

# Supporting Information

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## SI Text

**Best Supported Models for Each Species.** There were 2–7 plausible models in the confidence set for each species (Table S2) that were averaged to create a composite model (Table S3), from which we drew inferences. As noted in *Results*, we found that species hydroclimatic relationships were generally consistent with hypotheses. We also found that brook trout was more common in and near UVBs, whereas cutthroat trout was most common at an intermediate distance from UVBs and brown trout was most common far from UVBs (Table S3 and Fig. S1). The negative relationship of brown trout to UVBs was inconsistent with our hypothesis. Rainbow trout showed essentially no response to UVBs in the composite model. All species were most common at low slopes, but brown trout had the strongest slope response (Table S3 and Fig. S1). Brook trout tended to be found in the smallest streams, consistent with predictions. Brown trout and rainbow trout were more common in larger streams, and cutthroat trout showed little relationship with stream size except that they were less common in the smallest streams (Table S3 and Fig. S1). All nonnative species showed a modest positive relationship with road presence, consistent with our hypothesis; however, cutthroat trout showed no relationship with road presence, instead of the hypothesized negative response (Table S3).

**Model Performance Results.** In-sample model performance ranged from fair for brook trout (AUC  $\sim$  0.7) to good for brown trout (AUC  $>$  0.8), with cutthroat and rainbow trout intermediate (Table S4). Classification accuracy (i.e., the proportion of true presences and absences that were correctly predicted) ranged from 64% to 76%. The cross-validated (transferability) performance was lower for all models, as expected, but the difference was small ( $\leq$ 5% absolute difference in classification accuracy).

Much of the model error was at broader scales and reflected the fact that nonnative trout were patchily introduced across the study area and native cutthroat trout had been extirpated from some regions due to past anthropogenic activities. In an effort to improve error rates, we tested alternative model analysis methodologies (neural networks, Random Forests) but found that although they had superior in-sample classification accuracy they suffered from inferior transferability, and therefore might not yield reliable forecasts. Thus, we concluded that our modeling approach best captured the general relationships between predictor variables and species presence/absence. It is also worth noting that as conditions become more extreme (e.g., as temperatures increase well beyond a species' optimum) predictions become more certain. For example, despite the fact that brook trout model performance is only fair under current conditions, the confidence interval for suitable habitat in the 2080s is relatively narrow because so few locations are even potentially suitable. This is because many streams shift from predicted 30–40% occupancy (interpretable as a prediction of absence with an error rate of 30–40%) to predicted 10–20% occupancy (still a prediction of absence, but with an error rate of 10–20%).

**Additional Fish Collection Dataset Notes.** Because detection by snorkeling can be less efficient than electrofishing (1), snorkeling sites with fewer than four repeat visits were excluded from the dataset. We also excluded sites with drainage area larger than  $\sim$ 2,500 km<sup>2</sup> because (i) our method for estimating flows (2) was not intended for larger basins and (ii) detection probabilities for individual species tend to be lower in sites on larger rivers (3). Data from collections on the same stream within 50 m of one

another were considered to be from the same location and treated as a single site. Cutthroat trout were detected at 5,055 of the 9,890 sites, brook trout were detected at 2,820 sites, rainbow trout were detected at 1,031 sites, and brown trout were detected at 655 sites; 1,437 sites had none of these species. Historically, cutthroat trout could have been present at any or all of the sites.

Within their respective ranges, all species were considered to be truly absent at sites where they were not detected, even though it is possible that they could have been present but not detected. Although methods exist to incorporate imperfect detection in occupancy modeling (4), doing so in a multilevel modeling framework is complex (5), and we judged it to be of limited benefit for the reasons we explain here. Our dataset consisted of samples collected using multipass electrofishing (one or more surveys) and snorkeling (four or more surveys). Past studies have shown that multipass electrofishing capture efficiency (i.e., chance of detecting a single individual) of the species considered here is  $\sim$ 40–60% (6). This translates to a detection probability of 92–98% if as few as five individual fish are actually present at a site (detection probabilities for four snorkeling visits are comparable). Therefore, in our dataset only sites with very low abundances of fish were likely to be incorrectly labeled as absences, which we contend is reasonable because sites with very few individuals are not likely to represent optimal habitat or persistent populations for that species. A more significant concern is that covariates of interest (e.g., temperature) could be biased because capture efficiencies and occurrence probability respond to the same variables. Using published relationships between capture efficiency and temperature, slope and stream size (3, 6, 7), we calculated that the potential for bias was extremely small, as detection probability would not drop below 90% unless fish abundances were  $<$ 5 (a possible exception was detection in large rivers, which was why we excluded such locations). Otherwise, the principal consequence of ignoring incomplete detection is to underestimate the magnitude of covariates (8), which implies only that our hypothesis tests are somewhat conservative.

**Explanatory Variables: Methods of Calculation and Hypotheses Underlying Variable Selection.** We selected 12 abiotic variables including measures of temperature (2 metrics), winter high flow (4 metrics), proximity to unconfined valley bottoms (2 metrics), mean flow (2 metrics), stream slope, and the presence/absence of roads (Table S5).

In-stream temperature data were not broadly available, so we used air temperature as a surrogate (9–11). For consistency, we used the same air temperature dataset as was used in the VIC modeling (described below); these were gridded data interpolated from National Climatic Data Center Cooperative Observer stations (12). We developed site-specific temperatures based on the site's difference in elevation from the mean elevation for the cell, using a lapse rate of  $-6.0$  C  $\times$  km<sup>-1</sup> (10). We calculated the mean summer temperature for July 15th to August 31st, averaged across the 20 y from October 1977 through September 1997 (i.e., slightly preceding or contemporaneous with fish collection data), abbreviated ptemp; we also calculated the mean temperature in the drainage above the point (dtemp). We hypothesized that all trout species would have a unimodal response to temperature; that is, they would not be found in sites that were too hot or too cold. Based on previous studies, we hypothesized that brook trout and cutthroat trout would tend to be found at colder temperatures than rainbow trout and brown trout (13–15).

We derived estimates of winter high flow frequency from the VIC simulations run for the Great Basin and the Columbia, Colorado, and Upper Missouri river basins (12). Simulations on a daily time step from 1915 through 2006 were performed at 1/16th-degree spatial resolution (~5 km), except in the Great Basin where simulations were performed at 1/8th-degree spatial resolution. We routed simulated runoff and base flow using a simple approach (2) to produce daily hydrographs for stream segments in the 1:100K National Hydrography Database (NHD) Plus dataset (<http://www.horizon-systems.com/nhdplus/>). From these hydrographs, we calculated four metrics: w2, w1.5, w99, and w95. The first two measured the probability of a 2-y or 1.5-y recurrence interval flow event (respectively) during the winter. Flows of this magnitude are sufficiently large to mobilize bed material, potentially damaging redds and crushing embryos or alevins (16, 17). The latter two metrics, w99 and w95, were the number of days during winter that were among the highest 1% and 5% (respectively) of flows for the year. These were assumed to be flows with velocity sufficient to displace and kill newly emerged fry (18), but not necessarily destroy embryos in redds. Winter was considered to be December 1st through February 28th, and metrics were averaged across the same 20-y period as temperature metrics. Although winter weather can extend well beyond February for much of the region, we used an early cutoff to ensure we excluded the beginning of the spring flood in all areas. We hypothesized that fall spawning trout species (brook trout and brown trout) would display a negative response to winter high flows, but spring spawning species (rainbow trout and cutthroat trout) would not (18–21).

Unconfined valley bottoms (UVBs) are locations where the path of the stream is not laterally constrained by rock (as it is in canyons), and generally characterized by low slope, wetlands, and in some cases glacial deposits. We included two metrics of UVBs: a binary classification of whether a site was within a UVB (vbpres) and a measure of distance in kilometers to the nearest UVB (vbdist). Unconfined valley bottoms were delineated according to an algorithm that identified relatively flat areas adjacent to streams (22), using 30-m digital elevation models. Because UVBs

appear to be preferred spawning and rearing locations for fall-spawning trout species, possibly due to groundwater connectivity or moderated winter high flows (23–26), we hypothesized that fall-spawning species would be more frequently encountered in and near UVBs, whereas spring-spawning species would not.

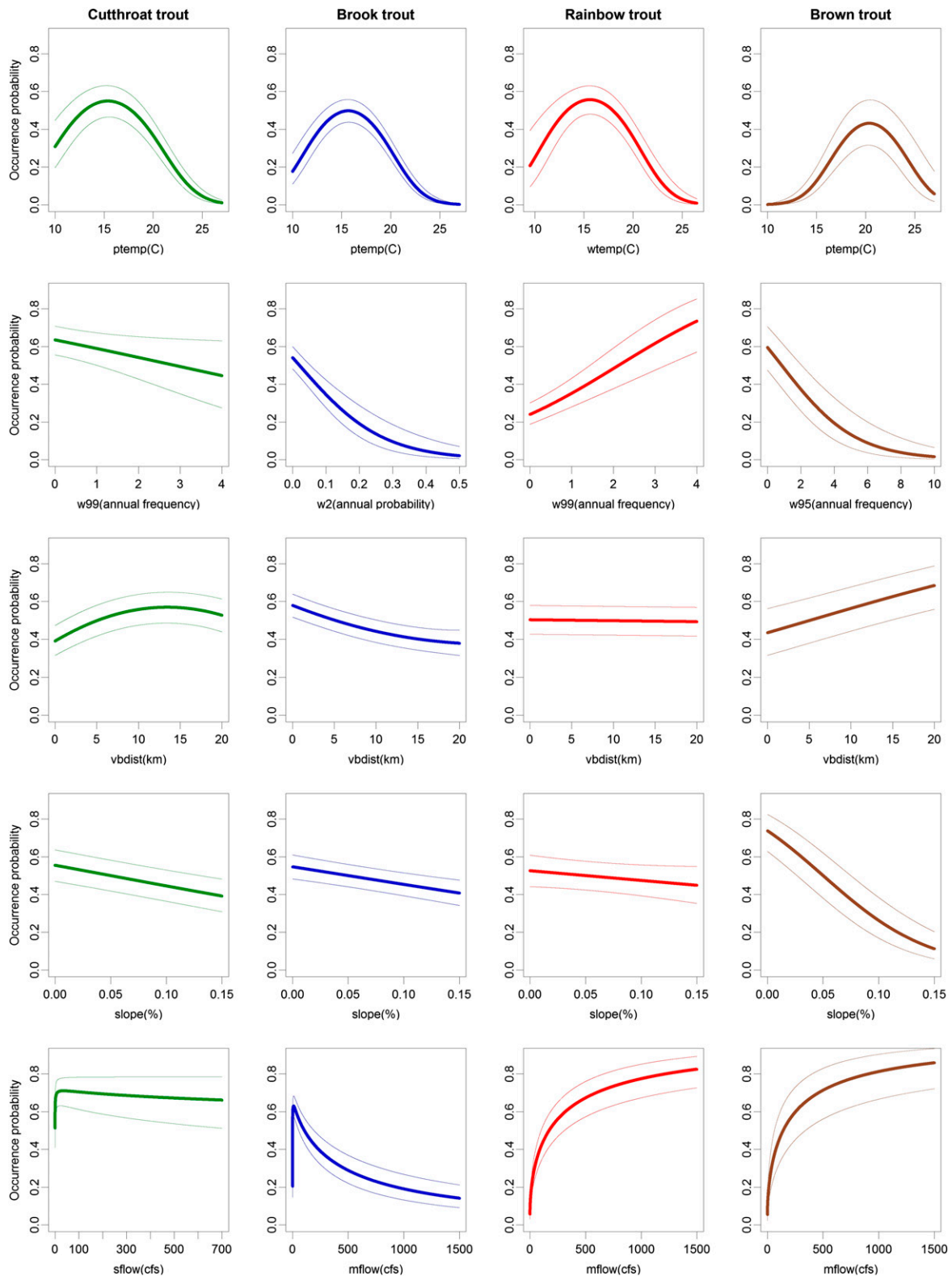
Stream slope values were from the NHDPlus dataset and were derived for stream segments from 30-m DEMs. We hypothesized that all trout species would show a negative relationship with increasing stream slope, possibly because of high frequency of dispersal barriers or unfavorable physical characteristics such as high velocities (23, 27, 28).

For mean stream flow we considered two metrics: mean annual flow (mflow) and mean summer flow (sflow), both derived from the VIC-modeled flow dataset described previously. Mean annual flow was the mean daily flow, averaged across the full year, and then averaged across the same 20-y period used for temperature metrics. The sflow variable was the same but calculated only for the summer, which was defined as the period between the decline of the spring flood peak and September 30th; the calculation of the spring flood decline was made independently for each year for each stream segment (2). Mean stream flow primarily served as an index of stream size. We hypothesized that brook trout would tend to occupy smaller streams, based on past studies (23, 29, 30). For other species, we made no specific hypotheses but allowed for the possibility that responses could be unimodal, with lower occurrence probability in streams that were too small and too large.

The road variable was calculated as a value of 1 if the 2000 TIGER/Line road database ([www.census.gov/geo/www/tiger](http://www.census.gov/geo/www/tiger)) indicated a road within 1 km of the stream segment on which the site was located, and 0 otherwise. We hypothesized that native cutthroat trout were less likely to occur in regions with roads near streams (road; Table 1) because roads may reduce habitat quality and connectivity and facilitate introductions of nonnative species (31, 32). In contrast, we hypothesized that nonnative brook trout would show a positive relationship with roads, due to greater probability of introductions (legal or illegal) of this species in locations accessible by road (33).

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**Fig. S1.** Occurrence probability of trout species as a function of predictor variables (abbreviations defined in *Methods* and [Table S4](#)). Heavy lines indicate mean values; fine lines indicate 90% confidence intervals.

**Table S1. Model-averaged parameter estimates for biotic predictor variables in composite cutthroat model**

Cutthroat lineage	Parameter estimate for response of cutthroat to					
	Brook	Brook-w	Rainbow	Rainbow-w	Brown	Brown-w
Westslope	-0.30 ± 0.11	-0.45 ± 0.07	-0.35 ± 0.11	-0.32 ± 0.15	-1.38 ± 0.34	NS
Lahontan/Yellowstone	-1.16 ± 0.09	NS	NS	-0.49 ± 0.11	-0.36 ± 0.15	NS

Biotic responses were tested at both the subwatershed scale (variables with the “-w” suffix) and the site scale (no suffix). NS = variable not supported.

**Table S2. Differences in AIC (AIC – AIC<sub>min</sub>) and Akaike weights (w<sub>i</sub>) for the confidence set of models for each species**

Model	ΔAIC	w <sub>i</sub>
<b>Cutthroat trout</b>		
<b>p</b> temp + <b>p</b> temp <sup>2</sup> + w99 + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + sflow + sflow <sup>2</sup> + brk* <b>w</b> est + brkw + rbtw* <b>w</b> est + rbt + brn* <b>w</b> est	0	0.42
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w99 + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + sflow + sflow <sup>2</sup> + brk* <b>w</b> est + brkw + rbtw + rbt + brn* <b>w</b> est	0.7	0.29
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + sflow + sflow <sup>2</sup> + brk* <b>w</b> est + brkw + rbtw* <b>w</b> est + rbt + brn* <b>w</b> est	3.0	0.09
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w99 + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + sflow + sflow <sup>2</sup> + brk* <b>w</b> est + brkw + rbtw* <b>w</b> est + rbt + <b>brn</b>	3.5	0.07
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w99 + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + sflow + brk* <b>w</b> est + brkw + rbtw* <b>w</b> est + rbt + brn* <b>w</b> est	4.2	0.05
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + sflow + sflow <sup>2</sup> + brk* <b>w</b> est + brkw + rbtw + rbt + brn* <b>w</b> est	4.3	0.05
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w99 + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + sflow + sflow <sup>2</sup> + brk* <b>w</b> est + brkw + rbtw + rbt + brn + brnw	5.8	0.02
<b>Brook trout</b>		
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w2 + <b>v</b> bdist + <b>v</b> bdist <sup>2</sup> + slope + mflow + mflow <sup>2</sup> + road	0	0.91
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w2 + <b>v</b> bdist + slope + mflow + mflow <sup>2</sup> + road	0.6	0.09
<b>Rainbow trout</b>		
w <b>temp</b> + w <b>temp</b> <sup>2</sup> + w99 + slope + mflow + mflow <sup>2</sup> + road	0	0.63
w <b>temp</b> + w <b>temp</b> <sup>2</sup> + w99 + mflow + mflow <sup>2</sup> + road	2.4	0.19
w <b>temp</b> + w <b>temp</b> <sup>2</sup> + w99 + <b>v</b> bdist + mflow + mflow <sup>2</sup> + road	2.5	0.18
<b>Brown trout</b>		
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w95 + <b>v</b> bdist + slope + mflow + mflow <sup>2</sup> + road	0	0.61
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w95 + <b>v</b> bdist + slope + mflow + mflow <sup>2</sup>	1.4	0.31
p <b>temp</b> + p <b>temp</b> <sup>2</sup> + w95 + <b>v</b> bdist + slope + mflow + road	4.0	0.08

Parameters that differ among models are highlighted in bold. Only candidate models with ΔAIC ≤ 6 are shown.

**Table S3. Parameter estimates (means ± 1 SE) for all predictor variables in the composite model for each species**

Trout	Intercept	Temperature		Winter high flow	Valley bottom distance		Slope	Stream size/flow		Road presence
<b>Cutthroat</b>		p <b>temp</b>	p <b>temp</b> <sup>2</sup>	w99	<b>v</b> bdist	<b>v</b> bdist <sup>2</sup>	Slope	sflow	sflow <sup>2</sup>	NS
	1.24 ± 0.20	-0.59 ± 0.12	-0.88 ± 0.13	-0.20 ± 0.11	0.74 ± 0.09	-0.50 ± 0.08	-0.34 ± 0.08	0.41 ± 0.11	-0.21 ± 0.09	
<b>Brook</b>		p <b>temp</b>	p <b>temp</b> <sup>2</sup>	w2	<b>v</b> bdist	<b>v</b> bdist <sup>2</sup>	Slope	mflow	mflow <sup>2</sup>	road
	-0.85 ± 0.14	-0.66 ± 0.12	-1.20 ± 0.12	-0.98 ± 0.14	-0.62 ± 0.09	0.18 ± 0.08	-0.29 ± 0.07	0.34 ± 0.09	-0.85 ± 0.09	0.39 ± 0.07
<b>Rainbow</b>		w <b>temp</b>	w <b>temp</b> <sup>2</sup>	w99	<b>v</b> bdist	NS	Slope	mflow	mflow <sup>2</sup>	road
	-2.14 ± 0.19	-0.32 ± 0.16	-0.89 ± 0.18	0.58 ± 0.11	-0.02 ± 0.14		-0.16 ± 0.16	1.20 ± 0.15	0.33 ± 0.12	0.38 ± 0.11
<b>Brown</b>		p <b>temp</b>	p <b>temp</b> <sup>2</sup>	w95	<b>v</b> bdist	NS	Slope	mflow	mflow <sup>2</sup>	road
	-2.66 ± 0.30	1.90 ± 0.28	-1.44 ± 0.26	-1.15 ± 0.22	0.58 ± 0.14		-1.62 ± 0.21	1.28 ± 0.19	0.20 ± 0.03	0.20 ± 0.18

Variable abbreviations (e.g., “p**temp**” and “w**temp**”) are defined in Methods and listed in SI Table S4. Variables have been standardized by subtracting the mean and dividing by 2SD. NS = variable not supported.

**Table S4. Performance statistics for the top-ranked models for each species**

Trout	In-sample AUC	In-sample classification accuracy	Cross-validated AUC	Cross-validated classification accuracy
Cutthroat	0.758	69%	0.709	65%
Brook	0.680	64%	0.653	61%
Rainbow	0.746	69%	0.659	64%
Brown	0.822	76%	0.786	74%

AUC is the area under the curve of the receiver operator characteristic plot. Cross-validated values were calculated with sites assigned to five geographically distinct units.



**Table S5. Metrics used as abiotic predictor variables in multilevel logistic regression models of species occurrences. Range and mean are from the model-building dataset**

Group	Metric	Abbreviation	Units	Range	Mean
Temperature	Mean summer air temp. at site	ptemp	C	9.8–27.3	17.1
	Mean summer air temp. in drainage	dtemp	C	9.5–26.7	16.4
Winter High Flow	Winter high flow (2 y flow)	w2	Probability	0–3.6	0.12
	Winter high flow (1.5 y flow)	w1.5	Probability	0–13.3	0.36
	Winter high flow (99% annual flow)	w99	Frequency	0–4.5	0.28
	Winter high flow (95% annual flow)	w95	Frequency	0–9.65	0.85
Mean Flow	Mean annual flow	mflow	ft <sup>3</sup> *s <sup>-1</sup>	0–2233	25.8
	Mean summer flow	sflow	ft <sup>3</sup> *s <sup>-1</sup>	0–923	9.57
UVB	UVB (binary)	vbpres	—	0/1	0.22
	UVB distance	vbdist	km	0–31	5.11
Slope	Stream slope	slope	—	0–0.53	0.05
Road	Road presence (binary)	road	—	0/1	0.71