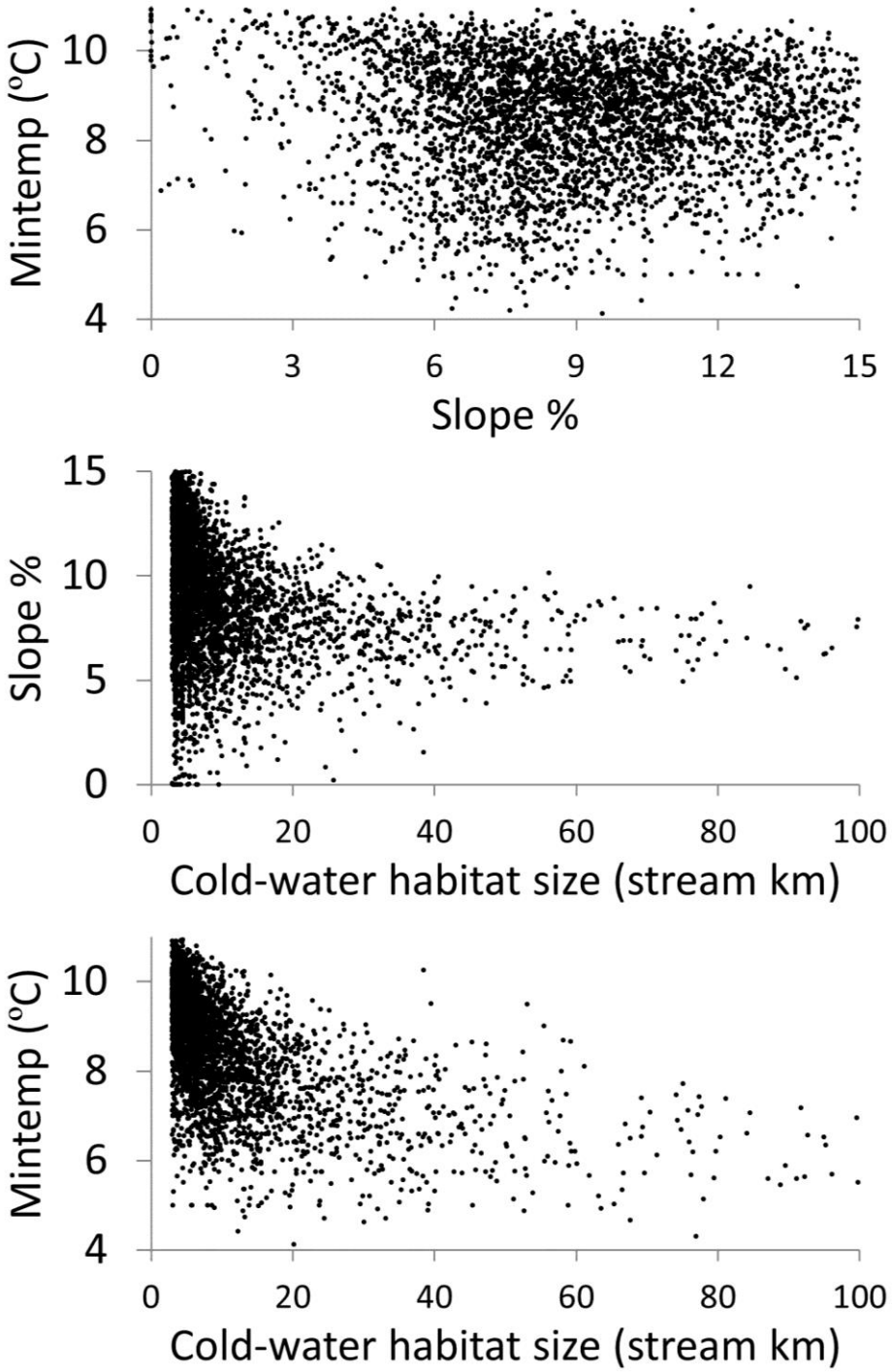

Fig. S4 Scatterplots of predictor variables associated with all 3,750 Bull Trout cold-water habitats across the study area during the 1980s climate period. The Bull Trout occupancy model was applied to those habitats to predict the probability of juvenile trout occurrence. Habitats >100 km are not shown.

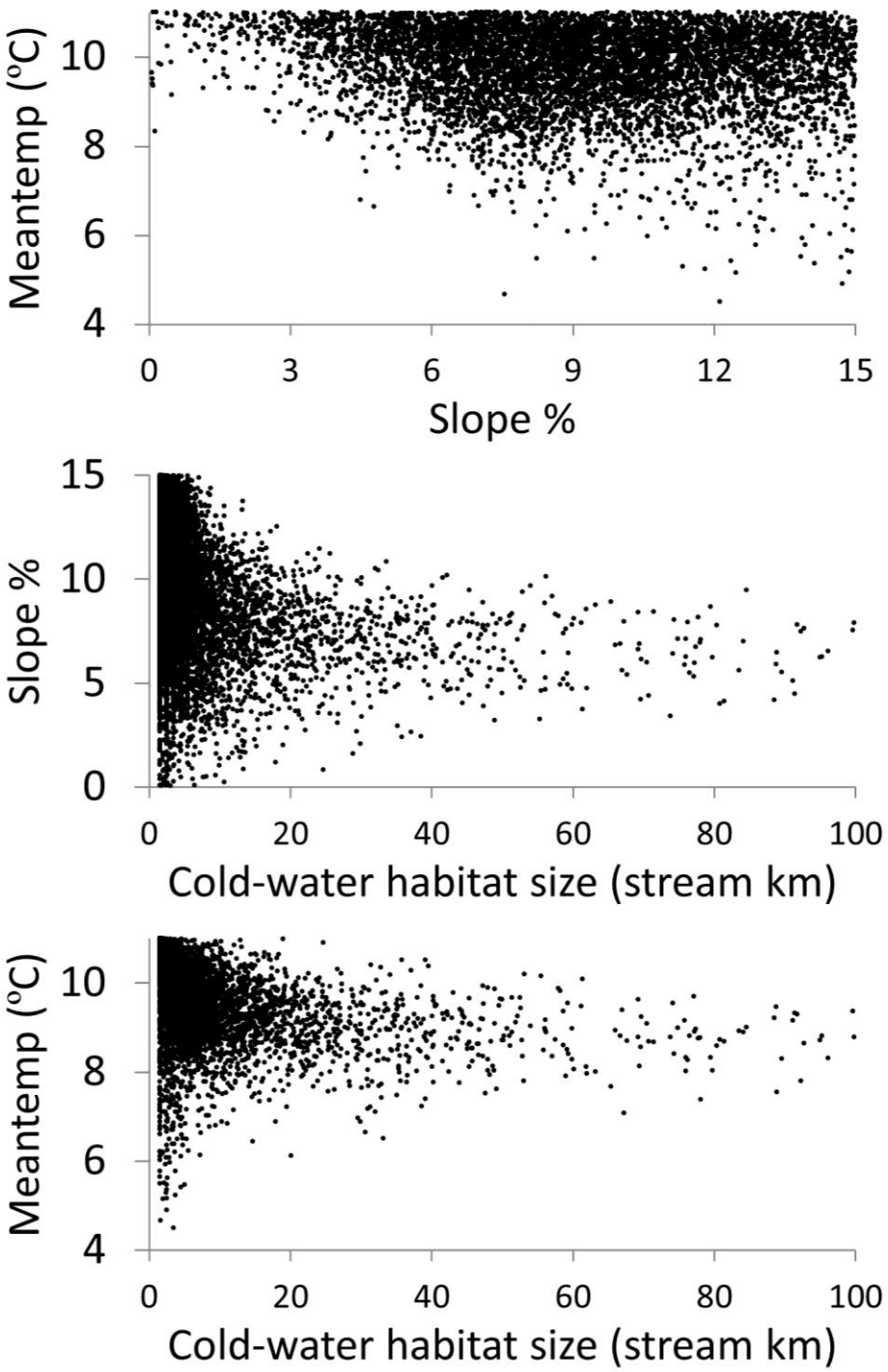

Fig. S5 Scatterplots of predictor variables associated with all 6,784 Cutthroat Trout cold-water habitats across the study area during the 1980s climate period. The Cutthroat Trout occupancy model was applied to those habitats to predict the probability of juvenile trout occurrence. Habitats >100 km are not shown.